

# PARKScience

Integrating Research and Resource Management in the National Parks

National Park Service  
U.S. Department of the Interior

Natural Resource Stewardship and Science  
Office of Education and Outreach



## CELEBRATING SOILS IN THE NATIONAL PARKS

Raising awareness of the influence of soils on the ecology, management, and enjoyment of our national parks

### Also in this issue

- Rocky Mountain science centennial
- Resource protection and safety-related training needs assessment
- Cascading effects of nonnative lake trout in Yellowstone Lake
- Attitudes toward Lyme disease risk and prevention at Greenbelt Park
- Nearshore water quality studies in Great Lakes parks
- Indicators and standards of quality for night sky viewing at Acadia



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# From the Guest Editor

## Reflecting on the detail(s)

As an education specialist with the Old-Growth Bottomland Forest Research and Education Center at Congaree National Park, South Carolina, I typically collaborate with park staff and partners to share “CongaReeSource” science and “CongaReeSearch” results with a wide variety of audiences. I love my job, but last spring I was thrilled to consider a summer–fall detail as guest editor for *Park Science*. I was excited about challenging the boundaries of my network and expertise. Now, preparing the final layout and with the privilege of hindsight, I find myself reflecting on what I learned along the way. The short summary is that the collaborative effort of editing is humbling.

The National Park Service cares for a tremendously diverse and dynamic suite of sites, resources, and programs. This responsibility is made more manageable, however, because of our collaboration with an equally diverse array of talented academic partners who help us to better understand our resources and ourselves. The studies presented here do not “happen” quickly, cheaply, or easily, but reflect the constant efforts of staff and partners to move our programs forward. While I often sense this at my own park, *Park Science* helps remind me that this collaboration operates on a grander scale, too.

As guest editor I was gently reminded of the effort that collaboration takes. I mean the honest kind of effort that is joyous and rewarding even as it can be uncomfortable and tiresome. I needed to learn—on a deadline—about topics like *Gammarrus*, MWDS, and nitrogen reduction plans (all in this issue!) while delving into the minutiae of grammar, writing conventions, and style guides. Another dimension of effort involved working with diverse teams of authors who each bring their own expertise and voice. The artful challenge was to probe for clarity, flow, and efficiency without compromising that voice. As a whole, both dimensions of this work have been a healthy reminder of the challenges faced by visitors and students as they discover our parks. This is true both in terms of visitors’ own “learning curves,” as well as the sensitivities of respecting individual voices while dealing with scientific topics that need to be discussed with accuracy and precision.

Freeman Tilden, the great teacher of national park interpretation, describes humility as “the patience born of gratitude for the opportunity to have had an experience.” Looking at this layout, I am simply glad that I have had the opportunity to contribute to this collaborative effort. In the grand view of the diverse partnerships, studies, and voices represented here I find patience, born of gratitude, to strive harder in my NPS work. I am inspired to consider new ways of thinking about our parks, hopeful to see new opportunities for stewardship, energized to listen and partner, and inspired to think of new ways to make science a meaningful part of a park experience. I hope that you, too, will discover some detail of yourself in this issue.

—David C. Shelley, Guest Editor

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

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# Contents

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CDC/JIM GATHANY

9

25

46

## DEPARTMENTS

### From the Guest Editor 2

Reflecting on the details

### Information Crossfile 5

Synopses or reviews of selected publications relevant to climate change and natural resource management

### Field Moment 79

Turtle T.H.i.S.—Gulf Island National Seashore, 19 October 2014, 1:12 a.m.

## ON THE COVER

📷 Soils of national parks offer an array of colors and textures that tell stories of their formation, provide hints to the past history of Earth, and help explain what we see today on the park landscape. From left to right: Soils of Redwood National Park (California), New River Gorge National River (West Virginia), Craters of the Moon National Monument and Preserve (Idaho), Sequoia–Kings Canyon National Parks (California), and Mojave National Preserve (California). *Note:* Depth scale applies only to the leftmost photo.

ALL PHOTOS USDA–NRCS, LEFT TO RIGHT: JOE SENEY, ROB PATE, BOB KUKACHKA, SUSAN SOUTHARD (2)

## RESEARCH REPORTS

### Indicators and standards of quality for viewing the night sky in the national parks 9

*This research program helps inform management of night skies at Acadia and other parks.*

By Robert Manning, Ellen Rovelstad, Chadwick Moore, Jeffrey Hallo, and Brandi Smith

### Resource protection, visitor safety, and employee safety: How prepared is the National Park Service? 18

*Researchers present the results of a training needs assessment of NPS Visitor and Resource Protection employees.*

By Gina L. Depper, Demica Vigil, Robert B. Powell, and Brett A. Wright

### Lake trout–induced spatial variation in the benthic invertebrates of Yellowstone Lake 25

*Invasive lake trout indirectly increased biomass and body mass of amphipods.*

By Oliver Wilmot, Lusha Tronstad, Robert O. Hall, Jr., Todd Koel, and Jeff Arnold

## CASE STUDY

### Nearshore conditions in the Great Lakes national parks: A baseline water quality and toxicological assessment 36

*Field survey results suggest generally good water quality, although nutrient concentrations were unexpectedly high near several parks, and metals and legacy pollutants continue to affect sediments and fish.*

By William O. Hobbs, Brenda Moraska Lafrancois, and Eva DiDonato

## SCIENCE FEATURE

### Knowledge, attitudes, and practices regarding Lyme disease prevention among employees, day visitors, and campers at Greenbelt Park 46

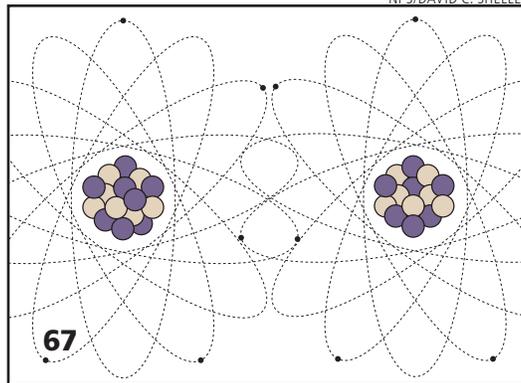
*A 2010 survey reveals that while perceived risk of Lyme disease and tick encounters was high in the park, use of preventive measures was low.*

By Erin. H. Jones, Amy Chanlongbutra, David Wong, Fred Cunningham, and Katherine A. Feldman



USDA/SUSAN SOUTHARD

54



NPS/DAVID C. SHELLY

67



PHOTO COURTESY PUBLIC LANDS HISTORY CENTER, 2014

76

## UPCOMING ISSUES

### Spring 2016

Seasonal issue. June release.  
In production

### Fall 2016

Seasonal issue. November release.  
Thematic issue: In production

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

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## IN FOCUS: SOILS

*Articles share insights into the near-universal and far-reaching effects of soils on the ecology, management, and enjoyment of our national parks.*

### Celebrating soils across the National Park System

By Susan Southard and Gregory Eckert

54

### Interactions underfoot: The subtle influence of soil moisture on vegetation pattern

By Jay Skovlin and David Thoma

60

### Wind, earth, and fire: The impacts of anthropogenic air pollution on soils in Joshua Tree National Park

By Michael D. Bell and Edith B. Allen

64

### Sidebar: Isotopes in environmental science

By David C. Shelley

67

## ROCKY MOUNTAIN SCIENCE CENTENNIAL

*Taking stock of science in park stewardship since 1915.*

### Honoring the past and celebrating the present: 100 years of research at Rocky Mountain National Park

By Isabel Ashton, Ben Baldwin, Ben Bobowski, Scott Esser, and Paul McLaughlin

68

### The role of science through a century of elk and habitat management at Rocky Mountain National Park

By Therese L. Johnson, Linda C. Zeigenfuss, N. Thompson Hobbs, and John A. Mack

70

### High elevations under threat from nitrogen deposition: Air quality monitoring, research, and management at Rocky Mountain National Park

By Kathy Tonnessen

73

### Nature, history, and environmental history at Rocky Mountain National Park

By Mark Fiege

76

### Inspiring the future: The next 100 years of research and learning at Rocky Mountain National Park

By Ben Bobowski

78

# Information Crossfile\*

## REVIEW

### A new science literacy standard

#### I THINK A LOT ABOUT THE FUNDAMENTALS OF SCIENCE

literacy here at the Old-Growth Bottomland Forest Research and Education Center at Congaree National Park. As a Ph.D. scientist and educator, I am constantly struck by how science literacy includes so much more than just factual findings. At a cognitive level, it also addresses methods of knowing as well as conceptual paradigms—and these do not even address emotional dimensions of science, which are just as important. All of these factors come to mind as I approach science communication with park staff and partners, use the interpretive equation<sup>1</sup> in park programs, and converse with K–12 students and teacher partners.

Over the last several years I have found one reference that increasingly affects my understanding of science literacy: the *Framework for K–12 Science Education* (NRC 2012). The framework was originally conceived by the National Academy of Sciences as a prerequisite for updated K–12 academic standards that could be implemented broadly across the country. The document was developed in coordination with a wide array of private, public, and nonprofit partners as well as public comments. It was based on a consensus-driven approach to synthesize STEM (science, technology, engineering, and math) expertise with recent research in the learning sciences (an interdisciplinary field that includes dimensions of psychology, sociology, neuroscience, policy, and more—including studies of how students learn in informal settings such as parks). The framework vision is “a broad description of the content and sequence of learning expected by all students” to help science educators map out relevant, age-appropriate K–12 curricula and lesson plans. I find it a magnificent resource for science education aimed at adult staff, visitors, and partners as well.

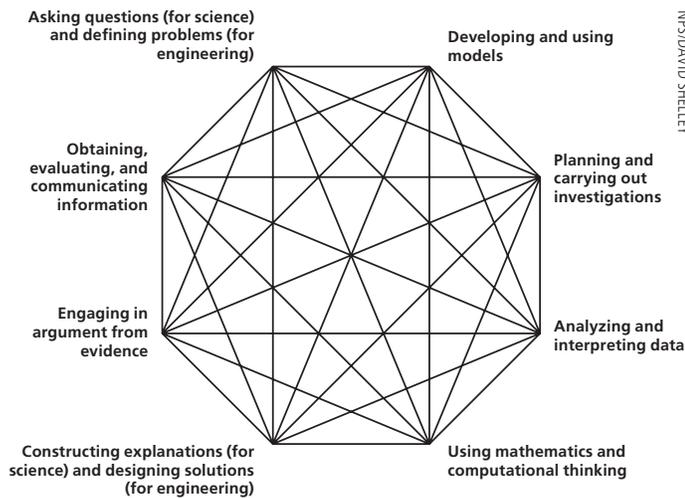
The full document is lengthy at 401 pages, but the National Science Teachers Association has also published a condensed summary to help “unpack” the full-length framework (Pratt 2013). The simplest distillation of the framework is that any science lesson should center on three essential, equally important components. These are metaphorically represented in the document as a three-strand rope:

<sup>1</sup>The interpretive equation is an analogy for understanding the relationship among foundational elements of effective interpretation. The equation is  $KR + KA \times AT = IO$  and it stands for *Knowledge of the Resource* (KR) plus *Knowledge of the Audience* (KA) times *Appropriate Technique* (AT) equals an *Interpretive Opportunity* (IO) to make intellectual and emotional connections between visitors (students) and a resource (e.g., park, site, tree, building, bird, artifact).

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

1. **Disciplinary core ideas (DCIs):** DCIs include factual topics, such as photosynthesis, magnetism, or tectonics, that are all organized in an outline perhaps akin to a Dewey Decimal System. From a park perspective, the DCIs *are* the “KR” (Knowledge of the Resource) in the interpretive equation.
2. **Science and engineering practices (SEPs):** The SEPs are an integrated, iterative set of practices that place any lesson firmly in the context of science as a *verb*. There are eight SEPs and my own evolving analogy of them is an octagonal web (fig. 1, next page). The SEPs vibrantly redefine the older, static model of the scientific method as a linear, proscriptive, non-negotiable “fact recipe” that starts with a hypothesis. In this way the SEPs help define the “AT” (Appropriate Technique) in the interpretive equation.
3. **Crosscutting concepts:** These are broad paradigms for thinking that can be similarly applied in many areas of science. In no particular order they are (1) patterns; (2) cause and effect; (3) scale, proportion, and quantity; (4) systems and system models; (5) energy and matter; (6) structure and function; and (7) stability and change. They are, of course, defined very specifically in the context of the framework, but they open up *worlds* of possible connections with related disciplines, humanities, interpretive TIU models (i.e., tangibles, intangibles, and universals), and others. Defining crosscutting concepts on equal footing with the DCIs and SEPs is, for me, a huge development. They have always been components of good instruction, but have not always been clearly woven and fairly weighted in the considerations of curriculum development.

In addition to the three dimensions, the framework makes two more important contributions to science literacy. First, it effectively differentiates the language of science and engineering in context; *science* is defined as fundamental understanding of phenomena in the natural world, while *engineering* is defined as the application of understanding toward solving human problems. The second major contribution of the framework is its very presentation of logical, appropriate progressions in the DCIs, SEPs, and crosscutting concepts. There are countless ways to organize such an outline, but at the end of the day educators working across diverse settings—especially rangers and educators working for an organization as large and diverse as the National Park Service—need some consistent, common denominator. As a standing consensus of the country’s leading scientists and educators, this document provides just that. While many different



**Figure 1.** The author’s own octagonal model for the eight science and engineering practices (SEPs). This vision is not linear like the traditional, proscriptive scientific method, but iterative. Any practice may lead a researcher, park ranger, manager, or student to any other practice.

states still develop their own K–12 academic standards for science, evolving iterations cannot ignore (and are not ignoring) this document. This means that the document and its language are here to stay and driving significant changes in how teachers think and talk about science.

The framework authors note that the document is not static but subject to change as it is implemented and evaluated. For my own part, I might expect (or even hope for) two changes. One hope is that the SEP “obtain, evaluate, and communicate information” may eventually be split into two. Skills in obtaining and evaluating information as a media consumer are certainly related to designing such communications, but at the end of the day they are indeed two different skill sets. Scientific communication (with nonscientists) also needs to be distinguished from other forms of communication in its reliance on models, data, analysis, and peer review per the SEPs. My second thought is that the crosscutting concept of “patterns” may be subdivided more explicitly to separate out classification in a relational sense (i.e., biological taxonomy, mineral identification, or the international stratigraphic code) from spatial (i.e., maps and GIS) and temporal patterns (i.e., time series) found in data.

Understanding this document and incorporating it into NPS communication—both external and external—are extremely relevant to a second century of NPS success in many ways: First, as a consensus document that increasingly underpins the public education system, working with the framework is critical to effectively reaching today’s K–12 students as well as an increasingly broad spectrum of tomorrow’s visitors (and even future staff).

Second, it can efficiently streamline staff work to match specific audiences, content (especially age-appropriate vocabulary and prior knowledge), and techniques without constantly reinventing the wheel. Third, the common language can help facilitate education program/information transfer between parks in different states as well as staff relocations between diverse park units. Fourth, the authors acknowledge that the framework does not simply stand alone in a vacuum, but requires collaborations to explore “considerations of the historical, social, cultural, and ethical aspects of science and its applications, as well as of engineering and the technologies it develops.” Parks can shine second to none in this regard, and perhaps help define the gold standard. Fifth, the mutual success of the NPS and the document are synergistic; by working with the framework, NPS staff and partners can play an important role in supporting its ultimate success.

In the context of all of these benefits, I find the framework an earth-shattering foundation—if that isn’t an oxymoron—for rethinking staff, visitor, and K–12 education in the greater service of the NPS mission. As many NPS programs can attest, cultivating science literacy that is more than just facts is fundamental to helping park managers, partners, and visitors make stewardship decisions about the precious natural and cultural resources in our care. As the framework emphasizes, “personal and civic decision making is critical to good decisions about the nation’s future.” The vision laid out here is an ambitious but worthy one, I think, with great promise for the National Park Service as we move into our centennial and beyond.

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—David C. Shelley

## RESEARCH REVIEW

## Bats, moths, and Research Learning Centers: A story of collaborative research

### RESEARCH PARTNERS WITH THE NPS OLD-GROWTH BOT-

tomland Forest Research and Education Center (the Center) have recently published final studies on Rafinesque's big-eared bats (Lucas et al. 2015) and moth biodiversity (Culin et al. 2014) at Congaree National Park (South Carolina). These studies each offer their own insights into old-growth floodplain forest ecology, but considered together they reflect something bigger: an evolving, multiyear collaboration between NPS staff and research partners that exemplifies the NPS Research Learning Center (RLC) network mission to "increase the effectiveness and communication of science in national parks" (NPS 2015). Such work provides fundamental value—not just value added—for park management and interpretation efforts as well as a host of NPS strategic initiatives that include (among many) Call to Action item 20 (Scholarly Pursuits) and all items under the "Preserving America's Special Places" theme (NPS 2014), the Revisiting Leopold Report (National Park System Advisory Board 2012), and the original 1999 Natural Resource Challenge program that created the RLCs (NPS 2012).

These studies built on the work of the Southeast Coast Inventory and Monitoring Network to inventory bats and other mammals, which are vital sign indicators of a park's health. The bat portion of the mammal inventory, conducted by a research scientist from the USDA Forest Service, documented six bat species at Congaree (Loeb 2006). These included Rafinesque's big-eared bat (*Corynorhinus rafinesquii*) and the southeastern myotis (*Myotis austroriparius*), which are species of conservation concern. Scientists and managers know relatively little about the ecology of these species. While the Southeast Coast Network moved on to other inventory and monitoring surveys in accordance with their mission, staff of the Center partnered with the USDA researcher and secured a grant to follow up with a conservation biology study of Rafinesque's big-eared bat.

The study, which resulted in one master's thesis (Lucas 2009) and culminated in the publication of Lucas et al. (2015), focused on tree roost use and selection by Rafinesque's big-eared bats in Congaree's old-growth floodplain forest. Rafinesque's big-eared bats were netted and tagged with radio transmitters. Bats were re-located and their roost trees were described in relation to forest characteristics in the surrounding area. Research showed that the ideal bat roosts were very large, hollow, live-but-damaged water tupelo (*Nyssa aquatica*) trees in areas with abundant old-growth trees and relatively high (seasonally to semipermanently flooded) water levels. Maternity colonies moved around more frequently and preferred trees with upper cavities relative to solitary males, who were more likely to reoccupy trees with only basal cavi-

ties. Researchers suggested the maternity colony roost switching helped to minimize threats to young from predation, rising water levels, and parasites.

At a local level, these results can help park staff identify and manage prime roost habitat while informing interpretation of bats, champion trees, and popular night programs. By documenting bat roost preferences in one of the largest and best-preserved tracts of old-growth bottomland forest remaining on the continent, these results also represent novel, baseline information for both scientists and resource managers working across the larger southeastern and Gulf coastal plains. At a continental scale, scientists are interested in forested bat habitats of the Southeast because white-nose syndrome, a fungal disease, has devastated bat populations in many of the cooler cave systems across North America; populations in forested habitats may be more resilient to the spread of white-nose syndrome, but more work is needed to understand population dynamics, distribution, and ecology.

### From bats to moths

During the bat research, partners and NPS staff identified an additional research question: What were the bats eating? Moths were presumably a major food source, but they were not an I&M vital sign and had not been well studied locally or regionally. Staff at the Center collaborated with new academic partners and secured another grant to research the park's moth communities. New research partners included entomology faculty from three universities, one of which is a specialist in micro-lepidoptera who had partnered with other RLCs on moth inventories for Acadia (Maine) and Great Smoky Mountains (Tennessee and North Carolina) National Parks.

Researchers worked with park staff and youth interns to systematically sample moths at several sites monthly for a year. Sampling used a combination of blacklight traps and trees baited with a mixture of molasses and beer. Researchers also helped to lead several "moth-blitz" programs that engaged the public in moth collection and identification from backlit bedsheets. The results of the study increased Congaree's known moth list from 40 species, 40 genera, and 10 families to 1,014 species, 546 genera, and 48 families (fig. 1, next page) (Culin et al. 2014; also see Snyder 2015)! These results are estimated to reflect 90% of the park's total moth biodiversity. Overall moth abundance peaked from April to September but dropped from November to February. Nonnative species were detected in very low numbers, and there were several species unique to bald cypress and floodplain habitats. A total of 173 species were previously unreported from South Carolina, and for some species the closest known occurrence was as far away as New Jersey or Arizona.

At a local level, these results of this study provide a baseline for moth diversity, abundance, and phenology at Congaree. Results



NPS PHOTO/THERESA A. THOM

**Figure 1.** A false crocus geometer moth (*Xanthotype utricaria*) at Congaree National Park. A 2010 NPS-funded moth inventory at Congaree was coordinated through the Old-Growth Bottomland Forest Research and Education Center and the Cooperative Ecosystem Studies Unit (e.g., Culin et al. 2014). This research was originally inspired by bat conservation studies that framed questions about bat food sources. The bat conservation studies were in turn framed by Inventory and Monitoring network studies to document vital signs—including mammal surveys—at multiple parks. As outlined in Culin et al. (2014), the moth inventory project helped raise the park’s species list from 40 to 1,014 species, and provided important data on the distribution and phenology. Research Learning Centers serve to make research and education collaborations like this possible.

confirm that the park provides high-quality habitat for a large population that includes specialized endemic species. Interpretively speaking, moths are ubiquitous and charismatic micro-fauna that are good indicators of ecosystem condition. This makes them very relevant “tangible” resources for interpreting flood-plain forest ecology and stewardship. An official species count of over 1,000 represents a positive psychological threshold when interpreting the meaning of biodiversity at Congaree, an international biosphere reserve. At a regional scale, these results compare well to other longer-term moth-sampling efforts and help document moth distribution across North America.

The intertwined story of these two publications points to enduring support of three strategic goals outlined in the recent RLC strategic framework: (1) to “promote national parks as premier places for scientific inquiry,” (2) to “facilitate and promote the use of science to make resource management decisions,” and (3) to “improve science literacy by incorporating science into park visitor and staff experiences” (NPS 2015). This is not, however, the end of the story. Staff and partners at the Old Growth Bottomland Forest Research and Education Center have begun a parallel bat ecology study focused on the southeastern myotis. Fieldwork is under way, and

research partners are also pursuing additional work to monitor for white-nose syndrome at Congaree. Furthermore, this work is but one example of similar efforts through the Center and other RLCs across the country. These research collaborations do not happen quickly, easily, or randomly, but take long-term vision, support, and dedication to bring to fruition. The fundamental value to the National Park Service, however, is very real as we increasingly leverage science to inform and inspire both appreciation and stewardship of our parks as we head into our second century.

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—David C. Shelley and Theresa A. Thom

# Research Reports

## Indicators and standards of quality for viewing the night sky in the national parks

By Robert Manning, Ellen Rovelstad, Chadwick Moore, Jeffrey Hallo, and Brandi Smith

### Night skies as a “new” park resource

**T**HE FOCUS OF THE FIRST NATIONAL PARKS ESTABLISHED in the last half of the nineteenth century was on “scenery,” or the vast, sublime landscapes of the American West. In the early 20th century, the significance and meaning of national parks was extended in two important ways. First, historical and cultural resources were recognized as increasingly important, and additional national parks were created under the auspices of the Antiquities Act (Public Law 59-209, 34 Stat. 225, 8 June 1906) and other programs. Second, the birth of the modern science of ecology suggested that the landscapes of national parks comprise geologic and biologic resources that are intertwined to form complex ecosystems. This ecological reality implied that national parks be established and managed in a more holistic way and that the National Park System be extended to encompass the full array of North American ecosystems and associated biodiversity. In the latter half of the 20th century, the recreational values of national parks were given growing emphasis as manifested in the Mission 66 program, an initiative that funded park visitor centers and other infrastructure designed to accommodate rapidly expanding visitation. At the transition to the 21st century, the definition and significance of national parks is being extended again to include a host of “new” park resources, including a suite of ecological services (e.g., air and water quality, climate stability), natural sounds (the sounds of nature uninterrupted by human-caused noise), and natural darkness (darkness undiminished by artificial light) ([http://www.nature.nps.gov/sound\\_night/](http://www.nature.nps.gov/sound_night/)). This article focuses on the latter, specifically night skies.

The emerging importance of natural darkness and night skies is a function of the intersection of a growing consciousness about their values and a crisis over their rapid disappearance. For millennia, people have “gazed upon the cosmos” in their enduring efforts to understand both the physical and metaphysical worlds, and this suggests that night skies are an important cultural resource (Bogard 2013). Human culture is conventionally organized

#### Abstract

Night skies are increasingly recognized as an important park resource that demands more management attention. Management of night skies can be guided by a management-by-objectives framework that requires formulation of indicators and standards of quality. Two surveys were conducted at Acadia National Park to identify indicators and standards for stargazing. The first survey used an importance-performance approach and documented light pollution as an important indicator variable. The second survey used a normative approach and visual simulations to identify a range of standards of quality for light pollution. This program of research was designed to help inform management of night skies at Acadia and other parks.

#### Key words

Acadia National Park, indicators and standards, night skies, stargazing

around the rhythms of the sun, moon, and stars; observations of the night sky are embodied in the religions and mythology of cultures around the world; and the celestial world has been the inspiration for art, literature, and other forms of cultural expression (Rogers and Sovick 2001b; Collison and Poe 2013). Modern science has extended the importance of night skies by demonstrating the relevance of darkness in the biological world; many of the world’s species rely on the absence of artificial light for breeding and feeding patterns and other behaviors (Lima 1998; Witherington and Martin 2000; Le Corre et al. 2002; Alvarez del Castillo et al. 2003; Longcore and Rich 2004; Pauley 2004; Perry and Fisher 2006; Rich and Longcore 2006; Wise and Buchanan 2006; López and Suárez 2007; Navara and Nelson 2007; Chepesiuk 2009; Luginbuhl et al. 2009). Light pollution can even affect humans through sleep disturbance and other health effects (Nicholas 2001; Clark 2006; Chepesiuk 2009).

Unfortunately, the night sky is disappearing from view primarily because of “light pollution” that reduces the brightness of the stars and prevents the human eye from fully adapting to natural darkness. Outdoor lighting that is excessive, inefficient, and ineffective can produce light pollution that degrades the quality of natural darkness and the night sky by creating “sky glow.”

## *Many of the world's species rely on the absence of artificial light for breeding and feeding patterns and other behaviors.*

Cinzano et al. (2001) estimated that more than 99% of the U.S. population (excluding Alaska and Hawaii) lives in areas that are light polluted and that two-thirds of Americans could no longer see the Milky Way from their homes.<sup>1</sup> Light pollution is caused by increasing development, but may be more related to lighting that is oriented upward or sideways rather than down at the intended target. Light from urban areas can reduce the brightness of the night sky over 200 miles (322 km) away ([http://www.nature.nps.gov/sound\\_night/](http://www.nature.nps.gov/sound_night/); Smith and Hallo 2013).

National parks, especially those far from urban areas, are some of the last refuges of dark night skies, and the importance of night skies is increasingly reflected in National Park Service (NPS) policy and management. For example, Duriscoe (2001) argues that the night sky should be recognized as an important and increasingly scarce resource that must be managed and preserved, and that this is a natural extension of the NPS Organic Act (16 U.S.C. 1, 39 Stat. 535, 25 August 1916) as well as the Wilderness Act of 1964 (Public Law 88-577, 16 U.S.C. 1131–1136, 3 September 1964). Current NPS management policies include a requirement for managing “lightscares,” or natural darkness and night skies (National Park Service 2006), and a relatively new administrative NPS unit, the Natural Sounds and Night Skies Division, was created to help carry out this responsibility. Night sky interpretive programs are now conducted in an increasing number of units of the National Park System, as manifested in night sky festivals and “star parties” at Yosemite (California), Acadia (Maine), and Death Valley (California) National Parks; creation of a night sky ranger position at Bryce Canyon National Park (Utah); and development of an observatory at Chaco Culture National Historical Park (New Mexico). The National Park Service established its Night Sky Team, a small group of scientists, in 1999 and this has led to rigorous measures of night sky quality and associated monitoring in the National Park System. Night sky quality is included as a “vital sign” by many of the 32 NPS Inventory and Monitoring Networks that cover the National Park System. The recent influential NPS report, “A Call to Action,” includes a recommendation that the National Park Service “lead the way in protecting natural darkness as a precious resource and create a model for dark sky protection” (National Park System Advisory Board 2012). A recent survey of managers across the National Park System found that night skies (and “night resources” more broadly, including the opportunity to observe nocturnal species) are frequently used by visitors and that managers are interested in identifying and managing night resources more actively (Smith and Hallo 2011).

<sup>1</sup>This sentence was revised on 9 September 2015. See Erratum for further information.



**Figure 1.** Management-by-objectives framework for parks and outdoor recreation.

### Indicators and standards of quality for night sky viewing

Contemporary approaches to park and outdoor recreation management rely on a management-by-objectives approach as illustrated in figure 1 (Manning 2007; Whittaker et al. 2011; <http://visitorusemanagement.nps.gov/>). This management approach relies on formulation of indicators and standards of quality that serve as empirical measures of management objectives (such as protection of natural darkness). Indicators of quality are generally defined as measurable, manageable variables that are proxies for management objectives, while standards of quality (sometimes called “reference points” [Manning 2013] or “thresholds” [<http://visitorusemanagement.nps.gov/>]) define the minimum acceptable condition of indicator variables (Manning 2011; Whittaker et al. 2011; <http://visitorusemanagement.nps.gov/>). For example, a conventional indicator of quality for a wilderness experience is the number of groups encountered per day along trails, and a standard of quality is the maximum acceptable number of groups encountered, such as five. Once indicators and standards of quality have been formulated, indicator variables are monitored and management actions implemented to help ensure that standards of quality are maintained. This is an adaptive process that has been incorporated into NPS visitor use planning and management (<http://visitorusemanagement.nps.gov/>).

Formulation of indicators and standards of quality that address recreational use of parks can include engagement of park visitors. A growing body of research illustrates how this can be done through visitor surveys and associated theoretical and empirical approaches (Manning 2011). Several recent studies have concluded that there is a need for this type of research applied to night sky viewing or stargazing. For example, reflecting on their recent survey of park managers about nighttime recreation, Smith and Hallo (2013)

**Table 1. The importance of viewing the night sky to Acadia National Park visitors**

Statement	Frequency of Rating (%)					Mean	Standard Deviation	n
	Strongly Disagree		Strongly Agree					
	-2	-1	0	1	2			
Viewing the night sky (stargazing) is important to me.	0.0	1.0	9.4	35.4	54.2	1.4	0.7	192
The National Park Service should work to protect the ability of visitors to see the night sky.	0.0	1.1	8.9	36.8	53.2	1.4	0.7	190
The National Park Service should conduct more programs to encourage visitors to view the night sky.	0.5	2.1	27.1	37.5	32.8	1.0	0.9	192
Acadia has a good reputation as a place to view the night sky.	1.6	2.6	44.4	25.9	25.4	0.7	0.9	189
One of the reasons I chose to visit Acadia is to view the night sky.	4.2	12.1	39.5	26.3	17.9	0.4	1.1	190
I would visit Acadia less often if it became more difficult to see the night sky.	7.9	17.9	40.0	22.6	11.6	0.1	1.1	190

conclude that “visitors must be polled about their perspectives of night recreation and night resources” (p. 58). In their evaluation of night sky interpretation at Bryce Canyon National Park and Cedar Breaks National Monument (Utah), Mace and McDaniel (2013) conclude that “additional research could lead to development of standards and indicators of quality for night skies in parks and protected areas, a perspective that has been very successful in the field of park and outdoor recreation management” (p. 55).

## The study: Visitor surveys

We conducted this study to help guide formulation of indicators and standards of quality for night sky viewing in the national parks. The program of research included two visitor surveys conducted at Acadia National Park (Acadia). Acadia is located primarily on Mount Desert Island, Maine. Many visitors stay overnight in one of the park’s two campgrounds, Blackwoods and Seawall. Because of its location away from large metropolitan areas, Acadia prides itself as a premier location to view the night sky in the eastern United States. The importance of the night sky at Acadia is manifested in the park’s annual Night Sky Festival, a four-day event featuring special presentations, activities, and star parties. Acadia’s regularly scheduled ranger programming also features night walks and astronomy evening programs.

The first survey addressed the importance of night sky viewing and associated indicators of quality. The survey instrument included two batteries of questions. The first addressed the importance of night sky viewing to park visitors by posing a series of statements (shown in table 1) and asking respondents to report the extent to which they agreed or disagreed with each statement using a five-point response scale that ranged from -2 (“strongly

**Table 2. Questionnaire list of items seen and not seen at Acadia**

The Milky Way
Constellations
Stars or planets
Meteors/shooting stars
The moon
Satellites
Aircraft
Lights from distant cities
Lights from nearby towns
Campfires
Automobile lights
Flashlights
Lanterns
Streetlights
Portable work lights
Park building lights
Emergency vehicle lights

disagree”) to 2 (“strongly agree”). The second battery of questions presented a series of items (shown in table 2) that visitors might see after dark in the park. The list included celestial bodies and human-caused sources of light. We asked respondents to report which items they did or did not see and indicate the extent to which seeing or not seeing these items added to or detracted from the quality of their experience in the park. A nine-point response scale that ranged from -4 (“substantially detracted”) to 4 (“substantially added”) was used. This latter battery of questions is adapted from a “listening exercise” that has been used to assess natural and human-caused sound in national parks and its effects on the quality of the visitor experience (Pilcher et al. 2009; Manning et al. 2010).

We administered the survey to park visitors at the two campgrounds in Acadia. We sampled campground visitors because they were the most likely to be in the park at night (there are no other accommodations in the park). We intercepted groups of campers as they entered the campgrounds and gave a questionnaire to the group for a self-identified group leader to complete. We asked respondents to complete the questionnaire before they went to sleep that night or early the following morning, and then return the completed questionnaire to a drop box as they left the campground the next morning. We administered the survey for 13 days in August 2012. We contacted 277 groups and 273 agreed to participate; 194 completed questionnaires were returned representing a 70% response rate. The survey was administered under a grant to Clemson University by Musco Lighting and was approved by the university's Institutional Review Board. In addition, a research permit was received from Acadia National Park.

The second survey addressed standards of quality for night sky viewing. We prepared a series of eight visual simulations of the night sky at Acadia as shown in figure 2. These simulations portrayed equally spaced degrees of light pollution. We asked respondents to rate the acceptability of each of the simulations using a seven-point response scale that ranged from -3 ("very unacceptable") to 3 ("very acceptable"). We asked an additional suite of questions based on the series of visual simulations, as follows:

- Which image shows the night sky you would prefer to see in the park?
- Which image represents the maximum amount of human-caused light the National Park Service should allow in and around this park?<sup>2</sup>
- Which image is so unacceptable that you would no longer come to this park to stargaze or view the night sky?
- Which image is so unacceptable that you would not stargaze or view the night sky when visiting this park?
- Which image looks most like the night sky you typically saw in this park during this trip?
- Which image looks most like the night sky you think is "natural" in this park?
- Which image looks most like the night sky you typically see from your home?

We administered the survey to park visitors at seven attraction sites in Acadia. Visitors were sampled if they had spent at least one night on Mount Desert Island in the vicinity of the park. We intercepted visitors as they entered the attraction sites and gave

<sup>2</sup>The National Park Service can help control light generated within parks through design and installation of park lighting, and can work with surrounding communities to help manage light generated outside parks.

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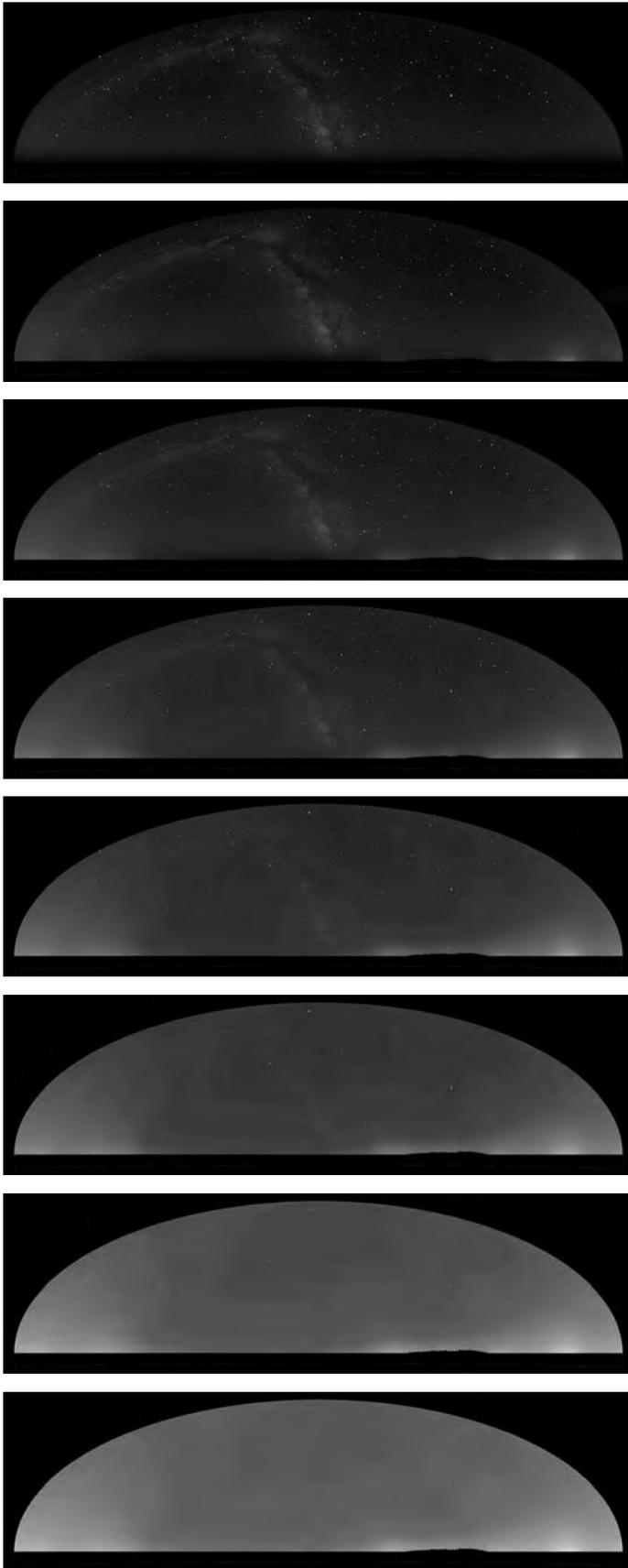
*Light pollution is caused by increasing development, but may be more related to lighting that is oriented upward or sideways rather than down at the intended target.*

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a questionnaire to the group for a self-identified group leader to complete. We instructed respondents to complete the questionnaire at that time and return it to the survey attendant stationed there. The survey attendant answered any questions respondents had about the questionnaire. We administered the survey for nine days in August and September 2013. We contacted 274 groups, and 137 visitors agreed to participate and completed questionnaires, representing a 50% response rate. Because this study was funded by the National Park Service, the survey was submitted for approval by the federal Office of Management and Budget under the NPS expedited approval process. A research permit was also received from Acadia National Park.

Surveying visitors about the night sky can be challenging. One of the survey objectives was to ensure that survey participants had spent time in or just outside the park at least one night to help make certain they had had an opportunity to view the park's night sky. A pilot test recruited visitors at the park's evening campfire programs, but few visitors were willing to participate at this late hour. The two other sampling approaches described earlier were more successful in reaching the target population while attaining an acceptable response rate. Another challenging issue is determining the night sky conditions that respondents experienced, since these conditions can be highly varied and transitory. In this study, we asked respondents to report the study photograph that was most like the conditions they typically experienced in the park.

Visual research methods are an effective approach to measuring standards of quality for parks and related areas (Manning and Freimund 2004; Manning 2007). For example, visually based studies can be especially useful for studying standards of quality for indicator variables that are inherently difficult or awkward to describe in conventional narrative/numerical terms, such as trail erosion. A visual approach has been used to study a wide variety of indicators of quality, including crowding, conflict, resource impacts, and management practices (Manning 2011). Several stud-



ies have addressed multiple dimensions of the validity of visual research methods, and findings are generally supportive (Manning 2007). However, findings are mixed on the issue of the order in which study photographs should be presented to respondents and the range of potential standards of quality presented (Manning 2011; Gibson et al. 2014). This study addresses these issues by presenting study photographs on posters, allowing respondents to see all photos at the same time (rather than one at a time), and presenting a complete range of night sky conditions from pristine to severely light polluted (see fig. 2).

## Study findings

### *Importance of night skies*

Findings from the battery of questions addressing the importance of night sky viewing are shown in table 1 and indicate that the vast majority of visitors feel that (1) night sky viewing is important, (2) the National Park Service should protect opportunities for visitors to see the night sky, and (3) the Service should conduct more programs to encourage visitors to view the night sky. Most visitors also reported that Acadia has a good reputation for night sky viewing and that this is one of the reasons they chose to visit Acadia. However, feelings were mixed as to whether respondents would visit Acadia less if it became more difficult to see the night sky (40% reported that they were unsure about this).

### *Indicators of quality for night sky viewing*

Findings from the battery of questions addressing indicators of quality for night sky viewing are presented in the form of an importance-performance framework as shown in figure 3. Importance-performance analysis is a way to evaluate visitor desires and associated experiences and has been used to identify indicators of quality in a range of park and outdoor recreation settings and for several recreation activities (Guadagnolo 1985; Mengak et al. 1986; Hollenhorst and Stull-Gardner 1992; Hollenhorst et al. 1992; Hunt et al. 2003; Pilcher et al. 2009). For example, importance-performance analysis was used to identify indicators of quality for natural quiet in national parks (Pilcher et al. 2009). Similarly, a study of visitor experiences in wilderness used importance-

**Figure 2 (left).** Visual simulations of night sky quality at Acadia National Park. These are panoramas of “light domes” as seen from Cadillac Mountain in Acadia. Image 1 (top) is a natural night sky based on observations taken in the park in 2008. Each of the following images shows a three-times increase in artificial light. Image 8 (bottom) shows a severely light-polluted sky. These simulations were prepared by the NPS Natural Sounds and Night Skies Division.

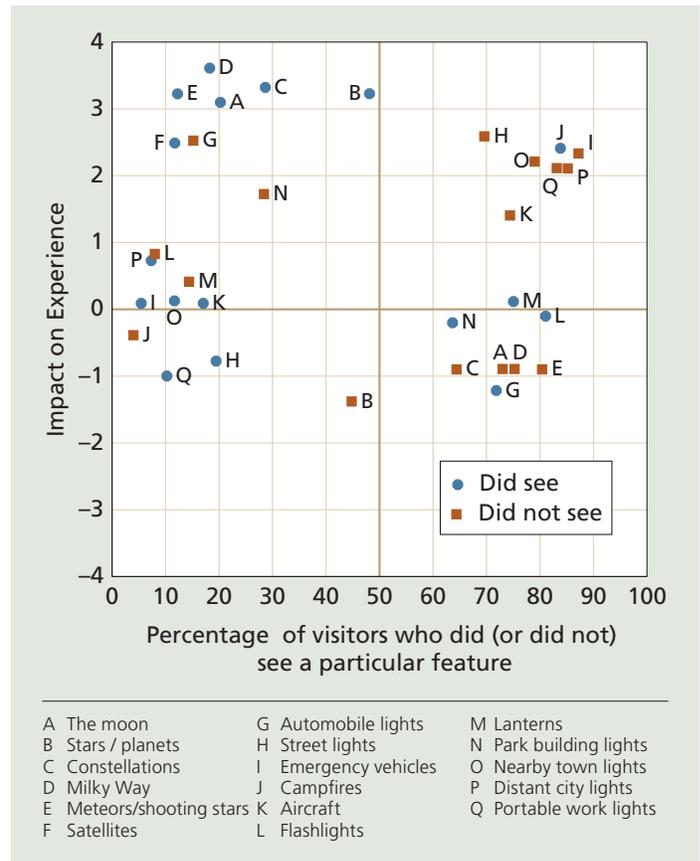
*Most visitors did not see many of the celestial objects included in the questionnaire, but . . . when they did, it substantially added to the quality of their experience.*

performance analysis to reveal indicators of quality for resource and experiential conditions on trails and in campgrounds (Hollenhorst and Gardner 1994).

Figure 3 graphs the percentage of visitors who did or did not see the items listed in table 2 (x-axis) and how seeing or not seeing these items affected the quality of visitors' experiences (y-axis). Generally, the graph shows that most visitors did not see many of the celestial objects included in the questionnaire, but that when they did, it substantially added to the quality of their experience. Likewise, most visitors did not see many of the sources of human-caused light and this also substantially added to the quality of their experience. Campfires are an exception to these generalizations: most visitors saw campfires and this added to the quality of their experience. Overall, the findings suggest that the brightness of celestial bodies and, therefore, light pollution is an important indicator of quality at Acadia.

#### **Standards of quality for night sky viewing**

Findings from the questions addressing standards of quality for night sky viewing as manifested in the brightness of celestial objects (or alternatively, the amount of light pollution) are shown in figure 4 and table 3. The graph in figure 4 is derived from the average (mean) acceptability ratings for each of the eight visual simulations. This type of graph has been used to help formulate standards of quality for resource and experiential conditions in a number of national parks (Manning et al. 1996; Shelby et al. 1996; Freimund et al. 2002; Hsu et al. 2007). It is clear from the graph that increasing amounts of light pollution are increasingly unacceptable. Average acceptability ratings fall out of the acceptable range and into the unacceptable range at around image 5 in the series presented in figure 2, and this represents a potential standard of quality (defined earlier as the minimum acceptable condition of an indicator of quality). However, the data in table 3 suggest a range of other potential standards of quality. For example, Acadia managers have identified night skies as an especially important re-

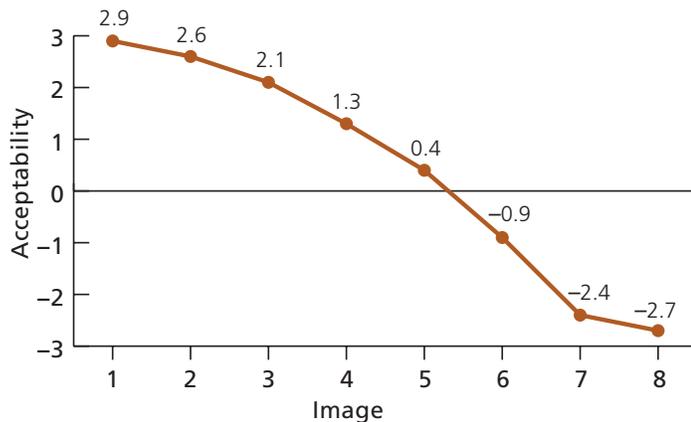


**Figure 3.** Importance-performance framework. The graph shows (1) the percentage of respondents who saw (in blue) and did not see (in red) items A through Q on the x-axis, and (2) the positive or negative impact of this on the y-axis. For example, about 50% of respondents reported seeing stars and/or planets (item B in blue) and also reported that this had a very positive impact on the quality of their experience (registered a scale value of 3.2).

source and this suggests that a higher standard of quality—closer to what visitors feel is the maximum amount of human-caused light the NPS should allow (between images three and four in figure 2)—may be appropriate.

## Conclusion

Night skies are increasingly recognized as an important resource—biologically, culturally, and experientially—in the national parks, and this is reflected in recent NPS policy and management. This study documents this importance to national park visitors. The importance of night skies will require more explicit management in the national parks, including formulating indicators and standards of quality for viewing the night sky. The program of research described in this article suggests how park visitors and other stakeholders can be engaged in this process.



**Figure 4.** Social norm curve for night sky viewing at Acadia National Park. This curve graphs the average acceptability scores for each of the images shown in figure 2.

Findings from this study suggest the amount of light pollution is a good indicator of quality for management of night skies, and that standards of quality range from approximately study photo 1 (the condition visitors would prefer) to approximately photo 6 (the condition at which visitors would no longer stargaze [table 3]). Of course this study applies specifically to Acadia, but it could be replicated in other parks or regions.

As described earlier and illustrated in figure 1, management of night skies will also require monitoring the brightness of celestial bodies and the amount of light pollution, as well as actions designed to maintain standards of quality by controlling light pollution in and around national parks. The NPS Night Skies Team is engaged in a program of monitoring the condition of night skies in the National Park System (Albers and Duriscoe 2001; Moore 2001). However, controlling light pollution is likely to be more challenging. Of course, the National Park Service can and should adopt best lighting practices designed to minimize light pollution within national parks (Chan and Clark 2001). But controlling light pollution outside park boundaries will require a proactive approach of working with surrounding communities. Acadia offers a good example of this approach, working with the gateway town of Bar Harbor, which recently adopted a new lighting ordinance for the town designed to encourage efficiency and reduce light pollution (Maine Association of Conservation Commissions

**Table 3. Alternative standards of quality of night sky viewing**

Study Question	Image Number	Standard Deviation
The point at which the social norm curve crosses the neutral point of the acceptability scale (from fig. 4)	5.2	—
Which image shows the night sky you would prefer to see?	1.1	0.4
Which image shows the maximum amount of human-caused light the National Park Service should allow?	3.7	1.8
Which image is so unacceptable that you would no longer come to this park to view the night sky?	6.1	1.4
Which image is so unacceptable that you would no longer view the night sky when visiting this park?	6.1	1.4
Which image looks most like the night sky you typically saw in this park during this trip?	2.3	1.2
Which image looks most like the night sky you think is “natural” at this park?	2.0	1.2
Which image looks most like the night sky you typically see from your home?	4.9	2.1

2010). Chaco Culture National Historical Park offers another good example, working with stakeholder groups successfully to encourage the state legislature to pass the New Mexico Night Sky Protection Act, regulating outdoor lighting throughout the state (Rogers and Sovick 2001a; Manning and Anderson 2012).

Controlling light pollution in and around national parks might further be promoted by “astronomical tourism” (Bemus 2001; Collison and Poe 2013). Paradoxically, as the opportunity for high-quality stargazing has diminished, its value may be increasing. In this way, the economic benefits of tourism based on stargazing (and other elements of natural darkness) may encourage communities in and around national parks to help reduce light pollution.

Fortunately, natural darkness, particularly the night sky, is a renewable resource; light pollution is largely transitory in both space and time. Though light pollution may have already had irreversible biological and ecological impacts, it can be controlled and even reduced, thus restoring the brightness of the night sky. The national parks, with their emphasis on protection of natural and cultural resources and the quality of visitor experiences, are a good place to advance this cause.

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<sup>3</sup>This reference was revised on 9 September 2015. See Erratum for further information.

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## Erratum

On 8 September 2015 a reader called our attention to two errors in this research report, which had been published four days earlier in the advance online version of the article. The first half of the third sentence in the third paragraph was incorrect and read, “By 2000, it was estimated that 99% of the world’s skies were light polluted ...” The citation, given as “Cinzano, P., F. Falchi, and C. D. Elvidge. 2001. Naked-eye star visibility and limiting magnitude mapped from DMSP-OLS satellite data. *Monthly Notices of the Royal Astronomical Society* 323:34–46,” was also wrong. The sentence and reference have been corrected and are indicated as such in the text (9 September 2015).

# Resource protection, visitor safety, and employee safety: How prepared is the National Park Service?

By Gina L. Depper, Demica C. Vigil, Robert B. Powell, and Brett A. Wright

**N**ATIONAL PARKS TODAY FACE HIGHLY COMPLEX issues in a rapidly changing environment. Climate change, invasive species, fire, and human activities both inside and outside of the parks threaten natural and cultural resources (Council on Environmental Quality et al. 2011). The changing demographics of the United States and the profile of park visitors also have significant implications for the management of national parks (Rodriguez et al. 2012; National Parks Second Century Commission 2009). Future park visitors may have different needs, knowledge, values, biases, and skill sets than current or former visitors, which may pose significant changes in how staff across the service, and specifically with the Division of Visitor and Resource Protection (VRP), must prepare for and respond to resource protection and visitor safety concerns. Currently VRP staff are responsible for a wide range of tasks, including law enforcement, emergency management services, search and rescue, and wilderness and backcountry management, among others.

To operate in such a complex environment it is vital that the NPS workforce have the capacity to meet the bureau's core mission and the ability to adapt to these changing conditions influencing national parks. In particular, three VRP responsibilities—resource protection, visitor safety, and employee safety—are central to fulfilling the mission of the National Park Service (e.g., National Park Service 2014). Natural and cultural resource protection is critical to the preservation of park resources for future generations, and protecting the safety of visitors is essential for providing enjoyment. The safety of Park Service employees is equally necessary for protecting resources and ensuring visitor safety.

The National Park Service has an obligation to the American people and its workforce to provide effective employee education and training programs that enhance its ability to meet the challenges of the 21st century. To do this and to comply with the Government Performance and Results Act of 1994, the National Park Service has periodically assessed the education and training needs of employees in different career specialties. In 2012 the NPS Office of Learning and Development, in collaboration with the Division of Visitor and Resource Protection and Clemson University, initiated the development of a comprehensive assessment of training needs of all NPS VRP employees. Over the following year, a group of VRP subject-matter experts developed a compre-

## Abstract

National parks in the 21st century confront many challenges. In such a climate, the ability of National Park Service (NPS) Division of Visitor and Resource Protection staff to perform specific duties related to resource protection, visitor safety, and employee safety is integral to meeting the NPS mission. It is important that employees be well trained to perform these responsibilities. For this reason the NPS Office of Learning and Development collaborated with Clemson University to assess Visitor and Resource Protection employees' perceptions of the importance and their preparedness to perform a comprehensive list of job competencies. This article reports the most critical training needs of three competency categories: natural and cultural resource protection, visitor safety, and employee safety. Training needs in resource protection included specialized law enforcement skills, gathering and synthesizing data, and collaboration and partnerships. Training needs in visitor safety focused on specialized investigative skills and the ability to synthesize data. Training needs identified with respect to employee safety involved the ability to apply Occupational Safety and Health Administration requirements. These findings as well as future training strategies are discussed. This article also reports on how NPS programs are responding to the survey through policy actions, priorities, and planning. By taking these actions in training and education, the National Park Service can support the role of the Visitor and Resource Protection Division in upholding the NPS mission for the future.

## Key words

employee safety, National Park Service, needs assessment, resource protection, skill performance, visitor safety, workforce capacity

hensive list of 87 VRP competencies related to 15 categories that were based on accepted best practices and considered necessary to perform successfully in today's park management environment (fig. 1). This led to the development of a survey that examined employees' perceptions of importance and preparedness to perform these competencies. In this article, we report some of the results of this study and examine the most critical training needs related to three categories of competencies—(1) natural and cultural resource protection, (2) visitor safety, and (3) employee safety—because these responsibilities are applicable to most VRP job

descriptions and their relative importance in fulfilling the mission of the National Park Service (e.g., National Park Service 2014).

## Methods

### Overview

Data reported in this study were collected as part of the larger Visitor and Resource Protection Training and Education Needs Assessment (Wright and Depper 2014, available from the authors). Following procedures outlined by Hammitt et al. (2007), Machnik et al. (2007), and Weddell et al. (2009 and 2013), we surveyed VRP employees to (1) identify the importance of specific competencies within each category, (2) assess the level of preparedness of employees to perform these competencies, and (3) quantify the gaps between the importance and perception of preparedness to perform each competency. We measured gaps using a diagnostic measure called a *mean weighted discrepancy score* (Robinson and Garton 2008; Edwards and Briers 1999; Bullard et al. 2013). These metrics are often used to guide the development of future education and training programs.

### Survey instrument

In addition to natural and cultural resource protection, visitor safety, and employee safety, the following 12 categories of competencies were investigated: backcountry management, incident management, emergency medical services, search and rescue, emergency communications and dispatching, public health, employee health and wellness, leadership, special park use management, NPS regulations, project management, and use and management of technologies. Associated with these 15 categories, we investigated the importance and preparedness related to 87 specific competencies.

Because of the breadth and complexity of VRP duties, the size of the survey, and the potential for respondent fatigue, we designed “skip” features in the Web-based survey. We asked respondents to rate the importance of the 15 categories of competencies on a seven point scale from “unimportant” (1) to “extremely important” (7). If the respondent rated a category as “extremely important” to their position (6 or 7), they were directed to a



COURTESY OF DEMICA VIGIL

**Figure 1.** The Visitor and Resource Protection Advisory Committee pose with the associate director for Visitor and Resource Protection and representatives from Clemson University at the Visitor and Resource Protection Academy Development Workshop at the National Conservation Training Center on 10 April 2014. The workshop discussed the results of the Visitor and Resource Protection Education and Training Needs Assessment to develop a strategic learning and development plan for the Division of Visitor and Resource Protection.

subsequent series of questions about specific related competencies. If the respondent rated a category of competencies less than “extremely important” to their position, they were skipped to the next category. In this way, respondents were spared the burden of completing those portions of the survey that they felt were unimportant to their current position. This provided the additional advantage of having data only from respondents who believed those competencies were important to their current positions. Respondents also had an option for a “not applicable” category for competency questions, but such responses were excluded from the analysis and treated as missing data. Finally, the instrument included a set of demographic and bureau-related questions pertaining to age, education, grade level, position series, position title, number of years in current position, number of years in the National Park Service, and number of years in the Visitor and Resource Protection Division.

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*Competencies related to applying specialized crime scene investigation and other enforcement techniques that effectively identify, apprehend, and prosecute resource violators were most critical.*

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### Data collection and response rates

For this Visitor and Resource Protection Training and Education Needs Assessment, we attempted to survey all NPS employees with primary visitor and resource protection duties. We identified 2,494 employees through the NPS human resource database (FPPS). We also added 656 individuals who were subsequently identified by supervisors or requested to participate and had visitor and resource protection duties. This brought our total to 3,150 individuals.

Data collection took place over a five-week period from 3 September to 2 October 2013. First, we electronically distributed a cover letter to 3,150 VRP employees. This letter contained

a unique Web link that provided access to the online survey instrument. After three weeks, we sent a second e-mail to these employees reminding them of the importance of completing the survey. On 2 October 2013, the data collection associated with the study was closed. A total of 1,092 respondents had returned surveys with usable data. This resulted in an effective response rate of 36.4%.

### Data analysis

We calculated the frequencies and mean (average) score for the importance of each competency to job performance and the respondents' perceived level of preparedness to perform each competency. Next we calculated a mean weighted discrepancy

**Table 1. Scores for natural and cultural resource protection competencies ( $n = 684$ ) sorted by mean weighted discrepancy score (MWDS)**

Competencies	Importance		Preparation		MWDS	
	Mean	SD	Mean	SD	Mean	SD
Natural and cultural resource protection (all items)	5.84	1.39	4.45	1.58	-8.12	9.33
Knowledge of special provisions/allowances (e.g., enabling legislation, special regulations)	5.73	1.40	4.83	1.51	-5.22	7.72
The ability to provide resource education to special audiences (e.g., violators, external cooperators, special use groups)	5.79	1.35	4.86	1.58	-5.47	9.00
Knowledge of threats to resources from illegal activities and damaging visitor behaviors (e.g., resource theft, vandalism, impacts from camping, climbing)	6.33	1.11	5.42	1.40	-5.73	7.97
Knowledge of those natural, cultural, and paleontological resources that are impacted by visitor use activity or illegal behaviors	5.95	1.25	4.73	1.45	-7.28	8.59
The ability to exhibit basic knowledge of social behaviors and outdoor recreation psychology as they influence parks and park resources, and the ability to apply that knowledge to address changing visitor needs and behaviors	5.52	1.49	4.16	1.67	-7.45	9.26
The ability to demonstrate comprehensive knowledge of resources that are threatened by commercial value and developing markets (e.g., medicinal plant or archaeological commercial marketing, poaching, looting)	5.89	1.43	4.51	1.53	-8.10	9.35
The ability to evaluate research and science project proposals aimed at better understanding threats to resources at risk from, at least in part, illegal and visitor use behaviors	5.28	1.60	3.72	1.60	-8.26	9.36
The ability to work within an interdisciplinary team to conduct risk analysis to prioritize resource threats, plan and implement mitigation strategies (e.g., physical security, site hardening, setting public use limits, applying targeted enforcement strategies)	5.87	1.35	4.41	1.67	-8.46	10.77
Understanding of and ability to apply federal and state resource protection laws, case studies, policies, and special authorities (e.g., forfeiture and criminal and civil cost recovery actions, such as Endangered Species Act, Comprehensive Environmental Response, Compensation, and Liability Act, Archeological Resources Protection Act, Park System Resource Protection Act)	5.86	1.46	4.32	1.58	-8.91	8.50
The ability to work in cooperation with external cooperating agencies and other stakeholders to protect resources at risk across their range	6.10	1.25	4.65	1.61	-8.93	10.11
Knowledge of and ability to incorporate current inventory and monitoring and other research into protection strategies for threatened park resources	5.62	1.41	3.90	1.62	-9.55	9.64
The ability to apply specialized enforcement techniques to effectively identify, apprehend, and prosecute resource violators and to prevent further degradation	6.13	1.41	4.55	1.66	-9.86	10.37
The ability to evaluate public use patterns and behaviors and to modify or establish regulation and policy to mitigate resource impacts	5.87	1.37	4.17	1.64	-10.06	9.74
The ability to apply specialized resource crime scene investigation techniques (e.g., Archeological Resources Protection Act, field forensics, evidence preservation, mapping/diagramming)	5.80	1.55	4.02	1.66	-10.45	10.21

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*Steps are now being taken by the Office of Learning and Development and the Division of Visitor and Resource Protection to remedy many of these critical training needs.*

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score (MWDS) to identify the gap between the two. We computed an individual mean weighted discrepancy score using the formula (individual preparedness – individual importance) × importance grand mean (Robinson and Garton 2008; Edwards and Briers 1999; Bullard et al. 2013). This individual mean weighted discrepancy score measures the gap between importance and preparedness while taking into account the overall importance (mean) of a competency as reported by the total number of respondents. For example, an individual rates the importance of a competency as a 7 (extremely important) and then ranks his or her perceived level of preparedness to perform this competency as a 5. The importance grand mean reported in table 1 for this competency is 6.1. The calculation is  $(5-7) \times 6.1 = -12.2$ . This is the individual's mean weighted discrepancy score for this competency. The mean of the MWDS is the average of all such individual scores for each competency and category of competencies. When interpreting the results, a larger negative number indicates a higher training priority. For example, a -9 MWDS would indicate that employees feel relatively less prepared to perform an important competency than a -2 MWDS; therefore, the competency with a -9 MWDS rises to a higher training priority.

## Results

### *Respondent characteristics*

Respondents to the Visitor and Resource Protection Training and Education Needs Assessment (n = 1,092) were, on average, 42 years old, with ages ranging from less than 20 to more than 60. Respondents were also well educated; 83% had completed a bachelor's degree or higher. Approximately 68% of respondents held the equivalent of a GS 9–12 pay grade. Respondents had been employed by the National Park Service for an average of slightly more than 14 years, with most of that time (mean = 13.7 years) being in VRP positions. Most respondents reported holding their current position for more than six years.

### *Resource protection*

Almost 63% of respondents rated the natural and cultural resource protection category as extremely important (6 or 7 on the seven-point scale) to their current position and were directed to

the 14 related competencies (see table 1). According to respondents, all 14 competencies were rated relatively high in importance (5.28 or higher). The competency rated the most important pertained to the “knowledge of threats to resources from illegal activities and damaging visitor behaviors” (6.33). Respondents also felt very prepared (5.42) to perform this competency, thus producing a relatively high MWDS (-5.73). The lowest MWDS, which indicates the highest priority for training, pertained to the “ability to apply specialized resource crime scene investigation techniques” (-10.45). Other low MWDS scores included the “ability to evaluate public use patterns and behaviors to modify or establish regulation and policy to mitigate resource impacts” (-10.06); the “ability to apply specialized enforcement techniques to effectively identify, apprehend, and prosecute resource violators and to prevent further degradation” (-9.86); and the “knowledge of and ability to incorporate current inventory and monitoring and other research into protection strategies for threatened park resources” (-9.55).

### *Visitor safety*

Almost 64% of the study respondents deemed the visitor safety category to be extremely important (6 or 7) and were directed to the eight visitor safety competencies (table 2). The competency rated as the most important was the “ability to recognize and respond to hazardous conditions or unsafe visitor behavior and document decisions that impact visitor safety” (6.50); respondents also felt the most prepared to accomplish this competency (5.60), resulting in a relatively high MWDS (-5.87). The lowest MWDS, and therefore the highest training priority, applied to the “ability to conduct root cause analysis and apply lessons learned to a safety program” (-8.37). The next lowest MWDS pertained to the “ability to investigate or assist in the investigation of a serious visitor incident or near misses” (-8.11), followed by the “ability to integrate safety, health, and wellness into operational programs” (-7.74).

### *Employee safety*

Almost 70% of the study respondents rated the employee safety category of competencies as extremely important (6 or 7) and were subsequently directed to the five corresponding competencies (table 3). Respondents rated the competency “ability to

**Table 2. Scores for visitor safety competencies (n = 698) sorted by mean weighted discrepancy score (MWDS)**

Competencies	Importance		Preparation		MWDS	
	Mean	SD	Mean	SD	Mean	SD
Visitor safety (all items)	5.92	1.30	4.75	1.61	-6.94	9.40
The ability to recognize and respond to hazardous conditions or unsafe visitor behavior and document decisions that impact visitor safety	6.50	0.88	5.60	1.32	-5.87	8.15
Knowledge of staff roles and responsibilities for visitor safety, risk management, and tort claims	6.04	1.18	5.05	1.49	-6.03	8.45
The ability to collaborate with internal and external safety specialists on a range of visitor safety issues	5.46	1.56	4.30	1.74	-6.41	9.73
The ability to collect and manage visitor safety data	5.40	1.59	4.20	1.75	-6.50	9.77
The ability to create and implement visitor safety policies and a park safety plan and to lead or coordinate with the park safety committee as applicable to your park unit	5.84	1.35	4.73	1.59	-6.51	9.25
The ability to integrate safety, health, and wellness into operational programs	6.22	1.07	4.98	1.53	-7.74	9.75
The ability to investigate or assist in the investigation of a serious visitor incident or near misses	6.27	1.16	4.99	1.62	-8.11	10.03
The ability to conduct root cause analysis and apply lessons learned to a safety program	5.63	1.58	4.15	1.82	-8.37	10.06

**Table 3. Scores for employee safety competencies (n = 755) sorted by mean weighted discrepancy score (MWDS)**

Competencies	Importance		Preparation		MWDS	
	Mean	SD	Mean	SD	Mean	SD
Employee safety (all items)	6.32	1.05	5.45	1.35	-5.42	8.07
The ability to perform work safely, including using proper personal protective equipment	6.79	0.51	6.21	1.01	-3.95	6.44
The ability to apply principles of best safety practices (including Job Hazard Analysis (JHA) and Operational Leadership (OL), and other risk management tools	6.19	1.24	5.54	1.38	-4.02	8.86
The ability to recognize and respond to hazardous conditions or unsafe visitor behavior and appropriately document decisions that impact visitor safety	6.47	1.00	5.63	1.30	-5.41	7.52
The ability to demonstrate knowledge of employee roles and responsibilities for adherence to occupational health and safety policies	6.21	1.11	5.25	1.37	-5.94	7.82
The ability to apply OSHA requirements	5.94	1.41	4.62	1.68	-7.77	9.71

perform work safely including using proper personal protective equipment” the most important; they also indicated a high level of preparedness to complete this responsibility (6.21), resulting in a relatively high MWDS (-3.91). The lowest MWDS, and therefore the highest in training need, pertained to the “ability to apply OSHA [Occupational Safety Health Administration] requirements” (-7.77). The next lowest discrepancy scores pertained to the “ability to demonstrate knowledge of employee roles and responsibilities for adherence to occupational health and safety policies” (-5.94) and the “ability to recognize and respond to hazardous conditions or unsafe visitor behavior and appropriately document decisions that impact visitor safety” (-5.41).

## Implications and conclusions

Our results revealed several potentially critical training needs. Pertaining to natural and cultural resource protection, three broad training needs emerged. First, competencies related to applying specialized crime scene investigation and other enforcement techniques that effectively identify, apprehend, and prosecute resource violators were most critical. In recognition of the importance of these competencies, the NPS Law Enforcement Training Center (LETC) provides basic, field, and advanced training. However, not all VRP employees can attend these classes. So the LETC Advanced Training Program developed and offers various courses to train experienced VRP rangers as instructors, who conduct training in the field on specialized law enforcement

skills. Some of these instructor training courses are Use of Force, Law Enforcement Control Tactics, Firearms, Defensive Tactics, and Physical Fitness. The VRP rangers enrolled in these courses have been identified and asked to participate by supervisors or are volunteers. We assumed that these specialized instructors are helping to close this training gap, but the NPS Law Enforcement Training Center, together with the NPS Office of Learning and Development and Temple University, are currently evaluating the program to confirm or reject these speculations.

The second broad resource protection training need related to gathering and synthesizing data from multiple sources. Specific competencies included (1) using visitor use data to inform policy and regulations, (2) incorporating current inventory and monitoring data and other research into protection strategies, and (3) evaluating research and science project proposals aimed at better understanding resources at risk from illegal and visitor use behaviors. These competencies require interdisciplinary training and cross-divisional collaboration with social science and natural resource specialists. Developing the relevant knowledge, skills, and abilities comes with both advanced training and experience working with these specialists.

Skills pertaining to collaboration and partnerships emerged as a third training need. The ability to “work in cooperation with external cooperating agencies and stakeholders to protect resources at risk across their range,” and the ability to “work within an interdisciplinary team to conduct risk analyses on threats to resources and implementing mitigation strategies to combat identified threats,” were both areas for future improvement. Respondents reported that these collaborations are essential to protecting resources, but they also reported being somewhat unprepared to do this. These results are consistent with findings of the previous assessment of partnership training needs reported by Weddell et al. (2009). This raises an important question: How do VRP field staff and managers perceive their respective responsibilities related to collaboration and partnership development? To address this question, we compared the MWDS of respondents with management responsibilities (operationally defined as employees with a pay grade level of GS 12 or above) with respondents with field responsibilities (defined for our purposes as employees with a pay grade level of GS 11 and below). Management staff had statistically higher MWDS scores for both items ( $-6.49$  vs.  $-9.33$ ;  $p > 0.01$ ) and ( $-5.93$  vs.  $-10.13$ ;  $p > 0.001$ ). This suggests that while both management and field staff felt these competencies were important, management felt more prepared to undertake these efforts. This indicates a need for increased training pertaining to partnerships and collaboration particularly focused on staff with grades of GS 11 and below.

As for visitor safety, two broad critical needs emerged: the ability to use specialized investigative skills and knowledge of how to apply data from multiple sources to enhance visitor safety. The two largest gaps in investigative skills training were the ability to conduct root cause analysis and the ability to investigate or assist in the investigation of a serious visitor incident. Both require specialized skills and the ability to synthesize data to inform policy. The ability to integrate safety, health, and wellness considerations into operational programs also had a low MWDS. Statistically there are far more visitor fatalities than employee fatalities annually (Heggie et al. 2008). In-person training programs (Serious Accident Investigation Interagency Training) exist for employee investigations, but generally this is not the case with investigations of visitor deaths. To fill this void in training offerings and augment existing classroom courses, the Office of Risk Management has undertaken steps to design, develop, and test Internet-based training modules focused on procedures and skills associated with both Board of Review Team investigations, which examine visitor accidents, and the Serious Accident Investigation Team inquiries, which focus on employee accidents.

Results suggest that NPS staff generally felt better prepared to undertake employee safety competencies than the two preceding competency categories. Only one specific technical competency was a potential critical training need: the ability to apply OSHA requirements. To address this gap, online training could be devised that considers OSHA requirements in tandem with NPS mandates using real-life situations as examples. However, given the relatively high MWDS for this competency, training and education here may be a lower priority than some of the other competencies.

Periodic assessment of the education and training needs of employees in different career specialties is essential if the National Park Service is going to meet the challenges of the 21st century. Our results related to competencies in resource protection, visitor safety, and employee safety revealed several potentially critical training needs. Steps are now being taken by the Office of Learning and Development and the Division of Visitor and Resource Protection to remedy many of these critical training needs. Additional innovative and creative training and education strategies must be developed, however, to meet changing demands. Once implemented, programmatic evaluation should occur to ensure the effectiveness of these programs and to provide opportunities for programmatic improvement. By taking these actions in training and education, the National Park Service can continue to support the role of the Visitor and Resource Protection Division in upholding the NPS mission for the future.

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# Lake trout–induced spatial variation in the benthic invertebrates of Yellowstone Lake

## Invasive lake trout indirectly increased biomass and body mass of amphipods

By Oliver Wilmot, Lusha Tronstad, Robert O. Hall, Jr., Todd Koel, and Jeff Arnold

**L**AKE TROUT (*SALVELINUS NAMAYCUSH*) HAVE BEEN widely introduced, both legally and illegally, throughout the western United States (Martinez et al. 2009) (fig. 1). These fish are considered apex predators in lakes because they occupy the top trophic level (Post et al. 2000). Lake trout have been successful invaders in many lakes and can alter ecosystems through competition, hybridization, predation, and trophic cascades, described below (Martinez et al. 2009). For example, lake trout in two Idaho lakes reduced bull trout (*Salvelinus confluentus*) populations through competition, and lake trout can hybridize with other trout, such as brook trout (*Salvelinus fontinalis*; Behnke 2002). These piscivores (fish predators) have reduced the native fish populations in many lakes and reservoirs (Martinez et al. 2009), which can lead to a trophic cascade that alters the structure of the pelagic (open water) food web (Tronstad et al. 2010). The effects of trophic cascades have been studied thoroughly in the pelagic zone of lakes, but few studies have examined trophic cascades in the lake benthos (life associated with the bottom substrate of aquatic habitats; fig. 2, next page).

Introduced lake trout can change lower trophic levels through direct and indirect effects (Tronstad et al. 2010). Trophic cascades are naturally occurring processes in ecosystems where

**Figure 1.** Lake trout were illegally introduced to Yellowstone Lake around 1985 and have been a disruptive influence to the lake ecosystem since.

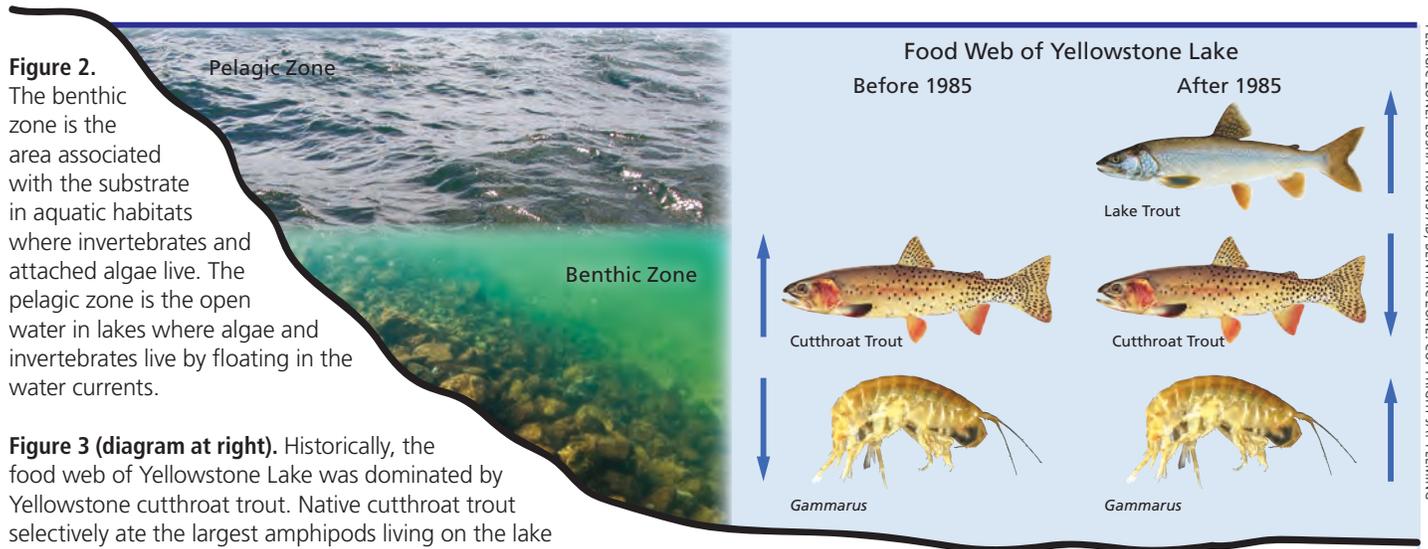
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### Abstract

Invasive predators can induce trophic cascades in the open water of lakes; however, much less is known about their effect on benthic invertebrates, which inhabit the lake bottom, or benthic zone. Lake trout (*Salvelinus namaycush*) were introduced to Yellowstone Lake, Wyoming, and reduced the Yellowstone cutthroat trout (*Oncorhynchus clarkii bouvieri*) population. We predicted that lake trout indirectly reduced predation of benthic invertebrates through cutthroat trout. To estimate how the benthic invertebrate assemblages differed under cutthroat trout– versus lake trout–dominated food webs, we collected benthic invertebrate samples from two areas of Yellowstone Lake in 2004 using a Ponar sampler and compared them with stomach contents from cutthroat trout. Cutthroat trout selectively ate benthic invertebrates with the largest body sizes. The amphipod genus, *Gammarus*, had the highest biomass of all benthic invertebrates. *Gammarus* biomass was higher in West Thumb (6,000 mg/m<sup>2</sup> [0.02 oz/ft<sup>2</sup>]) where lake trout dominated and lower in South Arm (3,160 mg/m<sup>2</sup> [0.01 oz/ft<sup>2</sup>]) where cutthroat trout dominated ( $p = 0.01$ ). Additionally, individual body mass of *Gammarus* was greater in West Thumb (1.6 mg/individual [0.000056 oz/individual]) than in South Arm (1.1 mg/individual [0.000039 oz/individual];  $p = 0.01$ ). Our results suggest that lake trout predation on cutthroat trout indirectly reduced predation on *Gammarus* in West Thumb, leading to a relative increase in the local *Gammarus* biomass and body mass. Monitoring the benthos of Yellowstone Lake may allow managers to understand the food web dynamics at higher trophic levels.

### Key words

diet, invasive species, invertebrates, trophic cascade, Yellowstone cutthroat trout



**Figure 2.**

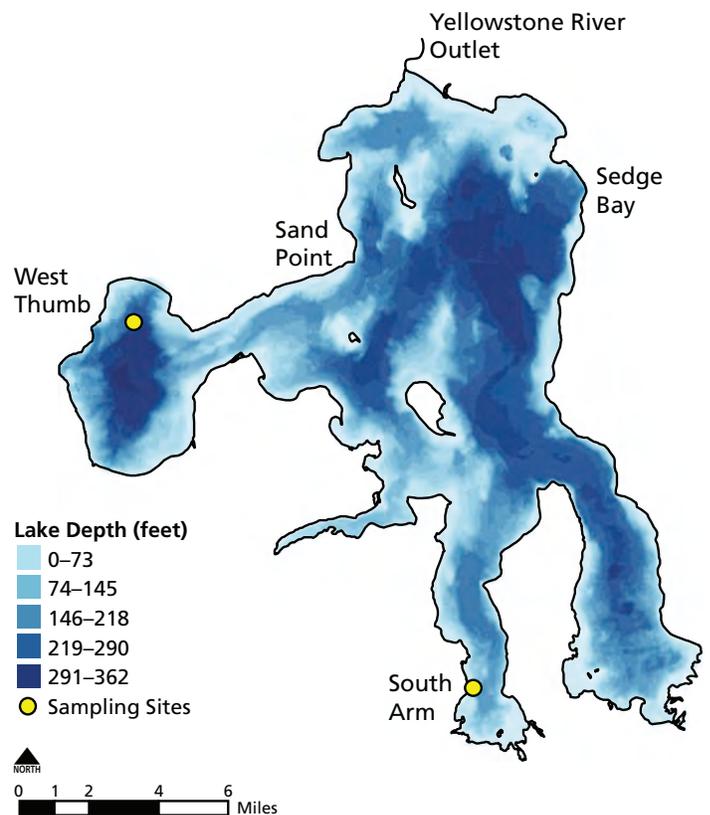
The benthic zone is the area associated with the substrate in aquatic habitats where invertebrates and attached algae live. The pelagic zone is the open water in lakes where algae and invertebrates live by floating in the water currents.

**Figure 3 (diagram at right).**

Historically, the food web of Yellowstone Lake was dominated by Yellowstone cutthroat trout. Native cutthroat trout selectively ate the largest amphipods living on the lake bottom. Lake trout were illegally introduced into Yellowstone Lake around 1985 and these fish likely caused a trophic cascade where the biomass (weight; arrows) of animals alternates between trophic levels. Lake trout have reduced cutthroat trout and increased the biomass and body size of amphipods (*Gammarus*) in areas where these invasive predators are abundant. Our study used South Arm as a representation of the pre-lake trout assemblages and West Thumb for the post-lake trout assemblages.

top predators control the biomass of lower trophic levels (the position an organism occupies in the food web). These top-down effects create a pattern of alternating biomass from high to low between trophic levels (e.g., Carpenter et al. 1987; fig. 3). Trophic cascades also alter the body size of herbivores. For example, the introduction of northern pike (*Esox lucius*) in a Canadian lake reduced the abundance of plankton-eating fish, increased the body size of zooplankton (microscopic invertebrates that live in the pelagic zone of lakes), and decreased phytoplankton (algae that live in the pelagic zone of lakes) biomass (Findlay et al. 2005). Introducing a species that occupies a new trophic level can alter the structure of the food web when interactions among trophic levels are strong.

Trophic cascades can occur when predators eat a variety of organisms, but predators can still affect lower trophic levels when they eat specific prey. For example, specialist fish predators preferentially fed on and drastically reduced specific prey taxa but had less of an effect on other benthic invertebrates (Brönmark 1994). Despite reducing only prey taxa, these fish indirectly increased benthic primary production. Current knowledge of benthic trophic cascades is based on enclosure manipulations (Brönmark et al. 1992; Brönmark 1994) and observations in ponds (Brönmark and Weisner 1996). Carpenter and Kitchell (1993) recommend conducting in situ studies on the lake benthos to better understand food web dynamics.



**Figure 4.** Map of Yellowstone Lake showing our study sites.



**Figure 5.** We compared invertebrates living on the lake bottom in two areas of Yellowstone Lake: Carrington Island in West Thumb (left) and South Arm (right).

## Yellowstone Lake ecosystem

Indigenous fish species within Yellowstone Lake include Yellowstone cutthroat trout (*Onchorynchus clarkii bouveri*) and longnose dace (*Rhinichthys cataractae*; Gresswell et al. 1997). Lake trout were illegally introduced into Yellowstone Lake around 1985 (Munro et al. 2005) and discovered in 1994 (Kaeding et al. 1996). In addition to lake trout, reidside shiner (*Richardsonius balteatus*), lake chub (*Couesius plumbeus*), and longnose sucker (*Catostomus catostornus*; Gresswell and Varley 1988) have been introduced to Yellowstone Lake. Lake trout and cutthroat trout are the dominant fish in the lake and the other species occur in much lower abundances. After their introduction, lake trout flourished and decreased the abundance of native Yellowstone cutthroat trout through predation (Koel et al. 2005). Lake trout feed heavily upon cutthroat trout and can attain relatively large body sizes (e.g., 120 cm [47 in] and 11 kg [25 lb]; Behnke 2002), allowing them to eat more and larger cutthroat trout. Additionally, Ruzyccki et al. (2003) estimated that lake trout can eat cutthroat trout up to 57% of their body length. In the Yellowstone Lake food web, lake trout filled a new niche (fourth trophic level) and induced a four-level trophic cascade in the pelagic zone of Yellowstone Lake (Tronstad et al. 2010; see fig. 3). The introduction of lake trout indirectly increased the biomass and body size of zooplankton, resulting in lower biomass of phytoplankton.

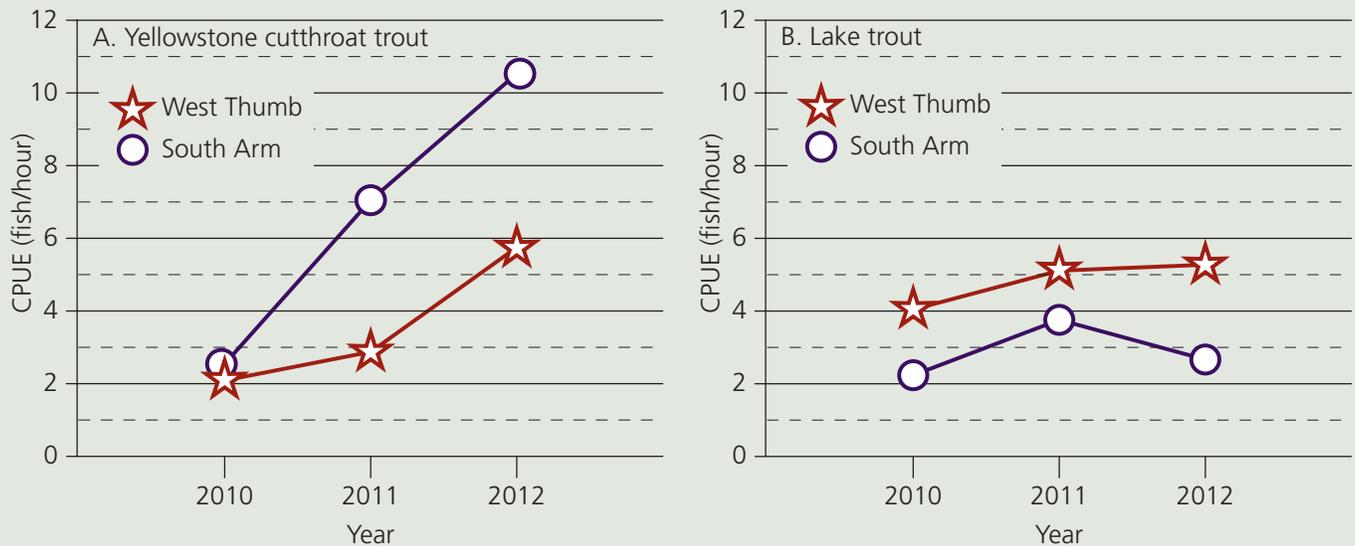
Despite an altered pelagic food web, the degree to which lake trout disrupted the benthic or lake bottom food web of Yellowstone Lake has not been studied before. Benthic invertebrates may have been altered indirectly by the lake trout invasion because cutthroat trout feed heavily on amphipods within the littoral or nearshore zone that is less than 20 m (66 ft) deep (Tronstad et al. 2015; see fig. 2). Amphipods or scuds are small crusta-

ceans that are abundant in Yellowstone Lake. *Gammarus* is the most common amphipod in the lake. Our goal was to estimate the degree to which lake trout indirectly altered the benthic invertebrates of Yellowstone Lake. We studied two sites within Yellowstone Lake (figs. 4 and 5) with varying densities of cutthroat trout and lake trout. This was necessary as a space-for-time substitution because benthic invertebrates were not collected when cutthroat trout were abundant. South Arm has higher cutthroat trout densities than West Thumb (fig. 6, next page) and is considered the last spatial refuge for this native trout within Yellowstone Lake (Koel et al. 2004). Our specific questions were: (1) How did the biomass of invertebrates compare between sites with different trout abundances? (2) To what degree did amphipod biomass and size differ between sites? (3) How did the assemblage and body mass of invertebrates in cutthroat trout diets compare with benthic samples? And (4) How strong were the interactions between lake trout, Yellowstone cutthroat trout, and amphipods?

## Material and methods

### Study area

Yellowstone Lake is located in Yellowstone National Park in northwestern Wyoming and is the largest lake in North America above an elevation of 2,000 m (6,562 ft; Gresswell et al. 1997). The lake has a surface area of 340.0 km<sup>2</sup> (131.3 mi<sup>2</sup>) and a mean depth of 43 m (141 ft; Kaplinski 1991). The littoral zone of Yellowstone Lake occupies 81.0 km<sup>2</sup> (31.3 mi<sup>2</sup>) and encompasses about 24% of the lake (Benson 1961). Ice covers the lake from December through May (Gresswell and Varley 1988) and the primary productivity is mesotrophic (moderate productivity by algae; Kilham et al. 1996).



**Figure 6.** (A) Catch per unit effort (CPUE) of Yellowstone cutthroat trout was higher in South Arm than in West Thumb over a three-year period. (B) CPUE of lake trout was higher in West Thumb than in South Arm over a three-year period.

Patterns of habitat use differ between lake trout and cutthroat trout. Lake trout live deep within the pelagic zone, feeding on invertebrates as juveniles and preying on fish as adults (Ruzycki et al. 2003). In Yellowstone Lake, lake trout have large home ranges and move throughout the lake in search of food (T. Koel and J. Arnold, personal observation). Juvenile cutthroat trout are thought to live in the pelagic zone (Gresswell and Varley 1988), which may make them more vulnerable to predation by lake trout. Adult cutthroat trout move into the littoral zone of the lake and feed on both zooplankton and benthic macroinvertebrates (Benson 1961).

Shortly after the discovery of lake trout in Yellowstone Lake, fisheries managers at Yellowstone National Park initiated an aggressive removal program in an attempt to conserve cutthroat trout (Koel et al. 2005). These efforts have progressively increased since implementation. Using gill nets, resource managers removed approximately 25,000 lake trout from Yellowstone Lake in 2004 and more than 200,000 in 2011 (Koel et al. 2012b)

#### Sampling and laboratory analysis

We collected invertebrate samples in the littoral zone of West Thumb and South Arm during the ice-free months of June to November 2004 to estimate their density and biomass. The West Thumb site was near Carrington Island and the South Arm site was near the southern end of the lake at the edge of the motorless zone (figs. 4 and 5). We collected four samples from each site on six dates: 30 June, 14 July, 29 July, 30 August, 23 September, and 21 October. We sampled the benthos using a Ponar grab sampler

(524 cm<sup>2</sup> [81 in<sup>2</sup>] sampling area) attached to a winch and a crane mounted on a boat (fig. 7). We sieved samples with 500  $\mu$ m (0.02 in) mesh and preserved samples in approximately 75% ethanol.

We removed invertebrates from the debris in the laboratory and identified individuals under a dissecting microscope using dichotomous keys (Merritt et al. 2008; Thorp and Covich 2010). We counted all individuals in each sample to calculate density. Additionally, we measured the first 20 haphazardly chosen individuals of each taxon to calculate biomass (ash-free dry mass [AFDM] of all animals per unit area of the lake bottom). We estimated invertebrate biomass for most taxa using previously published length-mass regressions (Benke et al. 1999; Johnson et al. 2012). For taxa that did not have published length-mass regressions, we calculated biomass using other methods. For leeches, we randomly selected five individuals from each species and dried them in an oven at 65°C (149°F) for 18 hours. The leeches were placed in a desiccator for 1 hour before weighing. To calculate biomass for oligochaetes, ostracods, copepods, nematodes, and acari we estimated a mean length and width based on individuals in the samples, and we assumed a specific gravity of 1.13 and a dry mass-to-wet mass conversion of 0.25 (Feller and Warwick 1988).

We measured the density and biomass of trout stomach contents to estimate the degree to which cutthroat trout feed on benthic invertebrates. We were unable to use historical information because biomass of stomach contents was not previously calculated (Benson 1961; Jones et al. 1990). We caught seven cutthroat trout



CHRISTINE FISHER

**Figure 7.** Ponar sampler and winch attached to a boat used to collect aquatic invertebrates from the littoral zone (<20 m [66 ft] depth) of Yellowstone Lake.

at Sand Point in June 2004 and flushed their stomachs to identify and measure what they were eating. Invertebrates in stomach contents were identified to the lowest possible taxonomic level, counted, and measured. We examined gut contents under a dissecting microscope and calculated individual and total biomass of gut contents using the same principles as for the benthic fauna analysis above (e.g., Benke et al. 1999).

We used the method by Cross et al. (2011) to compare the species impact of cutthroat trout and lake trout on *Gammarus*. The species impact is the production of *Gammarus* (accumulation of *Gammarus* biomass over time) consumed by trout divided by *Gammarus* biomass in the benthos of Yellowstone Lake. Cross et al. (2011) found an annual production-to-biomass ratio of 3.3/year for rainbow trout (*Onchorynchus mykiss*) in Lake Powell (Glen Canyon National Recreational Area, Utah and Arizona). This finding means that rainbow trout produce 3.3 times as much mass in a year relative to the mass of all these fish at a given time. We assumed that this value was similar for cutthroat trout and lake trout in Yellowstone Lake.

We multiplied annual trout production-to-biomass ratio by trout biomass in each area of the lake ( $\text{g}/\text{m}^2$ ) to estimate annual fish consumption ( $\text{g}/\text{m}^2/\text{yr}$ , or grams per meter squared per year). We used mean individual size to estimate trout biomass for cutthroat trout (350 mm [14 in] total length; 85 g [3 oz] dry mass; Tronstad et al. 2015) and lake trout (500 mm [20 in] total length; 264 g [9 oz] dry mass; Syslo et al. 2011) in Yellowstone Lake. We multiplied annual fish production by the proportion of *Gammarus* in trout stomach contents to estimate the production of trout from *Gammarus* ( $\text{Pgam}$ ;  $\text{g}/\text{m}^2/\text{yr}$ ). In other words, we calculated the amount

*Our goal was to estimate the degree to which lake trout indirectly altered the benthic invertebrates of Yellowstone Lake.*

of trout biomass that is produced annually from eating *Gammarus*. *Gammarus* made up 9.8% of lake trout stomach contents by volume (Ruzycki et al. 2003). The proportion of cutthroat trout diet from *Gammarus* was calculated based on biomass of *Gammarus* in each stomach sample divided by total biomass in each stomach.

The number of lake trout and cutthroat trout in each study area was estimated based on total population size and catch in each area. In 2004, the total cutthroat trout population in Yellowstone Lake was estimated at 1.4 million individuals (Tronstad et al. 2015) and the total lake trout population was approximately 125,000 individuals (Syslo et al. 2011). We calculated the number of lake trout and cutthroat trout in West Thumb and South Arm using proportions based on catch per unit effort (CPUE) values throughout the lake in 2010 (Koel et al. 2012a); however, previous years did not have estimates of lake trout CPUE. The littoral zone area was calculated for South Arm (11.0  $\text{km}^2$  [4.2  $\text{mi}^2$ ]) and West Thumb (8.6  $\text{km}^2$  [3.3  $\text{mi}^2$ ]) using ArcMap and bathymetry (underwater depth; unpublished data, Yellowstone National Park). Using total cutthroat trout and lake trout biomass, we calculated total biomass for each species per unit area of the littoral zone for both study sites. We calculated the species impact for cutthroat trout and lake trout on *Gammarus* in West Thumb and South Arm by dividing the production of trout from *Gammarus* ( $\text{Pgam}$ ) by the biomass of *Gammarus* from benthic samples ( $\text{g}/\text{m}^2$ ).

We used R version 3.0.0 (R Core Development Team 2013) for calculations and statistical analyses. We used the Wilcoxon signed rank test to test for differences in density, biomass, and individual body mass between South Arm and West Thumb, because our data were not normally distributed. We subtracted South Arm values from West Thumb values and tested whether the difference was significantly greater than zero, because we predicted that biomass and body size would be higher in West Thumb where lake trout are more abundant. We estimated error by “bootstrapping” 95% confidence intervals (CI; the region between the 2.5% and 97.5% quantiles), because our data were not normally distributed and contained many zeros for rare taxa (e.g., Hury 1996).

Bootstrapping uses the data we collected to estimate the uncertainty in our measures without making any assumptions about the distribution of our data. We sampled with replacement 10,000 times from the four replicate samples and six dates for each taxon at each site (i.e., 24 samples total from each site).

## Results

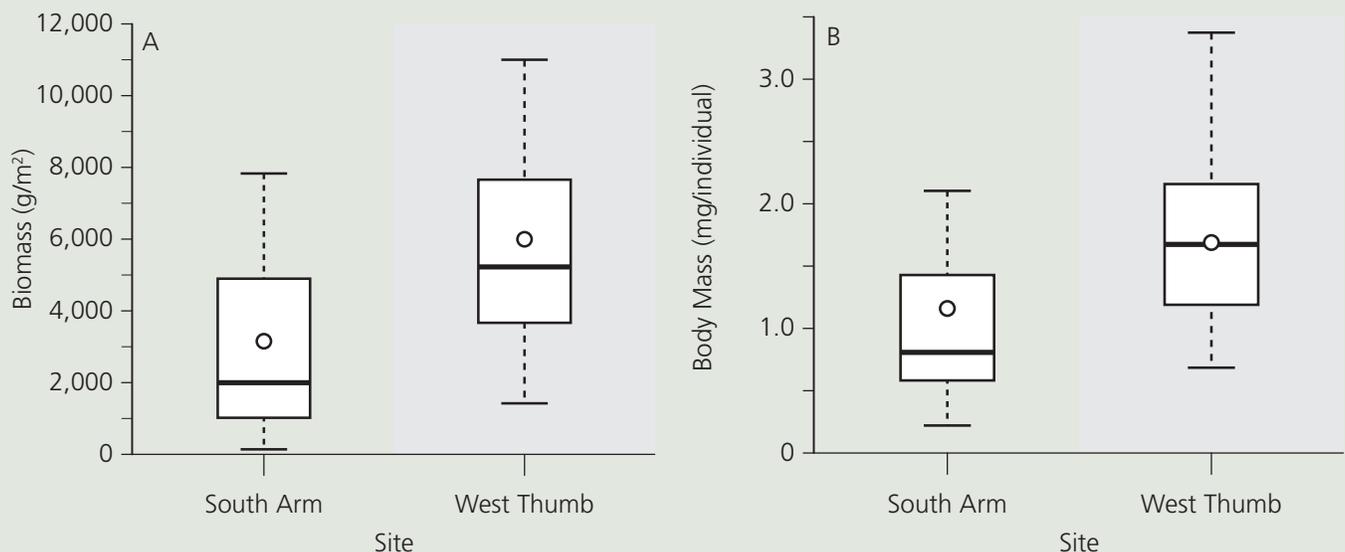
We collected 23 taxa of invertebrates in three phyla in the benthos of Yellowstone Lake. Noninsects (6,100 individuals/m<sup>2</sup> [600 individuals/ft<sup>2</sup>]) had lower density than insects (8,900 individuals/m<sup>2</sup> [800 individuals/ft<sup>2</sup>]), but they also had much higher biomass (7,100 mg/m<sup>2</sup> [0.02 oz/ft<sup>2</sup>]) than insects (500 mg/m<sup>2</sup> [0.002 oz/ft<sup>2</sup>]; table 1). Of the noninsects, amphipods had the highest density (2,500 individuals/m<sup>2</sup> [200 individuals/ft<sup>2</sup>]) and biomass (2,500 mg/m<sup>2</sup> [0.008 oz/ft<sup>2</sup>]), followed by oligochaetes (500 individuals/m<sup>2</sup> [50 individuals/ft<sup>2</sup>]) and 1,200 mg/m<sup>2</sup> [0.004 oz/ft<sup>2</sup>]). We collected three orders of insects, including Ephemeroptera (mayflies), Trichoptera (caddisflies), and Diptera (true flies). The family Chironomidae (nonbiting midges) had by far the highest density (8,800 individuals/m<sup>2</sup> [800 individuals/ft<sup>2</sup>]) and biomass (400 mg/m<sup>2</sup> [0.001 oz/ft<sup>2</sup>]; table 1).

Although values for density and biomass of most taxa were higher in West Thumb than in South Arm, the differences were not statistically significant ( $p > 0.05$ ). Total density ( $p = 0.81$ ) and biomass

( $p = 0.10$ ) of invertebrates was similar between sites (table 1). Conversely, Ephemeroptera density ( $p < 0.01$ ) and biomass ( $p < 0.01$ ) were greater in West Thumb than in South Arm. Noninsects had marginally higher biomass in West Thumb ( $p = 0.06$ ; table 1). This pattern is driven primarily by slightly higher biomass of crustaceans ( $p = 0.04$ ), and specifically *Gammarus* ( $p = 0.01$ ), in West Thumb where lake trout are more abundant.

*Gammarus* was a dominant taxon in the benthos of Yellowstone Lake and their biomass differed between sites. *Gammarus* comprised 69% of the assemblage in West Thumb and 49% of the assemblage in South Arm based on biomass. We collected 75% higher biomass of *Gammarus* in West Thumb than in South Arm ( $p = 0.01$ ; fig. 8A). Individual *Gammarus* body mass was 50% greater in West Thumb than in South Arm ( $p < 0.01$ ; fig. 8B).

*Gammarus* makes up a large proportion of the invertebrates that cutthroat trout eat in Yellowstone Lake. This amphipod (52%) dominated invertebrate biomass in cutthroat trout stomachs, followed by *Daphnia* (water fleas; 29%), Chironomidae (midges; 12%), Ephemeroptera (mayflies; 2%), and Copepoda (copepods; 2%). The individual body mass of invertebrates in cutthroat trout stomachs was larger than in individuals in benthic samples. Mean *Gammarus* body mass was 9.6 mg/individual (0.0003 oz/individual) in cutthroat trout stomachs compared to 1.3 mg/individual (0.00005 oz/individual) in benthic samples. Mean body mass of Ephemeroptera in cutthroat trout stomachs was 2.7 mg/individual



**Figure 8.** (A) Total biomass of *Gammarus* in South Arm and West Thumb, and (B) individual body mass of *Gammarus* in South Arm and West Thumb. Bold lines represent median values, and upper and lower edges of the boxes represent the 75th (top) and 25th (bottom) percentiles. Bars are minimum and maximum values and circles represent mean values.

**Table 1. Mean density and biomass of benthic invertebrates in South Arm and West Thumb of Yellowstone Lake**

Taxon <sup>a</sup>	Density (individuals/m <sup>2</sup> )		Biomass (mg/m <sup>2</sup> )	
	South Arm	West Thumb	South Arm	West Thumb
<b>Ephemeroptera</b>	<b>11</b> (0–32)	<b>94</b> (0–248)	<b>10</b> (0–51)	<b>67</b> (0–206)
<b>Trichoptera</b>	22 (0–76)	38 (0–97)	17 (0–91)	15 (0–54)
<b>Diptera</b>	9,289 (3,463–17,132)	8,319 (2,738–20,108)	522 (185–1,138)	372 (106–857)
Chironomidae	9,259 (3,420–16,949)	8,223 (2,565–19,676)	522 (185–1,137)	372 (108–866)
<b>Crustacea</b>	4,897 (2,359–7,749)	5,216 (2,165–9,762)	<b>3,880</b> <b>(1,340–7,402)</b>	<b>5,998</b> <b>(2,793–10,995)</b>
<i>Gammarus</i>	2,902 (1,342–5,163)	3,452 (2,186–6,255)	<b>3,160</b> <b>(957–6,597)</b>	<b>5,500</b> <b>(3,403–10,262)</b>
<i>Hyalalela</i>	1,923 (498–3,788)	1,699 (32–4,751)	671 (99–2,113)	486 (7–1,540)
<b>Annelida</b>	657 (152–1,483)	756 (173–1,710)	1,848 (535–3,774)	2,099 (594–4,254)
<i>H. stagnalis</i> <sup>b</sup>	36 (0–119)	70 (0–281)	34 (0–115)	68 (0–262)
<i>N. obscura</i> <sup>b</sup>	105 (22–206)	124 (54–303)	670 (139–1,316)	797 (346–1,939)
Oligochaeta	514 (54–1,342)	552 (76–1,483)	1,141 (120–2,979)	1,225 (168–3,316)
<b>Mollusca</b>	283 (11–844)	139 (0–541)	171 (0–568)	100 (0–473)
Sphaeriidae	267 (0–823)	114 (0–509)	45 (0–223)	6 (0–22)
Planorbidae	14 (0–54)	11 (0–54)	126 (0–471)	94 (0–471)
<b>Insect</b>	9,321 (3,528–17,262)	8,450 (2,813–20,022)	549 (198–1,167)	453 (152–954)
<b>Noninsect</b>	6,044 (2,825–10,649)	6,255 (2,565–11,970)	5,901 (2,488–9,895)	8,199 (3,929–14,208)
<b>Total</b>	15,365 (7,835–24,535)	14,705 (6,050–27,803)	6,450 (2,869–10,542)	8,652 (4,301–14,884)

Note: Boldfaced taxa represent summed means for all individuals within a group. Bootstrapped confidence intervals are in parentheses and boldfaced values represent significant differences where  $p$ -values  $\leq 0.05$ . Bootstrapping uses the data we collected to estimate the uncertainty in our measures without making any assumptions about the distribution of our data.

<sup>a</sup>We omitted taxa with biomass  $< 10$  mg/m<sup>2</sup> from the table, but we included these taxa in totals. Taxa not listed in the table were Ephemeroptera (Baetis, Ephemerella, Ephemerellidae, and Serratella), Trichoptera (Apatania, Brachycentrus, Molanna, and Oecetis), Diptera (Culicoides), Crustacea (Ostracoda and Harpacticoida), Annelida (*Glossiphonia complanata*), Mollusca (Planorbidae and Physidae), and Arachnida.

<sup>b</sup>*Helobdella stagnalis* and *Nepheleopsis obscura*.

(0.0001 oz/individual) compared to 0.8 mg/individual (0.00003 oz/individual) in benthic samples. Chironomidae mean body mass in cutthroat trout stomachs was 0.3 mg/individual (0.000001 oz/individual) compared to 0.05 mg/individual (0.000002 mg/individual) in the benthos.

Cutthroat trout strongly interacted with *Gammarus* in South Arm where these fish are numerous. They had a larger species impact on *Gammarus* in South Arm than in West Thumb, as we predicted

based on cutthroat trout numbers and food web dynamics (table 2, next page). Conversely, lake trout had a much smaller species impact on *Gammarus* at both sites (table 2, next page). Assuming the annual production-to-biomass ratio for *Gammarus* in Yellowstone Lake is 5 per year (Benke and Huryn 2007), cutthroat trout ate half of *Gammarus* production in South Arm and 17% of *Gammarus* production in West Thumb. Lake trout ate far less *Gammarus* production at both sites ( $< 5\%$ ).

**Table 2. Parameters for calculating species impact of Yellowstone cutthroat trout and lake trout on *Gammarus* in South Arm and West Thumb of Yellowstone Lake**

Fish Species	Site	Trout Biomass <sup>a</sup> in Littoral Zone (g DM/m <sup>2</sup> )	<i>Gammarus</i> consumed by trout (g DM/m <sup>2</sup> /yr)	Production of Trout from <i>Gammarus</i> Consumption (g DM/m <sup>2</sup> /yr)	Species Impact
Yellowstone cutthroat trout	South Arm	4.4	15	7.7	2.4
	West Thumb	2.9	10	5.2	0.9
Lake trout	South Arm	0.8	3	0.3	0.1
	West Thumb	1.9	6	0.6	0.1

<sup>a</sup>Biomass is the dry weight of animals, production is the accumulation of biomass over time, and units are in dry mass (DM) (Syslo et al. 2011; Koel et al. 2012a).

## Discussion

Invasive lake trout reduced the abundance of cutthroat trout in Yellowstone Lake (Koel et al. 2005), which increased the mean biomass and body size of cutthroat trout's dominant food source, *Gammarus*. Lake trout directly reduced cutthroat trout through predation and indirectly released *Gammarus* from predation by cutthroat trout (fig. 3). Cutthroat trout reduced *Gammarus* biomass and body size in South Arm where these fish are still relatively abundant (fig. 8). In contrast, *Gammarus* populations show greater biomass and greater individual body mass in West Thumb where lake trout dominated.

Our results suggest that cutthroat trout are eating the largest *Gammarus* in Yellowstone Lake, inducing spatial variation in the benthic invertebrate assemblage. Cutthroat trout feed heavily on *Gammarus* and higher abundances of native trout mean fewer and smaller *Gammarus*. Unfortunately, benthic invertebrate samples were not collected in the past when cutthroat trout were abundant throughout the lake, but differences in *Gammarus* biomass and individual body mass may be even greater in pre- versus post-lake trout invasion samples had they been available for comparison. We collected samples after lake trout invaded Yellowstone Lake and cutthroat trout had drastically declined. We used variation in present trout densities to assess the degree to which a benthic trophic cascade may have occurred. Based on our results, lake trout likely induced a benthic trophic cascade whereby fewer cutthroat trout released *Gammarus* from predation.

Fish selectively feed on larger amphipods (Newman and Waters 1984; Wellborn 1994; Laudon et al. 2005). Newman and Waters (1984), for example, observed that brook trout, brown trout (*Salmo trutta*), rainbow trout, and sculpins (*Cottus cognatus*) selectively fed on larger *Gammarus* in a Minnesota stream, despite seasonal variation in mean body size of amphipods. Mean and median sizes of *Gammarus* in stomach samples from these fish

were much larger than those in the benthos. Similarly, invertebrates in the stomach contents of cutthroat trout were larger than invertebrates in benthic samples from Yellowstone Lake. Furthermore, *Gammarus* had greater mean individual body mass in West Thumb than in South Arm, suggesting that size-selective predation differed between sites. Cutthroat trout ate the largest available *Gammarus* in Yellowstone Lake, but these amphipods did not grow as large in South Arm because cutthroat trout were more abundant and collectively ate more.

The diet of cutthroat trout in Yellowstone Lake has been sampled extensively in the past. Despite our small sample size, past studies support our diet results. The stomach contents of cutthroat trout were collected in 1957 and 1958 (Benson 1961;  $n = 344$  and 429 respectively), 1970 (Dean 1971;  $n = 81$ ), 1974 (Scott 1977;  $n = 56$ ), and 1989 (Jones et al. 1990;  $n = 132$ ). These studies report that amphipods comprised between 4% and 40% of stomach contents based on number of individuals in each stomach sample. Tronstad et al. (2015) showed that percentage of amphipods in the diet of cutthroat trout was a function of cutthroat trout abundance. Cutthroat trout numbers varied over time from low abundances in the 1940s and 1950s, when egg-taking and liberal creel limits reduced the fish population, to the 1970s and 1980s, when the cutthroat trout abundance peaked (Koel et al. 2005). When cutthroat trout are less abundant they have more amphipods in their diet, perhaps because these crustaceans are more available. Similarly, our results showed that amphipods, specifically *Gammarus*, made up a large fraction of cutthroat trout diet and our results are similar to past studies when cutthroat trout were less abundant.

Most studies have investigated trophic cascades in the pelagic zone of lakes, but few studies have shown top-down effects on lake benthos. Trophic cascades were observed in benthic communities by manipulating organisms using enclosure and exclosure experiments in which the removal of pumpkinseeds (*Lepomis gibbosus*) altered the biomass of benthic algae in two Wisconsin

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## *Based on our results, lake trout likely induced a benthic trophic cascade whereby fewer cutthroat trout released *Gammarus* from predation.*

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lakes (Brönmark et al. 1992). While we did not artificially manipulate fish densities in Yellowstone Lake, we used variation in the present densities of cutthroat and lake trout in two study areas as a space-for-time substitution. We did this to draw conclusions about the degree to which the invasion of lake trout and the subsequent decline of cutthroat trout altered benthic invertebrates in Yellowstone Lake.

Benthic trophic cascades have been observed less frequently in natural ecosystems. Brönmark and Weisner (1996) surveyed 44 ponds with two to four trophic levels in southern Sweden. Ponds with two or three trophic levels had strong interactions among organisms, but piscivores (fourth trophic level) weakly interacted with lower trophic levels. This is likely because piscivorous fishes could not eat their prey because they were too large. In contrast, we observed strong interactions among trophic levels in Yellowstone Lake. Differences in the benthic fauna in our study suggest lake trout prey heavily upon cutthroat trout. Change in body size of benthic fauna provides strong evidence that a trophic cascade occurred (Carpenter et al. 2001; Findlay et al. 2005) and we observed the predicted changes in body size of *Gammarus* (i.e., smaller in areas of more intense predation) in the benthos of Yellowstone Lake.

### Alternative hypotheses

Differences in the benthic invertebrate assemblages may be due to factors other than the introduction of lake trout. The differences we observed between our sites may be attributed to hydrothermal inputs. West Thumb is located within the Yellowstone caldera where the presence of hydrothermal activity alters the chemistry of the lake (Morgan et al. 2003), whereas South Arm is outside the caldera. Ammonium-nitrogen concentrations (464 ppb) from hydrothermal waters in Sedge Bay of Yellowstone Lake were much higher than in ambient lake water (2 ppb; Klump et al. 1988). This nutrient input affected the biota immediately surrounding the thermal vents where microorganisms and oligochaetes flourished (Klump et al. 1988). Additionally, amphipods have been observed at high densities around the hydrothermal vents located in shallow areas of Yellowstone Lake (Morgan et al. 2003). Balistrieri et al. (2007) estimated fluid input from hydrothermal vents to be 16–25 million liters/day (4.2–6.6 million gallons/day). Given the average discharge of the Yellowstone River was about 3.5

billion liters/day (9.2 billion gallons/day; U.S. Geological Survey data, available at <http://waterdata.usgs.gov>; gage 06186500), the contribution of hydrothermal water into the lake is relatively low (<1%). Therefore, nitrogen inputs from hydrothermal vents probably do not contribute a substantial amount of nitrogen to the lake. Furthermore, hydrothermal water is transported and mixed throughout the lake (Balistrieri et al. 2007), suggesting that water chemistry does not vary significantly from location to location. We do not attribute higher biomass and larger body mass of *Gammarus* to hydrothermal activity in West Thumb.

Lake trout may alter the biomass and body size of amphipods because these fish also feed on invertebrates. Amphipods comprised 25% of the diet of juvenile lake trout in Yellowstone Lake (Ruzycki et al. 2003). Although juvenile lake trout feed upon amphipods, they do so only for the first few years of their lives. Conversely, cutthroat trout feed on amphipods throughout their lives, suggesting that these fish eat far more amphipods than do lake trout. These differences are reflected in the species impacts on *Gammarus*, whereby the interaction between *Gammarus* and cutthroat trout is much stronger than the interaction between lake trout and *Gammarus*. Lake trout ate about 2% of *Gammarus* production at both of our sites in Yellowstone Lake. Therefore, the difference in amphipod biomass between our sites is probably not due to lake trout feeding on amphipods.

### Management implications

Lake trout can indirectly affect lower trophic levels in the pelagic (Tronstad et al. 2010) and benthic zones of Yellowstone Lake. However, the effects of introduced lake trout may reach much further and actually alter nutrient cycling in tributary streams (Tronstad et al. 2015). Lake trout spawn within the lake and live deep in the water column, making them relatively inaccessible to avian and terrestrial predators. Conversely, cutthroat trout spawn in the shallow tributary streams of Yellowstone Lake and are more vulnerable to these kinds of predators. Historically, avian and terrestrial predators relied heavily on cutthroat trout as a food source (Koel et al. 2005). Currently, lower abundances of spawning cutthroat trout correlate with declining bear activity around Yellowstone Lake (Koel et al. 2005). Evidence suggests that the introduction of lake trout caused a trophic cascade that

began in Yellowstone Lake and rippled into tributary streams (Tronstad et al. 2015) and the surrounding terrestrial ecosystems (Middleton et al. 2013).

In an attempt to suppress the lake trout, the National Park Service implemented an aggressive removal program to conserve cutthroat trout. Although removal of lake trout has increased every year since their introduction (Koel et al. 2005), this highly invasive species has proven to be difficult to remove because they live deep in the pelagic zone, and Yellowstone Lake is relatively large and deep. Monitoring the benthic invertebrates of Yellowstone Lake, specifically *Gammarus*, may help managers to assess food web dynamics occurring at higher trophic levels. Combining benthic invertebrate and trout data will yield stronger and more informative results than either separately.

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# Case Study

## Nearshore conditions in the Great Lakes national parks: A baseline water quality and toxicological assessment

By William O. Hobbs, Brenda Moraska Lafrancois, and  
Eva DiDonato

### Abstract

In summer 2010 the coastal water quality in Great Lake national parks was assessed in conjunction with the EPA National Coastal Condition Assessment program (NCCA). Here we present the main findings from this survey, summarize environmental quality, and test whether conditions within park boundaries differ from those in the larger lake. We found that water quality was generally good within park boundaries, as assessed using NCCA criteria, and did not differ significantly from the larger Lakes Michigan and Superior with one exception. Dissolved nitrogen concentrations within three park boundaries were shown to be significantly different than in the larger lakes. The presence of contaminants in sediments and fish in all nearshore parks was widespread. However, contaminant concentrations only exceeded environmental criteria in two sites in Lake Michigan parks, and toxicology results revealed that concentrations at these sites were not acutely toxic to sediment dwelling invertebrates. Ultimately, the data set compiled during this study offers managers a common baseline on which to build future monitoring efforts.

### Key words

coastal parks, contaminants, Great Lakes, nearshore health, water quality

Nearshore water quality monitoring station near Sand Island, Apostle Islands National Lakeshore, in Lake Superior.

NPS PHOTO

## ENCOMPASSING 18% OF THE COASTAL WATER ACREAGE

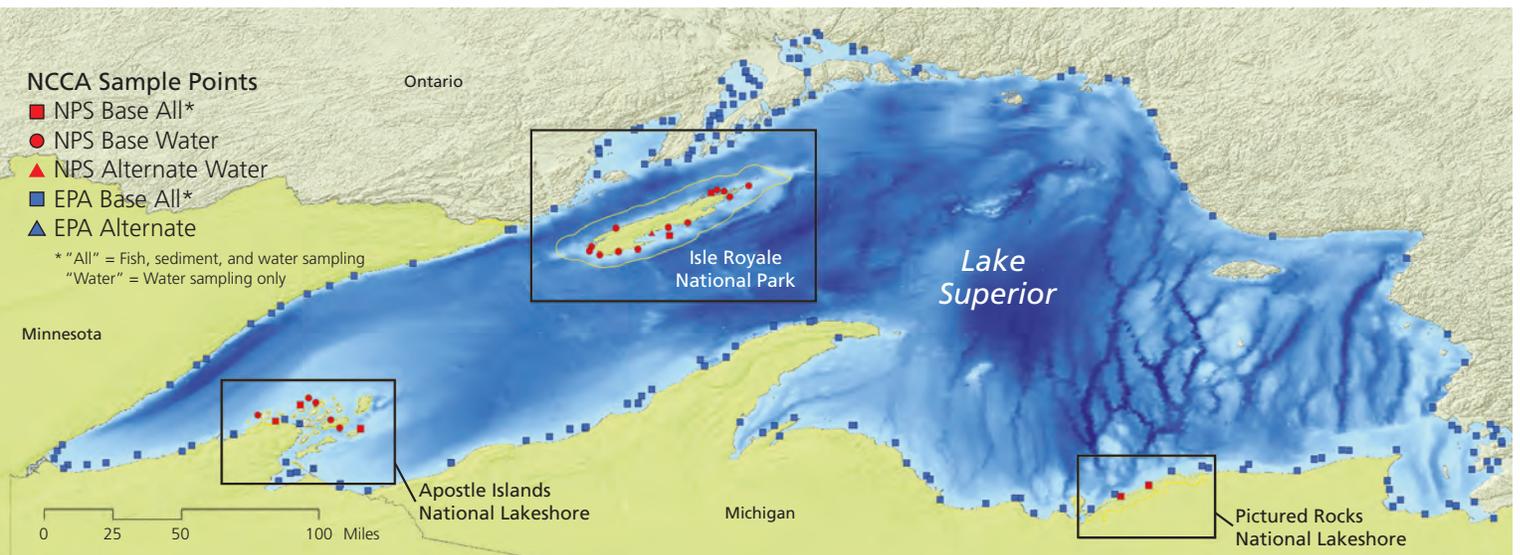
In the National Park System, the Great Lakes national parks protect exquisite shorelines and nearshore waters as well as key fishery resources (National Park Service 2008). Like the Great Lakes in general, these parks face increasingly complex management issues, ranging from beach health and contaminant concerns to fisheries management, invasive species, and climate change (Allan et al. 2013). However, nearshore waters have largely been left out of NPS monitoring programs because of financial, logistical, and jurisdictional constraints. In addition, the monitoring work of other agencies and partners has generally been limited in scope or focused on specific research or management goals. Consequently baseline data on nearshore waters in these national parks are scarce, patchy in time and space, and in general poorly suited for a comprehensive assessment of nearshore conditions (Lafrancois and Glase 2005).

Many have recognized this gap in nearshore data availability. Davis (2004) outlined a Service-wide effort to enhance the NPS role in coastal park stewardship, noting a need to inventory, assess, and monitor coastal resources. Similarly, in 2008 the NPS Midwest Region released a strategy for protecting coastal waters in Great Lakes national parks, identifying a need to acquire and interpret baseline data on nearshore conditions (NPS 2008). These needs have been further emphasized in subsequent NPS natural resource condition assessments for Great Lakes parks, with significant nearshore data gaps noted at even the most prominent of these parks (e.g., Kraft et al. 2010). Concerns about

nearshore conditions and data availability are echoed more broadly throughout the Great Lakes management community (Seelbach et al. 2013).

In 2010 the U.S. Environmental Protection Agency (EPA) scheduled its first-ever National Coastal Condition Assessment (a repeatable, wide-ranging environmental assessment; hereafter, NCCA) in Great Lakes waters. Simultaneously, the National Park Service received a critical influx of funds via the new Great Lakes Restoration Initiative, a large-scale, multiagency restoration program coordinated by the EPA. These funds enabled managers and scientists from the NPS Water Resources Division, Midwest Regional Office, and Great Lakes Inventory and Monitoring Network to partner with EPA to include NPS-administered sites in the 2010 condition assessment. The result is a comprehensive nearshore data set collected with consistent methods, addressing multiple media (water, sediments, and fish), and spanning five Great Lakes national parks (Isle Royale National Park and Apostle Islands, Indiana Dunes, Pictured Rocks, and Sleeping Bear Dunes National Lakeshores) as well as the nearshore waters of the Great Lakes that are not part of a national park (fig. 1, next page).

Here we summarize the 2010 NCCA results, discuss NPS nearshore conditions relative to the broader Great Lakes NCCA data set and relevant environmental benchmarks, and describe implications for future NPS monitoring in the Great Lakes.

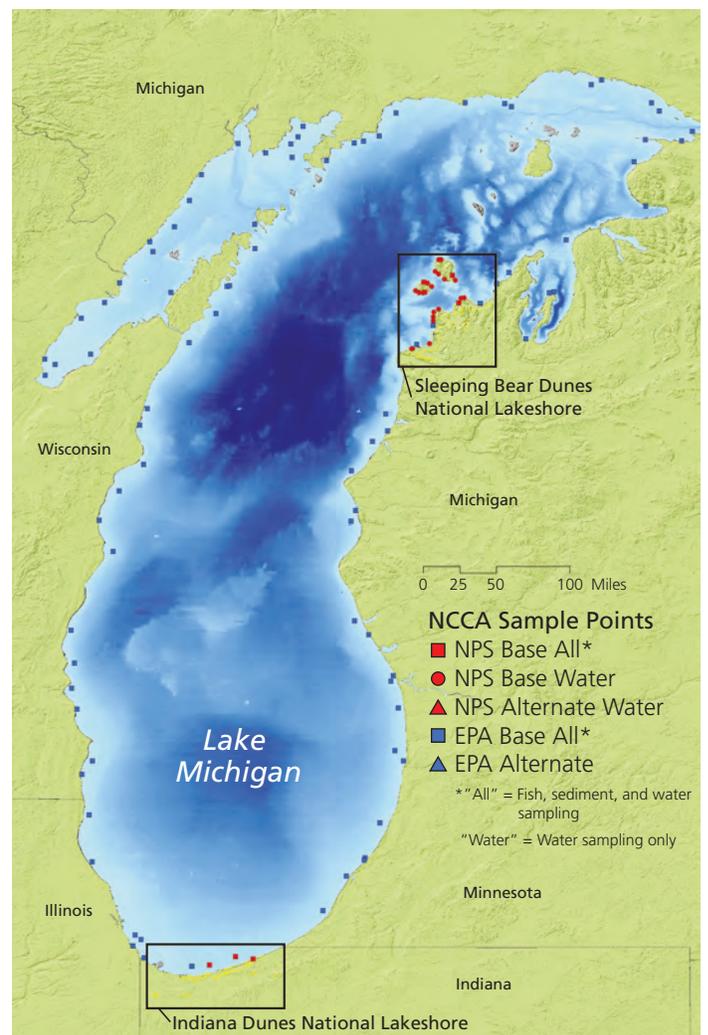


## Methods

### Sampling

Contractors sampled a total of 262 sites for water chemistry in Lakes Michigan and Superior, including 60 sites within Great Lakes national parks (30 in each of Lakes Michigan and Superior), over a 130-day period in the summer of 2010 (fig. 1). Sites were selected using a Generalized Random Tessellation Stratified survey design (Olsen 2009). Sampling (e.g., water, fish, and macroinvertebrates) and site reconnaissance protocols conformed to established EPA protocols for the NCCA program (USEPA 2010a). Sample depths ranged from 0.2 to 29.5 m (0.7–96.8 ft). Briefly, field measurements at each site involved water column profiles for light, temperature, dissolved oxygen, pH, and conductivity. Water quality and phytoplankton samples were collected at each site from a depth of 0.5 m (1.6 ft) via a pumping system or a bottle-based water sampling device. At a subset of sites, more extensive sediment and fish sampling occurred, detailed below. Multiple sediment samples were collected from these sites using a Ponar grab sampler for analysis of benthic species composition and abundance, physical and chemical characteristics, and use in acute whole sediment toxicity tests. Targeted fish species were collected for contaminant analysis using trawls and other appropriate methods.

Sediment chemistry and toxicity were assessed at 177 sites over both lakes; 13 of these sites were within a park's boundaries. To evaluate the potential toxicity of existing contaminants to sediment-dwelling aquatic invertebrates, sediment toxicity assays were carried out using freshwater invertebrates (*Hyaella azteca*). The assays determined the percentage survival of the invertebrates relative to a clean control sample (USEPA 2010b). Additionally, we compared measured sediment contaminant concentrations with the consensus-based threshold effect concentration



**Figure 1.** Distribution of sampling sites in Lakes Superior (top) and Michigan (bottom) for the 2010 sampling.

WATER RESOURCES DIVISION, MAY 2014. COORDINATE SYSTEM: GCS NORTH AMERICAN 1983.

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## *Nearshore waters have largely been left out of NPS monitoring programs [in the Great Lakes] because of financial, logistical, and jurisdictional constraints.*

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and the probable effect concentration (MacDonald et al. 2000). Results below the threshold effect concentration predict the absence of toxicity (lethality), and concentrations above the probable effect concentration tend to predict sediment toxicity accurately. A total of 192 samples were collected for benthic macroinvertebrates from depths ranging from 0.4 to 33.2 m (1.3–108.9 ft).

A total of 148 tissue samples were collected from resident fish and analyzed for toxics, including organochlorine pesticides, PCBs, and mercury. Sampling and analysis protocols for the NCCA program list the target fish species and length in each lake (USEPA 2010a). Analysis of contaminants in fish tissue is a useful estimator of the potential risk to human health (USEPA 2009b). We assessed all fish data against the ecological criteria under the Great Lakes Water Quality Agreement (GLWQA) (Governments of Canada and the USA 2012) and the EPA human health screening value,<sup>1</sup> which is intended for fillet tissue but is used here as a conservative comparison for whole-fish tissue concentrations.

### **Sample analysis**

Laboratory analysis and quality control adhered to EPA guidance for the assessment (USEPA 2010b). Water chemistry analyses included nutrient (ammonia nitrogen, nitrate + nitrite nitrogen, total nitrogen, soluble reactive phosphorus, and total phosphorus) and chlorophyll *a* concentrations, while sediment samples were analyzed for legacy and current-use organochlorine pesticides,<sup>2</sup> polychlorinated biphenyls (PCBs, 21 congeners measured), and heavy metals including total mercury. Whole-fish tissue samples were assessed for a similar suite of persistent toxic compounds as sediments; macroinvertebrate communities were also enumerated in a number of locations.

### **Data analysis**

To test for potential differences in water and sediment chemistry within and beyond national park boundaries in Lakes Michigan and Superior we grouped the data into each Great Lake to test

each water quality variable separately. We then tested the data for normality using a Shapiro-Wilks test and subsequently transformed all data except pH, dissolved oxygen, and secchi depth (table 1, next page). We conducted a one-way ANOVA (analysis of variance) with a Levene's test for equality of variance. Variables that showed significant differences were analyzed further to quantify the significance by park using either a Bonferroni or Dunnett's test depending on the homogeneity of the variance. Water quality variables were also compared with the NCCA criteria for classification as "good," "fair," or "poor" (table 2, next page; USEPA 2008; USEPA 2009a).

Macroinvertebrate sampling protocols (EPA) for bioassessment recommend a minimum of 100 individuals for community analysis (Barbour et al. 1999). Screening our data set yielded 101 of 192 sites that met this criterion. Macroinvertebrate species diversity was quantified by the Shannon-Wiener index and the number of individuals was standardized to a common count (100 as suggested above). The similarity of macroinvertebrate communities to one another was tested using a detrended correspondence analysis (DCA) (Hill and Gauch 1980). The DCA is a multivariate statistical tool that allows us to visualize how similar communities are by their proximity on a two-dimensional biplot (closer together is more similar). All data analyses were made using the program R (R Core Development Team 2014) and SPSS (SPSS 2009).

## **Results and discussion**

### **Water chemistry**

In general, water quality conditions in national park sites did not differ significantly from those outside these areas, with the exception of some nutrient variables. Dissolved inorganic nitrogen (largely as nitrate + nitrite, a nutrient variable) differed significantly within and beyond national park boundaries. In Lake Superior, Isle Royale had significantly higher dissolved inorganic nitrogen concentrations than the lake outside park boundaries ( $p = 0.038$ ) (fig. 2A, page 41). This difference in dissolved inorganic nitrogen led to a significantly lower nutrient supply ratio (dissolved inorganic nitrogen to total phosphorus) between Isle Royale and the rest of Lake Superior ( $p = 0.011$ ). Chlorophyll *a* concentrations (a surrogate measure for algae growth) were also significantly lower around Isle Royale when compared with the rest of the lake ( $p < 0.005$ ) or Apostle Islands ( $p < 0.005$ ) and Pictured Rocks ( $p < 0.005$ ). In Lake Michigan, Sleeping Bear Dunes ( $p < 0.005$ ) and Indiana Dunes ( $p < 0.005$ ) had significantly higher dissolved inorganic nitrogen than the lake outside park boundaries (fig. 2B). Sleeping Bear Dunes also had significantly higher soluble reactive phosphorus ( $p < 0.005$ ), the biologically available inorganic form of phosphorus that algae use.

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<sup>1</sup>EPA risk-based approach for a cancer health endpoint based on the consumption of four 8-ounce meals per month by a 150-pound adult human (USEPA 2000).

<sup>2</sup>dichlorodiphenyltrichloroethane (p,p' DDT), dichlorodiphenyldichloroethane (p,p' DDD), dichlorodiphenyldichloroethylene (p,p' DDE), and 13 additional compounds such as Mirex and Chlordane.

**Table 1. Summary of water chemistry parameters for Lakes Michigan and Superior national parks**

Parameter	Transformation	Lake Superior								Lake Michigan						
		Isle Royale National Park		Apostle Islands National Lakeshore		Pictured Rocks National Lakeshore		Lake Superior		Indiana Dunes National Lakeshore		Sleeping Bear Dunes National Lakeshore		Lake Michigan		
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
pH	none	7.68	0.32	7.63	0.13	7.78	0.26	7.75	0.34	none	8.39	0.16	8.20	0.21	8.21	0.25
Dissolved oxygen (mg/l)	none	10.6	1.8	10.7	0.7	10.7	2.6	10.6	2.1	none	10.4	2.4	10.0	0.7	10.2	2.1
Secchi depth (m)	none	9.5	3.9	6.0	1.6	8.0	0.0	6.1	3.6	none	4.3	2.0	6.3	3.1	4.9	3.4
% Photosynthetically active radiation at 1 m (3.3 ft)	log	0.69	0.12	0.56	0.11	0.60	0.12	1.56	9.59	log	0.69	0.15	0.60	0.19	0.63	0.66
NH <sub>3</sub> (mg/l)	square root	0.001	0.001	0.003	0.001	0.002	0.002	0.006	0.012	square root	0.003	0.002	0.006	0.004	0.008	0.010
NO <sub>3</sub> + NO <sub>2</sub> (mg/l)	log	0.369	0.031	0.343	0.024	0.333	0.016	0.323	0.054	square root	0.262	0.012	0.271	0.017	0.170	0.134
Total nitrogen (mg/l)	log	0.433	0.026	0.497	0.015	0.393	0.033	0.445	0.149	log	0.431	0.043	0.434	0.020	0.429	0.202
Soluble reactive phosphate (mg/l)	log	0.004	0.001	0.003	0.001	0.004	0.001	0.006	0.006	log	0.008	0.004	0.006	0.003	0.005	0.003
Total phosphorus (mg/l)	log	0.004	0.001	0.003	0.002	0.003	0.002	0.007	0.013	log	0.004	0.001	0.004	0.002	0.010	0.022
Dissolved inorganic nitrogen: Total phosphorus (molar)	none	93	20	208	141	196	146	131	104	none	65	11	74	22	75	90
Chlorophyll a (ppb)	log	0.64	0.15	1.07	0.24	0.86	0.01	1.17	1.09	log	1.63	0.44	0.81	0.42	3.00	7.12
<i>n</i>		15		9		4		91			4		24		98	

The water quality status, as defined by the NCCA criteria (table 2), was classified as “good” for all sample sites in the Great Lakes national parks. Using more stringent assessment criteria based on the National Lakes Assessment (USEPA 2009a), a similar status of “good” was identified for these sites. Outside boundaries of NPS-administered areas, coastal water quality was also classified as “good” for most sites. However, several non-national-park sites in Lakes Michigan and Superior were classified as “fair” or “poor” because of elevated nutrient concentrations. These sites are affected by urban, industrial, and agricultural runoff and received high nutrient loading ratings in a recent stressor assessment for the Great Lakes (Allan et al. 2013).

Our observation of elevated dissolved inorganic nitrogen concentrations at Indiana Dunes and Sleeping Bear Dunes is puzzling but may relate to localized inputs from groundwater or agricultural tributaries. More surprising were the elevated inorganic nitrogen concentrations at remote Isle Royale. Long-term monitoring of one Isle Royale watershed has documented a significant increase in the concentrations of dissolved inorganic nitrogen and dissolved organic carbon over the last several decades, likely due to climate change and related impacts on temperature, snow-pack accumulation, and soil microbial activity in park watersheds (Stottleyer and Toczydlowski 2006; 2011). Long-term increases

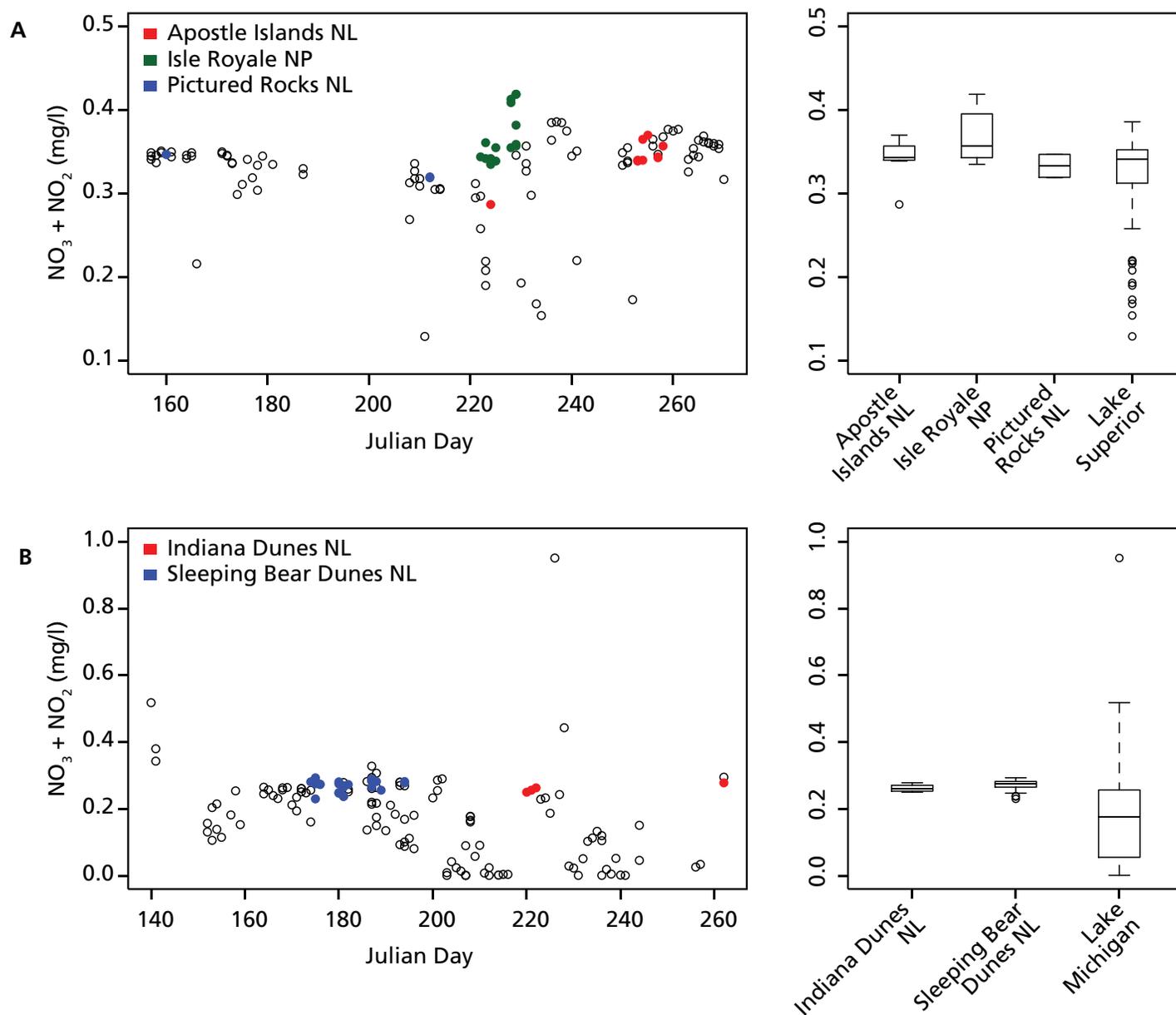
**Table 2. Water quality criteria used by EPA during the National Coastal Condition Assessment**

Parameter	Threshold		
	Good	Fair	Poor
Dissolved oxygen (mg/l)	>5	2–5	<2
Chlorophyll a (ppb)	<5	5–20	>20
Dissolved inorganic nitrogen (mg/l)	<0.1	0.1–0.5	>0.5
Dissolved inorganic phosphorus (mg/l)	<0.01	0.01–0.05	>0.05
Water clarity (% surface light at 1 m [3.3 ft])	>20%	10–20%	<10%
Notes: Overall sample site water quality			
Good = No component indicators rated poor; maximum of one rated fair.			
Fair = One component indicator rated poor, or two or more indicators rated fair.			
Poor = Two or more component indicators rated poor.			

in dissolved inorganic nitrogen have also been noted in Lake Superior as a whole (Stern et al. 2007; Stern 2011). Our findings suggest that increased nitrogen leaching from remote watersheds such as Isle Royale may increasingly influence Lake Superior’s nutrient status as climate changes.

#### **Sediment contaminants**

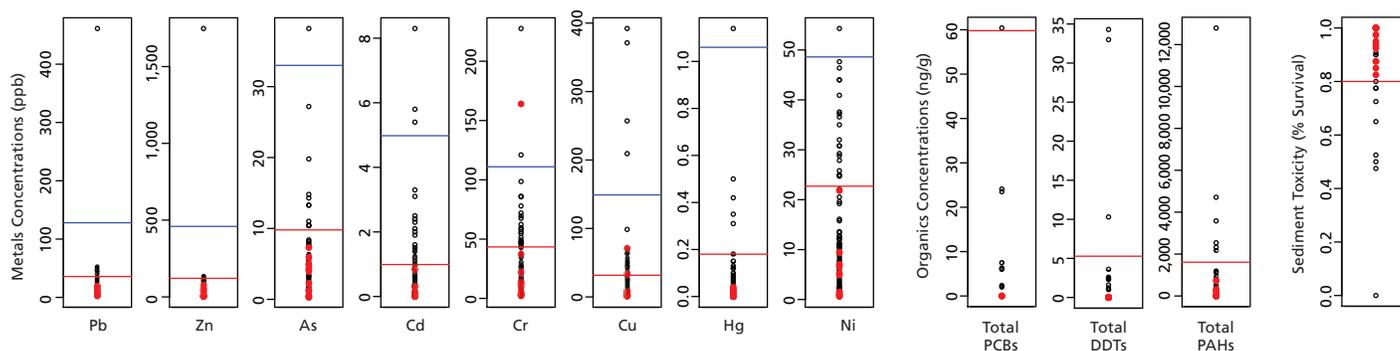
There were no statistical differences in sediment contaminants among sites within and outside park boundaries in either Lake



**Figure 2.** Nitrate + nitrite concentrations for (A) Lake Superior and (B) Lake Michigan sites. The left panels show the concentrations over time for the summer sampling period, and the right panels summarize the concentrations in box plots (median and quartiles) for the parks. In Lake Superior, Isle Royale has significantly higher concentrations than the larger lake or the other parks; in Lake Michigan, both Indiana Dunes and Sleeping Bear Dunes have significantly higher concentrations than the larger lake.

Superior or Michigan, although the total organic carbon concentrations in sediments collected within the boundaries of Pictured Rocks are significantly lower than those collected outside the park in Lake Superior ( $p = 0.027$ ). All sites in the Great Lakes parks were below threshold effect concentration values for total PCBs (sum of all PCB congeners), total DDTs (sum of *p,p'* DDE, *p,p'* DDD, *p,p'* DDT), total PAHs, and the majority of heavy metals including mercury (fig. 3), suggesting low toxicity to invertebrates. However, two sites did exceed the threshold effect

concentration for copper concentrations, one in Sleeping Bear Dunes and one at Apostle Islands; the same site in Sleeping Bear Dunes was also in excess of the probable effect concentration for chromium. The most heavily impacted sites in Lakes Michigan and Superior, where contaminant concentrations exceeded threshold effect concentration and probable effect concentration thresholds, were located adjacent to major urban and industrial centers and are recognized areas of concern. Additional sediment toxicity testing indicated that all sites within park boundaries



**Figure 3.** Summary of the main sediment chemistry variables with toxicity threshold effect concentrations (TEC; red line) and probable effect concentration (PEC; blue line) marked on each plot. NPS-administered sites are in red. The sediment toxicity threshold is based on the percentage survival in control bioassays, where a result above the red line suggests no adverse impacts to the test organism.

were within threshold limits (i.e., they showed greater or equal invertebrate survival in comparison to control assays), including the site at Sleeping Bear Dunes where concentrations of chromium were above the PEC threshold. Several sites in Lake Michigan and one site in Lake Superior exceeded threshold limits for invertebrate toxicity; however, these sites were not located near national parks (fig. 3).

Contaminated sediments in the industrialized regions of the Great Lakes contribute to cumulative ecosystem stress (Allan et al. 2013). Previous assessments of the sediment chemistry in these lakes have identified sediment quality as a primary contributor to degraded overall quality at many sample sites (USEPA 2008). Although sediments within park boundaries did not exhibit acute toxicity, each of the sites at Indiana Dunes had detectable concentrations of total PAHs, and the threshold exceedances for copper and chromium at Apostle Islands and Sleeping Bear Dunes are of concern. Elevated concentrations of PAHs are well documented at Indiana Dunes and are likely the result of deposition of atmospheric particulates from coal and other combustion sources (Egler et al. 2013). Causes for elevated copper and chromium concentrations at the Apostle Islands and Sleeping Bear Dunes sites are less clear since neither site is directly influenced by riverine runoff or substantial urban or industrial sources, and copper concentrations are thought to be relatively moderate in and near these parks (Allan et al. 2013). However, copper and chromium have been associated with a range of agricultural and marine applications and both parks share a common agricultural (e.g., orchards) and maritime context.

#### **Fish contaminants**

The accumulation of legacy organochlorine pesticides, PCBs, and mercury in fish of the Great Lakes has long been recognized as a human health risk and a significant impact on the ecological health of these ecosystems (Environment Canada and the USEPA 2011). Although a majority of all fish samples (83%) had detectable

concentrations of total PCBs, no samples from national park sites had concentrations exceeding a threshold of more than 100 ppb as per the GLWQA (Governments of Canada and the USA 2012), and only a few park sites (one from Apostle Island and seven from Indiana Dunes and Sleeping Bear Dunes combined) had concentrations exceeding the EPA human health screening value of 12 ppb (USEPA 2000). Similarly, most fish samples (86%) had detectable concentrations of total DDT, but none of the samples exceeded the threshold of 1,000 ppb as per the GLWQA (Governments of Canada and the USA 2012), and no national park samples exceeded the EPA's human health screening value of 69 ppb (USEPA 2000). All fish samples contained detectable concentrations of mercury; however, no samples from national park sites exceeded the EPA recommended methylmercury criterion of 300 ppb (USEPA 2001). Two fish tissue samples from Lake Superior and one from Lake Michigan had mercury concentrations greater than the USEPA criterion. Chlordane is an organochlorine pesticide that was banned in the United States for all uses in 1988; however, it is still prevalent in fish tissue throughout the country (USEPA 2009b). We found measurable concentrations in 27% of all samples analyzed, but none exceeded the EPA human health screening value of 67 ppb (USEPA 2000).

Although concentrations of PCBs and legacy pesticides continue to decline in Great Lakes fish (Salamova et al. 2013), we note that PCBs and DDT are still detected in a large majority of fish from the 2010 survey. Recent studies document a halt in the declining trend of organic contaminant concentrations in fish tissue over time from the Great Lakes (Carlson et al. 2010; Monson et al. 2011), possibly because of changes in the base of the Great Lakes food web, which alter the biomagnification of these contaminants. Relative to previous studies of contaminants in the same species of fish from Lakes Superior and Michigan, concentrations measured during the 2010 survey were generally lower (Carlson et al. 2010). A recent survey (near Apostle Islands) of bald eagles, which are dependent on fish and other aquatic prey, found that

## PCBs and DDT are still detected in a large majority of fish from the 2010 survey.

contaminant concentrations were below levels thought to impair reproduction (Dykstra et al. 2010). However, new contaminants such as perfluorinated compounds also pose a threat to aquatic life and wildlife that depend on them (Route et al. 2014).

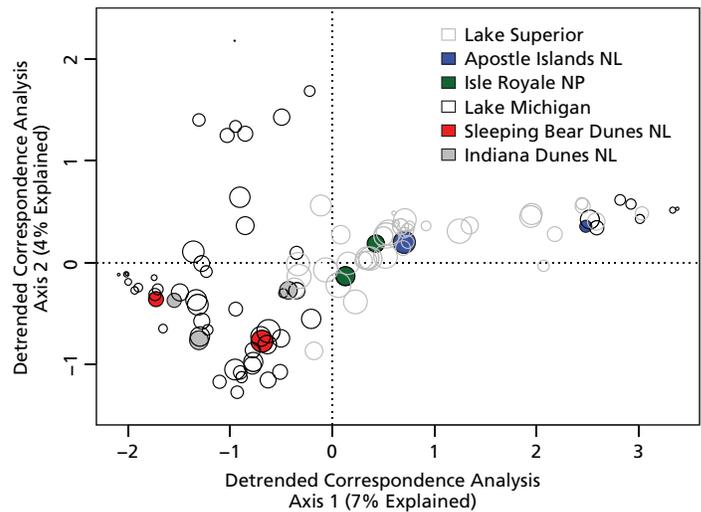
### *Benthic macroinvertebrate communities*

Macroinvertebrate species diversity did not differ significantly among parks and the nonpark waters of the Great Lakes, nor did species richness. In previous assessments of Great Lakes macroinvertebrate communities, indicator species of *Diporeia* and *Hexagenia* have been used to evaluate benthic health because of their importance at the base of the Great Lakes food web (USEPA 2012). However, *Diporeia* and *Hexagenia* were not abundant enough to consider using them as lake-wide assessment tools for the coastal sites. Only one *Diporeia* specimen was identified and very few samples contained more than five *Hexagenia* specimens.

Analysis of the macroinvertebrate community and the species diversity data reveals a clear separation of communities between Lakes Michigan and Superior (fig. 4). Goforth and Carman (2005) suggest that nearshore substrate has a significant influence on the community structure and density of benthic organisms in the Great Lakes. However, the vast majority of sites in the 2010 survey had similar substrates dominated by sand. A range of other factors (e.g., currents, sediment contaminants, and local food webs) likely accounts for the variation in community composition among these sites. A handful of samples from Green Bay on Lake Michigan resemble samples from some Lake Superior sites, which is interesting given the differences in water chemistry between the two lakes.

## Summary and management implications

The 2010 condition assessment survey indicated that coastal water quality in the Great Lakes national parks was generally good, and that sediment and fish contaminants were generally below levels



**Figure 4.** Community analysis of the macroinvertebrate samples. The parks do not differ from the surrounding Great Lake and there is a clear separation of communities between Lakes Superior and Michigan. Circle size is scaled to species richness, where a larger circle indicates a greater number of species.

of concern for consumption by humans and wildlife. However, we identified several potential management issues: (1) elevated dissolved inorganic nitrogen concentrations at Isle Royale, Indiana Dunes, and Sleeping Bear Dunes; (2) elevated heavy metal concentrations in sediments at Apostle Islands and Sleeping Bear Dunes; and (3) continued detection of legacy contaminants in whole-fish samples.

We found this broad-scale survey valuable for creating a baseline data set and providing a larger spatial context for understanding nearshore conditions in the Great Lakes national parks. Since conditions in NPS-administered waters did not differ greatly from those of the surrounding lake waters in the 2010 study, we conclude that the broader surveys of the EPA National Coastal Condition Assessment program (expected to recur every five years) may suffice for understanding general trends in coastal conditions at these parks. However, unless national parks are explicitly included in future NCCA study plans, it is not clear how many EPA sites will occur in or near national parks, or whether park-specific nearshore issues will be as readily identifiable. We expect results of this study to inform site selection for future interagency contaminant monitoring, inspire topical follow-up research, and serve as a foundation for understanding future trends in nearshore conditions at Great Lakes national parks.

## Acknowledgments

This work was funded by the Great Lakes Restoration Initiative. We thank the dedicated staff and contractors of the EPA for their work on the study design, site selection, and sample collection and analysis. We also thank our EPA colleagues, Treda Grayson and Hugh Sullivan, for help with data access, and our NPS colleagues, Jeremy Cantor, David VanderMeulen, and Bill Route, for mapping support and helpful comments on earlier versions of this article.

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## Science Feature

# Knowledge, attitudes, and practices regarding Lyme disease prevention among employees, day visitors, and campers at Greenbelt Park

By Erin H. Jones, Amy Chanlongbutra, David Wong, Fred Cunningham, and Katherine A. Feldman

**Figure 1.** The “black-legged tick,” *Ixodes scapularis*, is found on a wide range of hosts including mammals, birds, and reptiles. They are known to transmit Lyme disease, *Borrelia burgdorferi*, to humans and animals during feeding, when they insert their mouth parts into the skin of a host and slowly take in the nutrient-rich host blood.

ODDJIM GATHANY

**L**YME DISEASE IS THE MOST COMMONLY REPORTED vector-borne disease in the United States. Maryland is one of 13 states that contributed to 96% of all Lyme disease cases reported nationally in 2011, and in 2013 Lyme disease was the fifth most common nationally notifiable disease (CDC 2015). Lyme disease is concentrated heavily in the Northeast and upper Midwest. Concern for the disease is high in Maryland, as evidenced by the presence of several Lyme disease advocacy groups, an increase in congressional funding for Lyme disease prevention activities in 2007, and ongoing state and federal legislative activities. Black-legged tick (*Ixodes scapularis*) nymphs and adults infected with the bacteria *Borrelia burgdorferi* can transmit Lyme disease to hosts if attached and feeding for at least 24 hours (fig. 1). Nymphal ticks are the primary vectors because their small size

makes it difficult to see and remove them. In addition, their peak host-seeking behavior in the spring and early summer corresponds with peak human outdoor activity. Recommended tick preventive measures include (1) wearing repellents such as DEET, (2) showering within two hours after coming indoors, and (3) regularly checking the body for ticks after being outside.

Greenbelt Park, a National Park Service (NPS)–administered unit in Maryland located approximately 12 miles (19 km) northeast of Washington, D.C., is an urban oasis featuring a 174-site campground, 9 miles (14 km) of trails, and three picnic areas (fig. 2). From July to November 2010, there were 179,516 total park visitors (including both day visitors and campers) to and 32 employees working at the park. The park is home to numerous deer, mice,

### Abstract

In 2013, Lyme disease was the fifth most common nationally notifiable disease and is endemic in the Northeast. Greenbelt Park, a National Park Service–administered unit, is located in a highly endemic area of Maryland near Washington, D.C. In 2010, the National Park Service and the Maryland Department of Health and Mental Hygiene implemented a park-based knowledge, attitudes, and practices survey for employees, day visitors, and campers to better understand the risk of exposure to ticks. The survey was administered to employees both before ( $n = 32$ ) and one month after ( $n = 19$ ) a tick-borne disease training. Day visitors ( $n = 127$ ) and campers ( $n = 53$ ) were invited to participate voluntarily in a parallel survey; they did not receive training, but were asked to complete their survey one month after their visit. Many aspects of employee Lyme disease transmission knowledge improved post-training. Employees with previous Lyme disease were more likely to tuck their pants into socks. However, no other protective measures were significantly changed for employees, day visitors, or campers. Reinforcement of prevention messages, including seasonal education on tick prevention methods as well as signs and symptoms of tick-borne diseases, is warranted for all groups at Greenbelt Park and other national parks where tick-borne diseases are endemic.

### Key words

behavior, knowledge, Lyme disease, prevention, zoonoses

and other mammals that support a healthy population of ticks, including *I. scapularis* and the lone star tick (*Amblyomma americanum*).

National parks as well as other natural areas present environments for zoonotic disease transmission because of close encounters with fauna that are less common in other settings (Eisen et al. 2013; Adjemian et al. 2012; Han et al. 2014). At Greenbelt Park, both employees and park visitors may have prolonged occupational exposure to wildlife, including those that may harbor zoonotic pathogens. Because Lyme disease is concentrated primarily in the Northeast and upper Midwest in nonurban areas, park visitors from other parts of the United States and other countries may not know that the park has ticks or recognize the associated risk of Lyme disease. The same is true for park visitors who live in nearby urban settings where tick populations are not abundant. Unsuspecting visitors' lack of knowledge of Lyme disease may put them at increased risk of disease and decreased adherence to prevention practices. To better understand the potential risks of exposure to ticks, the NPS Office of Public Health and the Maryland Department of Health and Mental Hygiene (DHMH) embarked on a collaborative effort to assess the knowledge, attitudes, and practices of employees and park visitors.



NPS PHOTO

**Figure 2.** Greenbelt Park is a natural oasis that is conveniently tucked into the suburban landscape just 12 miles from Washington D.C. The park's 1,100 acres provide habitat for native plants and animals as well as diverse recreational opportunities for hiking, camping, biking, and picnicking.

## Methods

In July 2010, the National Park Service and DHMH implemented a visitor survey that assessed knowledge and attitudes regarding tick-borne disease, activities in the park, proven effective prevention measures taken in the park, and history of physician-diagnosed tick-borne disease. A similar survey was administered to park employees to assess their knowledge, attitudes, and practices regarding tick-borne disease and prevention measures.

The surveys were based on a survey instrument used in a previous collaborative effort between the National Park Service and the Pennsylvania Department of Health at Gettysburg National Military Park (Han et al. 2014). Question formats were true-false, multiple choice, and free form. Paper surveys distributed at the park included a stamped envelope for return to DHMH. Online surveys were administered using Survey Monkey.

On 2 August 2010, Greenbelt Park employees voluntarily and confidentially completed surveys immediately before taking part in required tick-borne disease prevention training. This training provided an overview of ticks and tick-borne diseases of the United States, highlighted those of local concern, and described prevention methods employees could use to protect themselves. One month later, employees completed a post-training survey that included identical knowledge, attitude, and behavior questions as on the pre-training survey. Pre- and post-training surveys were linked using unique identifiers so that responses could be compared directly.

*Unsuspecting visitors' lack of knowledge of Lyme disease may put them at increased risk of disease and decreased adherence to prevention practices.*

Day visitors and campers were invited to voluntarily participate in a parallel survey. To promote the survey for visitors, flyers were posted at trailheads, the campsite check-in, bathrooms, picnic areas, and other locations inside park headquarters and at the ranger station. Flyers were also carried by roving rangers from July to October 2010. The flyers included a link to the online survey and indicated the four park locations where paper surveys and the disclosure statement were available. The survey link was also displayed on the park Web site. To capture potential tick-borne disease exposure during their park visit, day visitors and campers were requested to complete their surveys approximately one month after their visit. Campers could voluntarily provide an e-mail address at check-in to receive a reminder to complete the follow-up survey. Surveys were also distributed during park events such as weekly bike races.

Analyses were conducted using SAS (SAS. 2011. SAS Version 9.3. SAS Institute, Inc., Cary, North Carolina, USA) and Excel (Excel. 2010. Microsoft Office 2010. Microsoft, Redmond, Washington, USA). Linked responses for the pre- and post-training surveys were compared using McNemar's exact test. Responses for day visitors and campers are presented jointly when there was no statistically significant difference between the two groups at the 95% confidence level using chi-square and Fisher's exact tests. Relative risk (RR) was calculated to determine magnitude of difference in outcomes between two groups. All P-values were two-sided with statistical significance evaluated at the 0.05  $\alpha$  level. Records with missing data were excluded from analysis.

## Results

### Employees

Thirty-two park employees completed the pre-training survey. Twenty-six (81.3%) were male, 23 (71.8%) were more than 45 years of age, and 20 (64.5%) reported that they had worked for Greenbelt Park for 10 or more years (table 1). Most employees had at least one exposure to tick habitat per week. The most frequently reported activities with a high likelihood of tick exposure in-

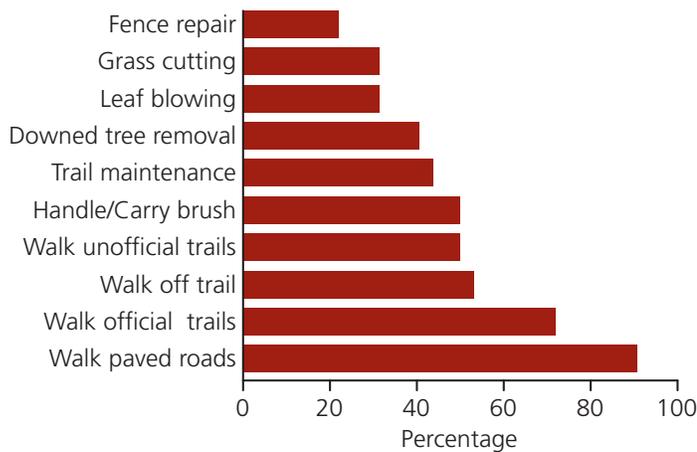
**Table 1. Characteristics of Greenbelt Park employee survey respondents, 2010**

Category	Number	Percentage
<b>Sex</b>		
Male	26	81.2
Female	6	18.8
<b>Age (years)*</b>		
<35	5	16.1
35–44	3	9.7
45–54	13	41.9
>55	10	32.3
<b>Employment Status</b>		
Full-time	23	71.8
Seasonal	4	12.5
Volunteer/Intern	5	15.6
<b>Length of Employment*</b>		
<1	1	3.2
1–2	7	22.6
3–5	3	9.7
6–10	0	0
>10	20	64.5
<b>Hours Worked Outdoors During Average Week*</b>		
None	1	3.6
<10	3	10.7
10–20	5	17.9
21–30	3	10.7
31–40	14	50
>40	2	7.1

Note: Total sample = 32.  
\*Missing data excluded.

cluded walking off trail ( $n = 17$ , 53.1%) and carrying brush ( $n = 16$ , 50.0%; fig. 3). Twenty-four (75.0%) employees reported finding at least one unattached (nonbiting) tick on their body during the past year and 22 (68.8%) reported finding attached ticks at least once in the past year.

Three preventive measures were frequently reported in the pre-training survey. Twenty-two employees (68.8%) reported wearing long pants as part of the NPS uniform, 26 (81.3%) usually or always checked their clothing, and 28 (87.5%) checked their bodies for ticks after working outdoors. All of the other preventive measures were used by less than half of the respondents. Less than half usually or always used other clothing (long pants, socks, and sleeves) or repellent preventive measures (permethrin-impregnated clothing, skin treatment; fig. 4). When asked why they did not take preventive measures more often, four (12.5%) reported that it was too hard to remember to check for ticks, three (9.4%) reported that they were unaware of clothing prevention measures,

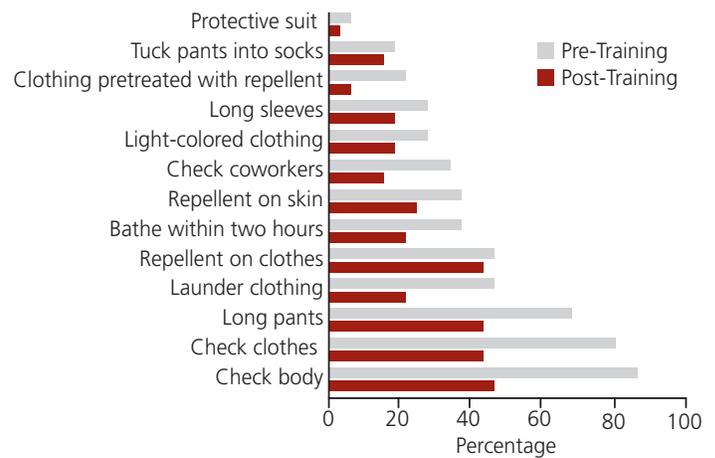


**Figure 3.** Pre-training survey responses of Greenbelt Park employees regarding exposures ( $n = 32$ ). Percentage of employees with exposure to a given outdoor habitat or activity at least once a week.

and two (6.3%) reported that uniform requirements did not allow clothing-related prevention measures. Employees reported not taking repellent-related prevention measures because they did not like the way repellent smelled or felt ( $n = 6$ , 18.8%), they were concerned about repellent safety ( $n = 4$ , 12.5%), it was hard to remember to use repellent ( $n = 4$ , 12.5%), and they were unaware of repellent-based preventive measures ( $n = 3$ , 6.3%).

Of the 32 employees who completed the pre-training survey, five (15.6%) reported a previous Lyme disease diagnosis and all five were diagnosed at the same time they were working for Greenbelt Park. No new diagnoses of tick-borne disease were reported on the post-training survey. Three of the previously infected employees worked in the Division of Interpretation with the role of interacting with the visitors and campers, one employee worked for the Facility Management Division and had frequent direct exposure to tick habitat, and one at the regional office had no exposure to tick habitat. Three reported working outdoors 10–20 hours per week, one reported working outdoors 31–40 hours, and one reported working outdoors for less than 10 hours per week. The employees with previous Lyme disease were more likely to tuck their pants into socks than those without a history of Lyme disease ( $p = 0.0039$ ). They were not, however, significantly more likely to employ repellent-based or tick check-based preventive measures or to avoid activities in the park known to be of high risk for tick encounters.

When responses from all 32 pre-training surveys were compared with the 19 post-training surveys, unlinked analysis demonstrated that knowledge improved for many questions. Employees were 5.6 (95% confidence interval [CI], range = 1.8–18.0) times more likely to answer correctly on the post-survey that ehrlichiosis is



**Figure 4.** Percentage of employees who usually or always used selected tick prevention measures prior to and one month following an educational training on ticks and tick-borne disease prevention ( $n = 32$  pre-training,  $n = 19$  post-training).

another tick-borne disease, and 2.0 (95% CI, range = 0.4–10.9) times more likely on the post-survey to answer correctly that the correct way to remove a tick is to pull it straight out using tweezers. Employees were 2.3 (95% CI, range = 1.4–3.9) times more likely to answer correctly on the post-survey than on the pre-survey that a tick must be attached for at least 24 hours for transmission of the bacterium that causes Lyme disease. Employees were less likely (relative risk ratio [RR] = 0.8, 95% CI, range = 0.4–1.7), however, to answer correctly on the post-survey that the red bull's-eye rash is not always present with Lyme disease. Employees were equally likely to answer correctly on both surveys (RR = 1.0, 95% CI, range = 0.8–7.4) that Greenbelt Park provided information about tick-borne disease prevention (fig. 5, next page). Similarly, the vast majority of employees responded correctly on both surveys that the park provided repellent for employees (RR = 1.1, 95% CI, range = 0.9–1.3). Most employees before and after the training felt that Lyme disease was a somewhat to very serious problem at Greenbelt Park (93.4% pre-training and 94.5% post-training) and felt that it was somewhat to very likely that they would acquire Lyme disease or another tick-borne disease while employed at Greenbelt Park (87.1% pre-training and 89.0% post-training). A linked analysis comparing the responses of the 19 employees who completed both pre- and post-training surveys confirmed similar results for knowledge and no significant difference in attitudes.

#### Day visitors and campers

Between 2 July and 1 September 2010, 180 surveys were completed by 127 day visitors and 53 campers (table 2); most completed the survey online. Of the 81 day visitors (64%) who provided a departure date, 30 (37.1%) responded to the survey on their departure date and 14 (17.3%) responded more than 30 days after departure;



Figure 5. Greenbelt park uses precautionary messages and provides information about risks of exposure to ticks.

NPS PHOTOS (3)

only nine campers (17.0%) completed the survey one month after their visit. Despite the instructions to wait 30 days from their park visit to complete the survey (to capture any tick-borne disease), 67 (82.7%) of 81 day visitors who reported a departure date and survey completion date completed surveys less than 30 days from their visit.

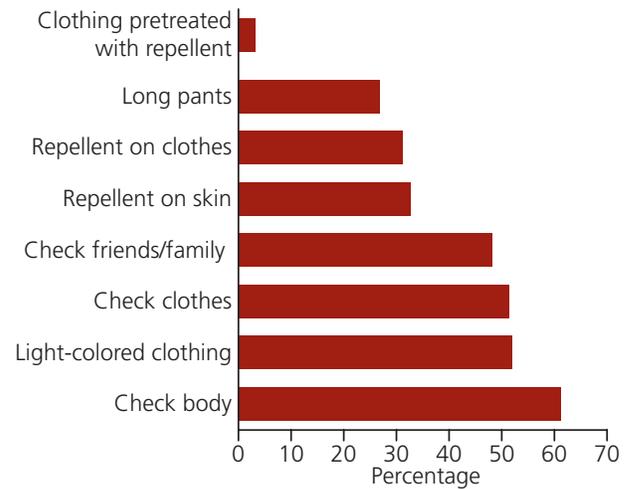
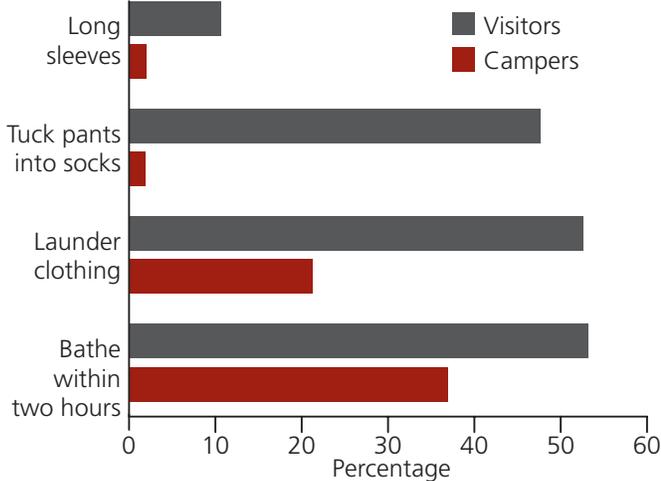
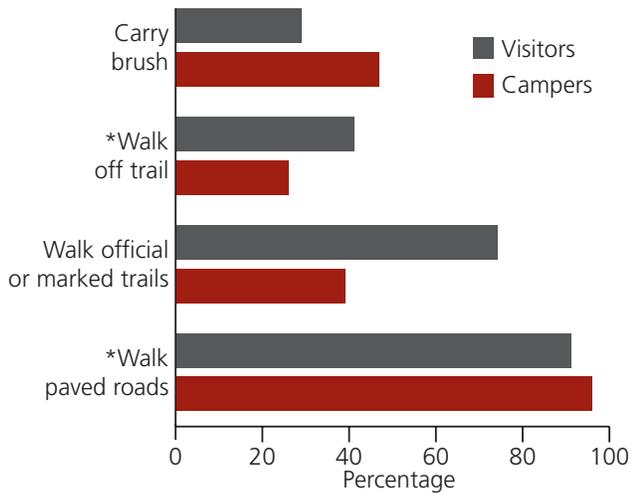
Over half of respondents were male ( $n = 96, 53.5\%$ ) and 81 (45.0%) were at least 45 years of age. Most day visitors and campers had at least one type of exposure to tick habitat. Of those who responded, the most frequently reported outdoor activities with high likelihood of tick exposure included walking on trails (72 day visitors [74.2%] and 18 campers [39.1%]) and carrying brush (27 day visitors [29%] and 22 campers [46.8%]; fig. 6). Forty-six day visitors (41%) and six campers (6.7%) found at least one unattached tick from their visit to Greenbelt Park, while 41 day visitors (45%) and three campers (12%) found at least one tick attached to them. Neither campers nor day visitors reported a new Lyme disease diagnosis after visiting the park, although 14 (7.8%) reported a previous Lyme disease diagnosis. Those with a previous history of tick-borne disease were no more likely to employ repellent-based ( $p = 0.9408$ ) or tick check-based ( $p = 0.8013$ ) preventive measures than campers and day visitors without a history of tick-borne disease.

For many preventive measures, there were no significant differences between campers and day visitors (fig. 7). Of those campers and day visitors who responded, 85 (47.2%) usually or always used more than one repellent-based preventive measure per visit and 141 (78.3%) usually or always used more than one clothing-based preventive measure. There were, however, significant differences between behaviors for laundering clothing, bathing within two hours, wearing long sleeves, and tucking pants into socks or boots (fig. 8). In all of these cases day visitors were more likely than campers to employ the preventive measures. When asked why they did not use preventive measures, 93 day visitors and campers (51.6%) responded that it was too hot to wear long sleeves and

Table 2. Characteristics of day visitor and camper survey respondents at Greenbelt Park, 2010

Category	Number	Percentage
<b>Use</b>		
Day visitor	127	70.6
Camper	53	29.4
<b>Origin*</b>		
U.S. resident	156	90.7
International	16	9.3
<b>Survey Type</b>		
Online survey	132	73.4
Paper survey	48	26.7
Reported <30 days after visit (visitor surveys only, $n = 81$ )	67	82.7
Follow-up survey (campers only, $n = 53$ )	9	17.0
<b>Sex</b>		
Male	96	53.5
Female	84	46.7
<b>Age (years)</b>		
<18	6	3.3
18–24	14	7.8
25–34	35	19.4
35–44	44	24.0
45–54	47	26.1
>55	34	18.9
<b>How much of day spent in the park*</b>		
Greater than or equal to half	37	40.2
Less than half	55	59.8
Note: Total sample = 180.		
*Missing data excluded.		

pants tucked into socks, 28 (15.6%) responded that they did not like the way repellent smelled and felt, 39 (21.7%) were concerned about pesticide safety, and 15 (8.3%) indicated that it was too hard to remember to check themselves for ticks. Only seven day visi-



**Figure 6 (top left).** Percentage of day visitors ( $n = 127$ ) and campers ( $n = 53$ ) who always or usually took tick prevention measures during their visit were significantly different between the two groups, Greenbelt Park, 2010. The differences in responses for items marked with an asterisk were not statistically significant.

**Figure 7 (top right).** Percentage of day visitors and campers combined ( $n = 180$ ) who always or usually took tick prevention measures during their visit to Greenbelt Park, 2010.

**Figure 8 (bottom left).** There were statistically significant differences between day visitors ( $n = 127$ ) and campers ( $n = 53$ ) who always or usually took the four tick prevention measures during their visit to Greenbelt Park, 2010.

tors (5.5%) reported being unaware of the tick checking method of prevention compared with 11 (20.7%) campers.

Slightly more than half of day visitors ( $n = 59$ , 55.7%) and about a fifth of campers ( $n = 11$ , 20.8%) responded that they thought it was somewhat to very likely they would acquire Lyme disease from being in Greenbelt Park (RR = 2.7, 95% CI, range = 1.5–4.7; fig. 9). Day visitors were 2.2 (95% CI, range = 1.3–3.7) times more likely than campers to feel that Lyme disease at Greenbelt Park was a serious problem. Day visitors were 2.3 (95% CI, range = 1.2–4.4) times more aware than campers that ticks must be attached for longer than 24 hours to transmit Lyme disease and 2.9 (95% CI, range = 1.7–5.1) times more aware that a bull's-eye rash does not always accompany Lyme disease infection. Less than a quarter of day visitors ( $n = 22$ , 20.8%) and campers ( $n = 6$ , 11.32%) were aware that ehrlichiosis is another tick-borne disease affecting residents in Maryland.

## Discussion

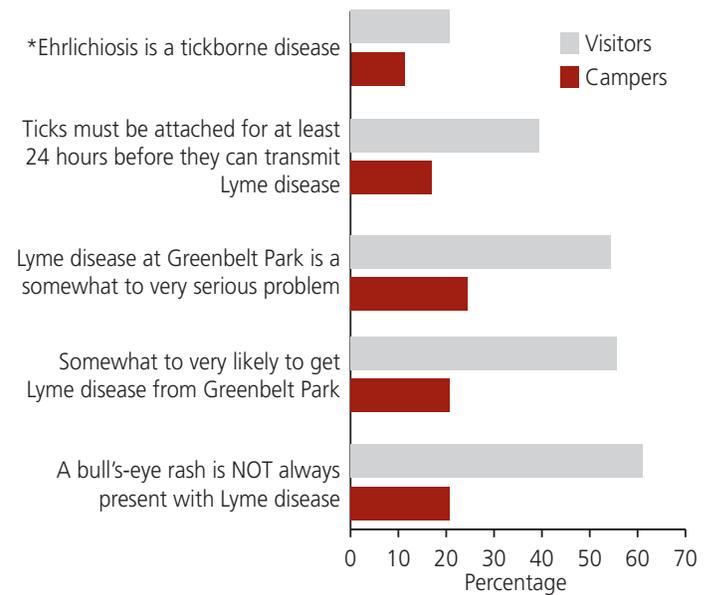
We learned that employees are concerned about ticks and Lyme disease, that their job activities frequently require them to work outdoors and in tick habitat during months when there are high nymph populations, and that the educational training for employees was effective in increasing knowledge of ticks and tick-borne diseases. Despite increased awareness that Lyme disease was a problem in Greenbelt Park and that certain work activities increased employees' risk of exposure, the intervention did not effectively increase the use of even the simplest of preventive measures such as checking oneself after going into tick habitat. This highlights the difficulty of behavioral change and emphasizes that a single training is not enough to influence daily tick checking and maintaining behavioral change.

Day visitors and campers also encountered ticks and participated in activities that took them into tick habitat. We did not receive

any reports of tick-borne illness through the survey, possibly because most day visitor and camper respondents did not wait at least 30 days to return their survey. This is the minimum time needed to account for the incubation period of Lyme disease plus time for physician diagnosis. Although day visitors perceived that Lyme disease was a problem in the park, half or less of the day visitors reported using protective measures when they were in the park. Paradoxically, day visitors had greater knowledge and implemented more protective measures than campers, even though day visitors spent the shortest time in the park and had relatively little exposure to ticks. Campers also presumably have a relatively increased risk of exposure because of activities such as gathering wood for campfires and clearing brush from campsites. This suggests that campers should be targeted for educational messages through methods such as ranger-led interpretive talks, reminders by rangers on campsite rounds, and online tick-borne disease information for campers making reservations online (Wong and Higgins 2010). Targeted messaging and communication strategies should be developed for different audiences.

That 15% of employees reported contracting Lyme disease while employed at Greenbelt Park demonstrates that the risk is real and is consistent with other reports of occupational risk for Lyme disease (Adjemian et al. 2012; Han et al. 2014; Smith et al. 1988). Employees and park visitors with a prior Lyme disease diagnosis were no more likely to employ protective measures than those who did not report prior Lyme disease. Variability in adherence to personal protective measures to prevent Lyme disease has also been documented previously (Gould et al. 2008; Hayes and Piesman 2003; Phillips et al. 2001; Smith et al. 2001; Vázquez et al. 2008).

Similar to other studies, our findings suggest that knowledge does not always translate to implementation of personal protective measures. However, these low-cost approaches to educate the public, especially if they address knowledge gaps such as those we identified, should not be dismissed, because they do have positive effect. Alternative approaches to reduce the risk of tick encounters should be developed in place of using pesticides that are unpleasant in feel and smell, including measures that rely less on individual motivation and actions or practices with low compliance. Incorporating permethrin-impregnated clothing into uniform requirements for park employees, and increasing the availability of permethrin-impregnated clothing and socks in appropriate fabrics for hot and humid temperatures where Lyme disease is endemic might be an effective way to protect employees. Park managers, for example, made both repellents and permethrin-impregnated socks available to employees immediately after the training. The National Park Service protects the natural ecosystems of its parks with minimal interference. Thus, implementing environmental controls such as widespread application of



**Figure 9.** Percentage of day visitors ( $n = 127$ ) and campers ( $n = 53$ ) who responded correctly to knowledge and attitude questions at Greenbelt Park, 2010.

\*The differences in responses for knowledge about ehrlichiosis were not statistically significant.

pesticide to reduce tick populations, exclusion of deer and other Lyme disease vectors, and treatment of tick hosts are generally not viable options to reduce the risk of human tick-borne disease in national parks, according to management policies.

National parks present unique environments for zoonotic disease transmission because of the abundance of fauna and because high-risk behaviors are conducted, often without adequate knowledge of public health risks. Because there were few reports of prior Lyme disease diagnosis and no reports of new diagnoses from the survey, our ability to analyze risk factors for disease was limited. Behaviors were self-reported and could not be validated. The day visitors and campers who responded to our survey were a convenience sample and may not represent the true nature of the visitor and camper population at the park, but these results do provide the best data available. Finally, while survey respondents provided insights regarding activities conducted within the park, they might also have additional potential to develop diseases from tick exposures outside of the park.

## Conclusions

We learned that respondents with previous Lyme disease diagnosis will tuck in their pants more often than those without a previous diagnosis, and that day visitors are more aware of the risk than campers who tend to travel the farthest. The lack of

other correlations provides numerous opportunities for education, including messaging to change behaviors and fill knowledge gaps. Even with knowledge of the risk, individuals are reluctant to implement personal protective measures, highlighting the difficulty of implementing interventions effectively to change health behaviors. These results and implications support the need for continued efforts to increase and monitor tick-borne disease prevention behaviors and knowledge among park visitors and employees alike.

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The DHMH Institutional Review Board approved the methodology (protocol 10-22) and the National Park Service provided a permit (NACE-2010-SCI-0019) to conduct the study. This study was supported in part by an appointment to the Applied Epidemiology Fellowship Program administered by the Council of State and Territorial Epidemiologists and funded by the Centers for Disease Control and Prevention Cooperative Agreement #1U38HM000414. The findings and conclusions are those of the authors and do not necessarily represent the official position of the Centers for Disease Control and Prevention, U.S. Army, or National Park Service.

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# In Focus: Soils

NPS/NEAL HERBERT

## Celebrating soils across the National Park System



By Susan Southard and Gregory Eckert

**Figure 1.** Cryptobiotic soil crusts at Arches National Park accumulate very slowly as cyanobacteria, algae, lichens, and other microscopic organisms grow in the desert climate. This one has become home for a young fish hook cactus. These fragile soils can take decades to recover from a careless footprint.

**THE 68TH UNITED NATIONS GENERAL** Assembly declared 2015 the International Year of Soils (FAO 2015). The goal of this designation was to increase awareness about the fundamental relevance of soils for human societies. The declaration also called for the initiation or renewal of policies and actions aimed at sustaining soils globally. Because they are slow to recover from disturbance, soils are considered a nonrenewable resource (fig. 1) and must be preserved in order to secure a sustain-

able future for humanity. The value of conserving soils lies with the fact that soils are the basis for (1) producing healthy food; (2) cultivating vegetation for animal feed, fiber, fuel, and medicinal products; (3) supporting Earth's biodiversity; (4) combating and adapting to climate change; and (5) storing and filtering water. As the International Year of Soils comes to a close and the National Park Service begins its centennial year, we hope to stimulate appreciation for the diverse and important—

### Key words

biodiversity, climate change, ecosystem services, soil carbon sequestration, soils

though often overlooked—roles that soils play as integral, ubiquitous park resources through this brief series of “In Focus” articles.



USDA/SUSAN SOUTHARD

**Figure 2.** Soils at Mount Rainier National Park preserve a geologic history of past volcanic eruptions.



USDA/SUSAN SOUTHARD

**Figure 3.** Soil horizons developed in chaotic, tilted landslide deposits associated with an earthquake and subsequent landslide at Lassen Volcanic National Park.



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NPS/DAVID YUBETA

## Soil and parks

Most people know soil<sup>1</sup> for its agronomic qualities—that our food grows in it. But soils are intrinsic to how we experience and interact with our national parks. Soils are underfoot when we hike a trail, pitch a tent, or stop at a scenic overlook. They support vegetation, terrestrial food webs, and park roads. Through their diversity and variability, soils help define the very character of the parks and their stories, which brings special meaning to these places.

Soils provide unique assemblages of nutrients via mineral and rock weathering that supports ecological niches. For example, at Golden Gate National Recreation Area and Point Reyes National Seashore in California, soils formed on old

hydrothermally altered seafloor deposits that have a relatively low calcium and high magnesium content. Only plants that can adapt to these growth-limiting conditions are able to survive in these soils. Some of the rare and endangered plants thriving on these soils derived from serpentinite are Presidio clarkia (*Clarkia franciscana*), San Francisco wallflower (*Erysimum franciscanum*), Raven’s manzanita (*Arctostaphylos hookerii* ssp. *ravenii*), and Franciscan thistle (*Cirsium andrewsii*).

Trees of the Pacific Northwest in Mount Rainier, North Cascades, and Lassen Volcanic National Parks thrive on the unique chemistry and physical properties of soils formed from volcanic ash (figs. 2 and 3). Ash parent material often weathers to form noncrystalline particles of aluminum and silica that have high capacity for storing and exchanging calcium, magnesium, and other cations that are important nutrients for plant growth. In contrast, plant

<sup>1</sup>The National Park Service defines soil as “the unconsolidated portion of the earth’s crust modified through physical, chemical, and biotic processes into a medium capable of supporting plant growth” (NPS 2014).

**Figure 4 (top).** Sod houses celebrated at Homestead National Monument of America were built from the Kennebec soil, which has the highest soil organic carbon content of any Mollisol in the National Park System. The dense grass roots, which incorporate and sequester organic carbon at depth in the soil, held sod bricks together as homesteaders cut them from the native prairie for building their historical sod homes. Based on Natural Resources Conservation Service certified soil survey data, Kennebec soil has 55 to 65 kilograms (121–143 lb) of soil organic carbon computed on a whole soil basis to 2 meters (6.6 ft). Using a conversion of 4.4515 to change kg/m<sup>2</sup> to tons/acre, the Kennebec sequesters 265 tons of carbon (C) per acre. Assuming a total of 6,000 board feet in a 2,000-square-foot house and 1 pound of C per board foot, the wood framing of a house contains 3 tons of C. Thus, 1 acre of Kennebec soil at Homestead has a C content equivalent to that in 88 single-family homes.

**Figure 5 (above, at bottom).** Soils are part of building materials, including adobe bricks such as these at Tumacacori National Historical Park. Cultural resource and historic preservation specialists work very hard to preserve these resources. In addition to sod houses (fig. 4, top) other examples of soil-based building materials include mortar and “daub” used to fill cracks between rocks and logs.

communities in the southwestern desert parks are adapted to living in harsh conditions with soils that have a high carbonate content and high salinity.

Human history and culture are also entwined with soils. In Dinosaur (Utah and Colorado) and Bandelier (New Mexico) National Monuments, for example, they provided paint and dyes for pottery and petroglyphs. They were used as building materials for sod houses at Homestead National Monument of America (Nebraska; fig. 4, previous page), prehistoric homes at Wupatki and Walnut Canyon National Monuments (Arizona), and pit house daub at Shiloh National Military Park (Tennessee and Mississippi). Soils are the adobe at John Muir (California) and Bent's Old Fort (Colorado) National Historic Sites, and Tumacacori National Historical Park (Arizona; fig. 5, previous page). They constitute the earthworks at Gettysburg National Military Park (Pennsylvania), Morristown (New Jersey), Valley Forge (Pennsylvania), and Hopewell Culture (Ohio) National Historical Parks; Effigy Mounds National Monument (Iowa); and other parks (figs. 6 and 7).

Soils figured in human stories memorialized at some parks. For example, Japanese-Americans who were interned at Manzanar National Historic Site (California) suffered from the high wind erodibility of the soils blowing off the granitic fans of the eastern Sierra Nevada and the relentless fugitive dust of Owen's Lake to the south (fig. 8). Today Manzanar is subject to water releases from diversion dams onto low-cohesion soils formed in granite that result in erosion of cultural resources (fig. 9). The failure of the South Fork dam in 1889, which is remembered at Johnstown Flood National Memorial (Pennsylvania), may have been due in part to high silt content of the soils formed in shale that was used to construct the earthen dam.



USDA/SUSAN SOUTHARD

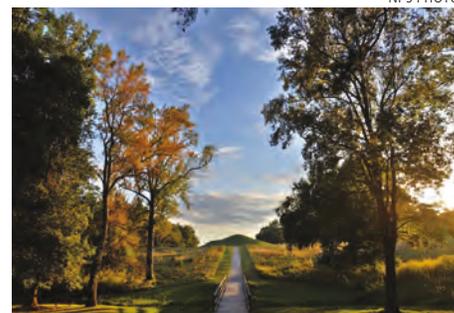
**Figure 6.** The earthen ramparts at Fort Necessity National Battlefield (Pennsylvania) were dug into a hydric soil and failed to keep George Washington's ammunition dry.



USDA/SUSAN SOUTHARD

**Figure 8.** Many cultural resources, such as these meditation gardens at Manzanar National Historic Site (California), were built out of soils that need protection.

Because they preserve events of the past, soils provide strong clues to the geologic processes that formed the landscape. For example, the layering of tephra (soils formed from volcanic ash) and glacial deposition in North Cascades (Washington), Mount Rainier (Washington), Denali (Alaska), and Lassen Volcanic (California) National Parks can both be observed in soil profiles. Continental-scale glacier margins from the last ice age are reflected in the soils of Voyageurs National Park (Minnesota), Delaware Water Gap National Recreation Area (Pennsylvania and New Jersey), and Pictured Rocks National Lakeshore (Michigan). Paleosols (fossil soils) preserve a history of paleoclimates in tectonically uplifted marine deposits on the California coast, including sites at Cabrillo National Monument and Golden Gate National



NPS PHOTO

**Figure 7.** Many American Indian cultures built mounds out of soil such as the earth lodge at Ocmulgee National Monument (Georgia).



USDA/SUSAN SOUTHARD

**Figure 9.** Artificial water releases from diversion dams upslope of Manzanar are eroding park lands and cultural resources such as the "hospital garden."

Recreation Area (fig. 10). The Big River soil mapped in Redwood National Park may preserve a record of past tsunamis.

Anthropogenic soils such as fill areas in Golden Gate NRA (California) and Gateway NRA (New York and New Jersey) serve as examples where human-modified soils have been identified and classified and are included in the NPS Soil Resource Inventory (fig. 11). These soils preserve important histories of why and how humans have altered their natural environment.

How do park environments play such fundamental roles in defining the character of our soils? It is diversity and combinations of physical, chemical, and biological characteristics and how these factors interact that distinguish soils (fig. 12). A five-part

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*Evidence of past climates can be observed in paleosols.*

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USDA/SUSAN SOUTHARD



**Figure 10.** Fossil soils, called paleosols, at Cabrillo National Monument record stories of the past. They formed in marine deposits that were tectonically uplifted during times when climatic conditions were warmer and wetter than those of today.

USDA/SUSAN SOUTHARD



**Figure 11.** The parade grounds at Fort Baker in Golden Gate National Recreation Area are formed on artificial fill, called a Xerorthent by soil scientists. The fill is derived from dredged material and can be susceptible to subsidence (settling) during earthquakes.

USDA/CHARLES DELP



**Figure 12.** Three distinct soil horizons, comprising dark-colored organic matter at the surface, white-colored leaching organic matter and clay in the middle, and black and orange-colored translocation of the organic matter and clay to the subsoil, are visible in this shallow soil pit dug by scientists in sandy river soils at Gauley River National Recreation Area, West Virginia. These soils, which scientists classify as Spodosols, tend to have low nutrient content because of leaching.

model helps scientists classify soils by discerning their properties based on the interaction of water and (1) parent material (rocky type), (2) organisms (including people), (3) time (often measured geologically), (4) climate, and (5) topography. Soil surveys have been conducted over the past 20 years through the NPS Natural Resource Stewardship and Science Inventory and Monitoring Program in partnership with the National Cooperative Soil Survey Program led by the USDA Natural Resources Conservation Service. This effort has provided basic information on soil types and their distribution in more than 270 national parks. The soils data and information are constantly being refined and updated, providing parks with important data sets that relate to the management of park natural and cultural resources, facilities, and operations.

### Three emerging issues

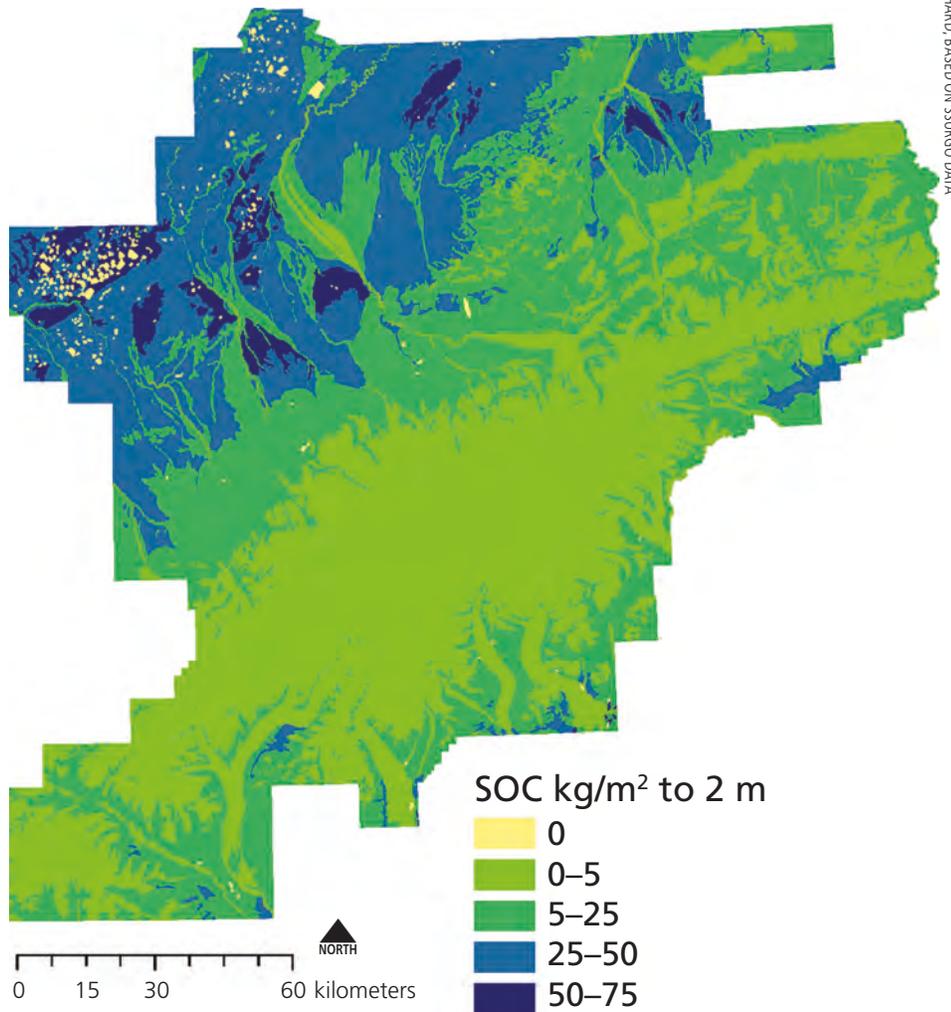
Just as it prescribes management guidelines for species and other park resources and values, *NPS Management Policies 2006* (NPS 2006, section 4.8.2.4) directs the National Park Service to conserve soils. An important component of this policy is the use of science to inform our understanding of soil formation processes, soil properties and behavior, and what activities are detrimental to soils. This information helps us determine best management practices.

Three contemporary management issues relate to soils in the following ways:

#### **Carbon sequestration**

Decomposing plants and animals contribute organic matter to soils, including organic carbon, nitrogen, and other plant nutrients. This soil organic matter is about half organic carbon and increases pore space and other soil properties, such as water-holding capacity, that are essential for plant growth. Microbial degradation of soil organic matter can either make nutrients available to plants or transform

## Denali National Park, Alaska Soil Organic Carbon by Map Unit Weighted Average



**Figure 13.** Soil organic carbon stocks of parks are easily obtained by using certified soils data, such as provided by this soil carbon map of Denali National Park and Preserve.

them to make uptake by plants difficult; in either case these processes create reserves of organic carbon in soil, resulting in soil carbon sequestration.

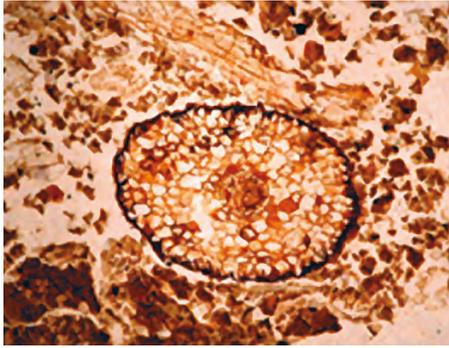
Soil is the largest terrestrial carbon sink on Earth, and parks contribute to the carbon sequestration process through their protected status. Carbon bound in soil buffers ecosystems against the effects of global climate change and is sustained in part through good park management. The aforementioned soil surveys provide a way

to account for soil carbon and have been used to highlight park soil carbon stocks (fig. 13). The role of soils in carbon sequestration on park lands will become increasingly important as we seek to understand and adapt to the impacts of climate change on park resources and processes.

#### **Biodiversity**

Soils host one-fourth of the world's biodiversity in bacteria, fungi, and invertebrates (fig. 14). They provide a critical habitat for plants (roots) and burrowing

NPS/ART COHEN



**Figure 14.** Microscopic analysis of organic-rich soils at Congaree National Park shows evidence of plant roots, insect burrows, fungal spores, charcoal, pollen, and other life-forms that have accumulated on the forest floor since the last ice age.

animals such as snakes, armadillos, prairie dogs, ground squirrels, gophers, moles, and burrowing owls. They also contain a broad range of climatic and chemical environments. Though taxonomists have only scratched the surface of inventorying the myriad species found in soils, biodiversity will surely increase significantly as these lesser-known soil microhabitats are explored. Similarly, although bioblitzes conducted broadly in national parks have added to our knowledge and understanding of life in these places, there have been few attempts to paint a picture of life belowground. Nevertheless, scientists can provide impressive estimates for soil organisms. These estimates range from 9,000 species of bacteria and Archaea per cubic centimeter (549/cu in), 100 genera of nematodes per square meter (131/cu yd), and more than 100 species of mites per square meter (131/cu yd) (Bardgett and van der Putten 2014). Altogether these species provide for a number of beneficial processes and services.

#### **Ecosystem services**

Soils play many important roles in ecosystems. By providing physical media and supplying water and nutrients for plants and animals, soils support the very basis of all food webs and park species. Soils store, filter, and purify water; regulate water

flow; control erosion; mitigate flooding; and cycle plant nutrients such as nitrogen, all of which are important services that help sustain landscapes across the National Park System. Outside of parks, soils are involved in the production of hundreds of everyday products that benefit humans, including clay, sand, and gravel in the construction of road beds, and raw materials used to manufacture insulation and filters. Microbes gathered from soils are used in the production of antibiotics (Ness 2015), and earthworms are important as fish bait. Soils even exert controls over pests and diseases through properties such as ionic strength and pH, and soluble organic carbon content (Comerford et al. 2013).

#### **Soil science**

Soils are ubiquitous in national parks and in our lives, and our efforts to understand how they behave and interact with their environments are critical. So to round out our primer the following two articles highlight important advances in resource science and management related to soils. In addition to their specific areas of focus, these investigations improve our understanding of how, through dynamic and static processes, soils are linked to numerous other resources and activities in parks and in the broader landscapes beyond parks. The National Park System includes an amazing array of soil types, functions, and services. By continuing to develop our understanding of them we can celebrate their importance in parks alongside memorials, rivers, and wildlife.

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# Interactions underfoot: The subtle influence of soil moisture on vegetation pattern

By Jay Skovlin and David Thoma

*The forests are also needed for mitigating extreme climatic fluctuations, holding the soil on the slopes, retaining the moisture in the ground . . .*

—Franklin D. Roosevelt<sup>1</sup>

## THE SHADOWY, BEAUTIFUL FOREST

along the shore of Lake McDonald is the image that many visitors take home with them and remember from Glacier National Park, Montana. These forests along the Going-to-the-Sun highway host a famous lodge, popular campgrounds, and favorite hiking trails as well as important habitats for a diversity of plants and animals. Both forests and soils evolved on this once-glaciated and barren landscape. Today a lush cedar and hemlock forest flanks the lakeshore, sustaining natural ecosystems and human activities to enjoy them. But what lies beneath this forest, what sustains it, and what will the future hold?

This year, 2015, is the International Year of Soil, a time to highlight the critical—but often overlooked—roles that soil plays in the ecological processes of natural landscapes (Food and Agriculture Organization of the United Nations 2015). In this article we describe how soil properties interacting with climate and terrain affect the seasonal availability of moisture for vegetation in Glacier National Park. Our approach uses a mathematical water balance model that integrates soil survey, digital terrain, and climate data to gain in-

sight into the interaction between physical factors and climate. This method is possible using freely available gridded climate and soil survey data (Thornton et al. 2014; NRCS 2013). The soil survey of Glacier is being updated, so we use it as a timely example that showcases the integration of soil survey data with climate and modeling tools to illuminate important seasonal ecological processes—namely variation in soil moisture.

Land managers, soil scientists, and even presidents have long recognized that soil plays an important role in temporarily storing water as it moves through the hydrologic cycle. More challenging is to quantify that role and how it affects vegetation patterns in remote and rugged landscapes like Glacier. Understanding variation in soil moisture can help us comprehend drought and wildfire probability, severity, and recovery, all processes that shape vegetation distributions. Indirectly, soil moisture also affects competition, forest disease, and vegetation response to extreme weather events, all of which contribute to the vegetation pattern in Glacier and other national parks (Kane et al. 2015; Stephenson 1998).

## Key words

climate, Glacier National Park, soil, water balance

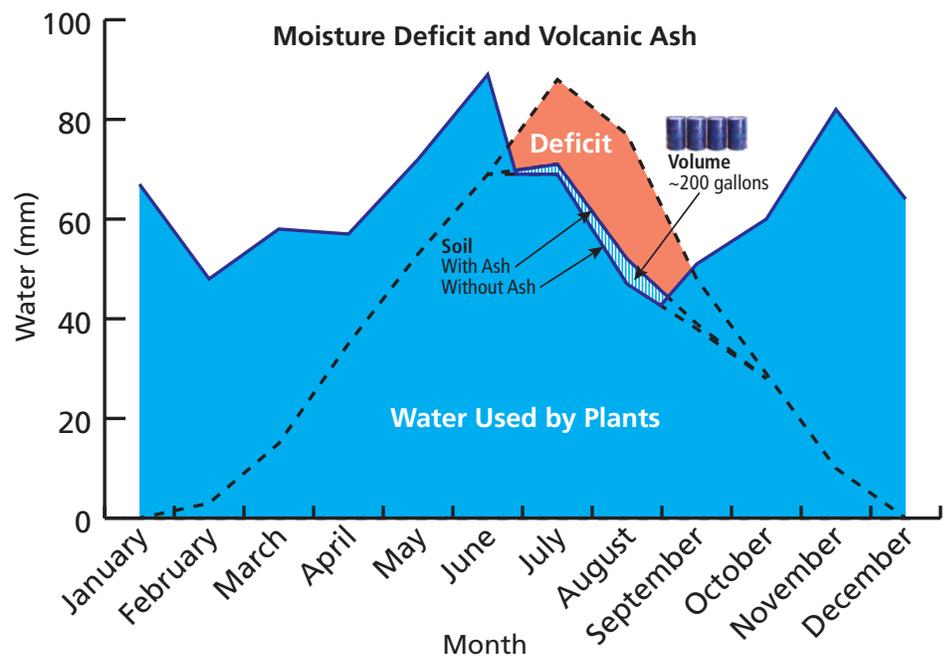
Climate interactions with terrain and soil properties are complex, but a water balance model helps integrate these factors quantitatively to estimate the persistence of moisture in soil (Lutz et al. 2010). If soil is considered a natural bank account and water is currency, then, like balancing a checkbook, water balance models track water input and loss. Each spring the deep winter snowpack melts, replenishing the soil moisture supply. What does not drain to groundwater or run off to fill rivers and lakes remains in the soil to be used by plants. As water is consumed over the course of the following summer, rain may occasionally replenish soil moisture. If not, however, then moisture deficits accrue. Deficit is the difference between water used and water needed by plants to grow optimally. Although different species are adapted to tolerate typical deficits where they grow (think cactus in deserts), an accrual of deficit above a species' tolerance can cause wilting or death. Following the banking analogy, a water deficit is akin to an increasing overdraft that stresses plants as the duration and magnitude of deficit grow during dry spells. In Glacier National Park a greater soil water-holding capacity confers an advantage through dry periods because plants have a greater volume of stored water to use and thus a greater chance of surviving through a hot and dry period with minimal stress.

<sup>1</sup>A presidential statement on the receipt of the award of the Schlich Forestry Medal (from the Society of American Foresters), 29 January 1935.

*If soil is considered a natural bank account and water is currency, then like balancing a checkbook, water balance models track water input and loss.*

### Terrain influences water storage

Terrain also plays a role in the variation of soil moisture through the effects of slope steepness and aspect. The *aspect* of a slope refers to the orientation or direction the slope faces, which determines its potential for solar gain (sun exposure). The significant effect of aspect is apparent in sun-sheltered, north-facing slopes that afford protection for glaciers and snowfields. On the other hand, south-facing slopes at the same elevation have more solar gain and energy to drive melt and evapotranspiration, which cause soil in those locations to dry more quickly. Plant species distributions follow patterns across landscapes that have similar water balance characteristics (Stephenson 1998). Plants use the effects of terrain to compensate for limitations of energy at higher elevations and for limitations of moisture at lower elevations. Evidence of this compensatory effect in Glacier is apparent not only for trees, but also for grasses like Idaho fescue (*Festuca idahoensis*), an important forage species for ungulates. This species can be found on north-facing slopes at lower elevations, where it minimizes moisture stress, and is only found on warm, south-facing slopes at higher elevations, where it maximizes



**Figure 1.** Volcanic ash shrinks water deficit. An annual soil water diagram generated from 34 years of climate data (1980–2013) for a site in a red cedar (*Thuja plicata*) and western hemlock (*Tsuga heterophylla*) forest in Glacier National Park. From January to June there is an abundance of soil moisture available for use by vegetation. Beginning in June a period of seasonal water stress occurs in most years. The presence of volcanic ash shrinks the seasonal water deficit by about 200 gallons, the blue shaded area. In this case the blue shaded area is the reduction in deficit resulting from the presence of a 36 cm ash layer in the soil.

the energy-limited conditions of lower temperatures through increased solar gain.

### Soil properties influence water storage

A fascinating soil feature in Glacier that affects water storage is the presence of volcanic ash derived from the former Mount Mazama, which collapsed to form the caldera that holds Crater Lake some 885 km (550 miles) to the southwest in Crater Lake National Park (Oregon). An eruption 7,600 years ago dispersed a tremendous volume of ash that blanketed large areas of North America (Zdanowicz et al. 1999). As a windborne material, volcanic ash consists of silt-sized glass particles that are nutrient-poor but are very porous and retain more water than typical soil particles of the same size class. Since deposition, surface runoff and erosion have redistributed the once-uniform blanket of ash to create the patchy distribution with varying

thicknesses as described by soil scientists working in the region today. In Glacier, Mazama ash varies in thickness from 15 to 60 cm (5.9 to 23.6 in) where it occurs, but is generally thicker west of the Continental Divide. Due to its porous nature, ash overlying a rocky and coarser-textured material such as glacial till results in a mulching effect that boosts water storage and availability for plants (McDaniel et al. 2005).

### A case study in nuance

A 34-year monthly average climate diagram for a red cedar (*Thuja plicata*) and western hemlock (*Tsuga heterophylla*) stand along the shore of Lake McDonald shows that this location typically experiences a period of soil moisture deficit during the summer months, the period that most strongly determines the distribution of western red cedar and western hemlock (fig. 1; Mathys et al. 2014).

However, hidden below the forest floor in some locations lies the Mazama ash. Where it occurs at lower elevations the soil with ash retains more water than non-ashy soil, which helps offset moisture stress during dry periods. The modeled moisture deficit during summer is about 15% lower in a soil that has a 36 cm (14.2 in)–thick volcanic ash layer (fig. 2). By making a few simplifying assumptions we determined that during this critical deficit period the relative difference is roughly 757 liters (200 gallons) of additional water per tree growing on soil with ash. While this relative difference in water availability is small compared with the annual water use of mature trees, it has been shown that the distribution of these two tree species is highly sensitive to variation in water-holding capacity of soil (Mathys et al. 2014). It also suggests that because red cedar and western hemlock are at the eastern extent of their range in Glacier they may persist longer in sites where climate and soil properties moderate the effects of increasing deficits that are likely with climate change (McKenzie 2012; Mathys et al. 2014). Although other factors like disturbance and competition matter, when we look broadly at vegetation distributions of many plant species the spatial patterns at biome, landscape, and site scales reflect variation in seasonal soil moisture availability (Stephenson 1998).

### Management implications

If deficits increase over time as projected (Fagre 2007) and cedar and hemlock stands decrease in area in Glacier, then these stands may become increasingly important to other animal and plant species that inhabit these forests. Understanding where suitable sites for plant species exist, and for how long those sites may confer resilience or resistance to climate change, could be useful to managers as they strive to mitigate impacts of the changing climate. For example, if managers want to retain or restore red cedar or hemlock stands in Glacier, they could use soil maps and water balance models to



**Figure 2.** A soil with a thick layer of volcanic ash (reddish zone above 40 cm [16 in]) that is low in rock fragments overlies a very gravelly subsoil in a red cedar (large tree pictured in the foreground) and western hemlock forest. When ash falls it is white or light gray but over time mixing, weathering, and organic matter darken its color.

help identify locations that are more likely to experience stress sooner and to find locally suitable conditions that may not exist presently but may exist in the future. As temperatures warm and summer deficit regimes change spatially, suitable potential habitat may be at higher elevations from current red cedar and hemlock forest stands or may be on different slopes or aspects with suitable soil, which could become target areas for active management. Soil survey data combined with a water balance model can help managers untangle the complicated interactions of these various factors that affect water availability and deficits.

### Conclusion

Small differences in soil properties play roles in the historical and current distribution of vegetation types in Glacier and will continue to influence vegetation patterns in the future. The Natural Resources Conservation Service soil survey of Glacier National Park describes the variation of soil in this rugged and spectacular landscape, and here we describe climate interactions with terrain and soil that affect seasonal moisture availability. Soil moisture is a temporally and spatially dynamic



PHOTOS COURTESY OF PATRICK O'CONNELL AND JAY SKOVILIN

landscape feature that affects drought, fire, and forest disease, which in turn influence vegetation patterns and subsequent use of the landscape by wildlife (Stephenson 1998; Kane et al. 2015; McCloskey et al. 2009; Singer 1979). Coupled with long-term vegetation monitoring like that being conducted by parks and the National Park Service Inventory and Monitoring Program, water balance models could help identify thresholds or tipping points of vegetation change and potential locations with optimum conditions for successful restoration efforts. Processes like fire and recovery are dramatic manifestations of climate and soil interactions, but some processes are more subtle, like the water balance character of a site that determines suitability for different species. These factors, bold and subtle, add character and nuance to the repeating theme in the architecture of vegetation pattern. In this International Year of Soils we call attention to these themes, especially those that are more subtle, and hope to raise awareness of soil and how considering interactions with climate could be used by park managers. Though often overlooked, these subtleties may be key to stewarding large landscapes in a rapidly changing world.

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*Water balance models could help identify thresholds or tipping points of vegetation change and potential locations with optimum conditions for successful restoration efforts.*

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### Acknowledgments

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# Wind, earth, and fire: The impacts of anthropogenic air pollution on soils in Joshua Tree National Park

By Michael D. Bell and Edith B. Allen



NPS PHOTO/MICHAEL BELL

INSET: EDITH B. ALLEN

**Figure 1.** Ephemeral annual species (including desert pincushion and desert dandelion) fill the interspace of a creosote bush shrubland in Pinto Basin at Joshua Tree National Park. As these species dry up at the end of spring, their biomass breaks down under harsh desert conditions. Alternatively, dried-out invasive grasses (inset) remain present through summer and have the capability of carrying fire between shrubs when present in high numbers.

## DESERT SOIL NUTRIENTS ARE MADE

up of various constituents and are not uniform in their spatial distribution in part because of perennial vegetation. Underneath desert shrubs, nutrients accumulate, moisture is greater because of shade and lower air temperatures, and organic matter is denser because of leaf fall and debris collection. In the shrublands of Joshua Tree National Park, California, creosote bushes (*Larrea tridentata*) act as “fertile islands” that provide nutrient-rich areas

where annual plants flourish during the limited precipitation season. Unfortunately, the introduction of invasive annual plant species threatens the native annual plant diversity that is present following winter precipitation. The spread of these invasive species is being enhanced by anthropogenic, or human-related, sources of nitrogen (N) from air pollution deposits on Joshua Tree and threatens the ephemeral plant community that attracts visitors to the park each spring (fig. 1). As nitrogen

## Key words

air pollution, invasive plants, Joshua Tree National Park, nitrogen deposition, stable isotopes

deposition increases, the spaces between native shrubs increase in nutrient concentrations, which can lead to increased growth of invasive species. These changes in soil processes have the potential to

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*As nitrogen deposition increases, the spaces between . . . shrubs increase in nutrient concentrations, which can lead to increased growth of invasive species.*

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influence overall desert plant communities by decreasing the richness of native plants and potentially leading to increased fires when invasive species get too dense.

### **Winds of change**

Mobile emission sources within the sprawling urban landscape of southern California release a mix of nitric oxides ( $\text{NO}_x$ ) and ammonia ( $\text{NH}_3$ ) gases that travel on ocean breezes from the Los Angeles air basin eastward into the desert. As these molecules are carried with the wind, they may be deposited directly on the soil surface (dry deposition) or dissolved in moisture and enter the soil matrix with precipitation (wet deposition). As nitrogen accumulates in the soil it can increase the growth of vegetation, change the rate of microbial processes such as denitrification, and reduce the number of mycorrhizae (microscopic fungal communities that grow symbiotically with plant roots). The differential response of species to the changing conditions will affect the community composition of desert vegetation.

Atmospheric nitrogen deposition peaks in the park in summer (predominantly as dry deposition) because of increased sunlight and more air mass movement from the L.A. air basin (USEPA 2015). We measured the atmospheric concentration of N in Joshua Tree National Park and the adjacent Coachella Valley using passive air samplers at 13 sites in summer 2010 and winter 2011 to identify how anthropogenic N additions were contributing to soil N (Bell 2012). The Coachella Valley is the area of desert between the L.A. air basin

and Joshua Tree National Park, and it is important as it provides an expansion of continuous creosote bush shrubland outside of the park boundaries. Data from summer N collections are presented here, as concentrations were significantly higher than in winter.

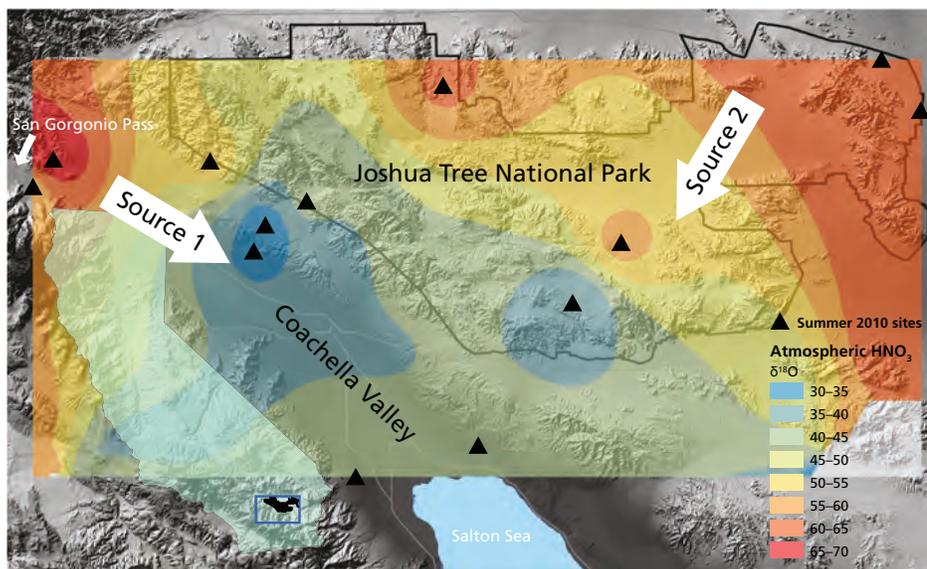
Concentrations of both nitric acid ( $\text{HNO}_3$ ) and ammonia ( $\text{NH}_3$ ) peaked on the western end of the study area where air masses move through the San Gorgonio Pass and head down the valley to the park (NADP 2014). Using stable isotope analysis (see sidebar, page 67) of the nitrogen and oxygen (O) within  $\text{HNO}_3$ , we determined that two different sources of nitrogen were having an impact on the national park (fig. 2, next page). The main signal from the isotopes came from enriched O molecules within  $\text{HNO}_3$ . Anthropogenic  $\text{HNO}_3$  molecules have an isotopic signature near 70‰ (Hastings et al. 2003) and mix with local, biogenic emissions, with an isotopic signature around 30‰ to create a gradient in isotopic signatures as nitrogen is deposited on the ground. Anthropogenic emissions are evident in two parts of the study area. The dominant source (“Source 1” on the map) of nitrogen, as expected, came from the west, where high concentrations of nitrogen come into the Coachella Valley from Los Angeles. The second source (“Source 2”) comes from the north end of the study area and dissipates south into the park. Although these are low concentration emissions, they are measurable because of low background N and are associated with emissions from vehicles around and inside the park.

Isotope analysis of soil samples at each site revealed that anthropogenic nitrogen was accumulating in the soil. Since most of the deposition comes down as dry deposition in summer, anthropogenic nitrogen accumulates in the upper 2 cm (0.8 in) of the soil profile, in the gaps of soil particles and soil crusts. With the first rains in winter, this accumulated nitrogen becomes bioavailable to germinating seedlings and increases the growth of annual vegetation. Understanding how soil processes are linked to atmospheric patterns can give managers an edge when dealing with the spread of an invasive plant species, as these plants often take advantage of increased resource availability.

### **Fire of life**

To understand how increasing soil N affects annual vegetation growth, we completed a second study in the creosote bush scrubland of Joshua Tree National Park (Allen et al. 2009). This experiment artificially increased soil N to measure its effect on winter vegetation. Four  $\text{NH}_3\text{NO}_4$  fertilizer treatments simulated the potential future effect of anthropogenic deposition. Within fertilized plots, both native and invasive annual species increased in cover. Native annual species have evolved in low-nutrient systems, so while the addition of N—the most limiting nutrient—led to greater growth, there was a differential response relative to the dramatic increase of the invasive species. Native species richness did not decline across the entire study area, but native cover did decline in each plot relative to the invasive common Mediterranean split grass (*Schismus barbatus*). The addition of nitrogen to the soil increased cover and standing biomass in the interspace areas, making these areas more similar to the undershrub habitats.

These growth responses—particularly the increase in invasive common Mediterranean split grass—were especially strong during high-precipitation years, such as 2004 when a pronounced El Niño event



**Figure 2.** Stable isotopes of nitric acid suggest that two anthropogenic sources of N are having an impact on Joshua Tree National Park. Red coloring indicates isotope values of oxygen representative of human inputs, whereas blues represent closer to background levels. Concentrations of atmospheric N are much lower in the eastern edge of the park, so while the local N sources are present, they are having less of an impact than those coming from the west.

increased winter precipitation far above the average for the area. This is because water is the most limiting factor for plant growth in the desert. Generally, desert soils are very coarse and do not have much organic matter, limiting water retention. When water did not limit growth, however, the added nitrogen had a significant impact on the amount of the invasive grass that grew. Based on calculations of biomass accumulation, we determined that increasing deposition past a critical load of 4 kg/ha/yr (3.6 lb/ac/yr) could increase cover of invasive grasses to the point where fire can spread among shrubs (Rao et al. 2010). The space between shrubs usually prevents fires in the desert from spreading quickly or getting too large, but when shrubs are connected by a carpet of annual vegetation instead of ephemeral native species (see fig. 1), fire can easily move from shrub to shrub and burn through the landscape. This change from historical smaller fires has the potential to have lasting impacts on the desert landscape because perennial species are not adapted to this type of disturbance.

### Future trends

Anthropogenic nutrient inputs to nutrient-limited ecosystems highlight the connectedness of the air-soil-plant continuum. Predictions for winter 2015–2016 are for above-average precipitation because of a strong El Niño Southern Oscillation building in the Pacific Ocean. If this occurs, it is likely that areas on the western edge of Joshua Tree National Park that are over the critical load of nitrogen for invasive plant growth may again experience above-average levels of biomass, which could cause fire to spread throughout the desert. While air quality has gotten better in southern California, even with continued population growth, the sensitive desert ecosystem is still at risk. Continued monitoring and modeling efforts by the National Atmospheric Deposition Program (NADP 2014) allow managers to keep track of the current deposition levels and increase their active management in high-risk areas.

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## Isotopes in environmental science

By David C. Shelley

So what is an **isotope**? Answering this question requires a review of basic atomic structure. Chemical elements are defined by the number of protons in the nucleus, called the **atomic number**. Hydrogen, for example, has one proton, so its atomic number is also one. Nitrogen has seven protons while oxygen has eight, so their atomic numbers are seven and eight, respectively. However, the nucleus also contains neutrons in addition to the protons. These two types of particles are effectively the same size and weight, and their sum constitutes an atom's **mass number**. The number of protons and neutrons is often—but not always—equal. Two atoms having the same atomic number (i.e., belonging to the same element) but having a different mass number (i.e., different numbers of neutrons) are called **isotopes** (fig. 1). Oxygen (O), for example, has three naturally occurring isotopes, which can be written as  $^{16}_8\text{O}$ ,  $^{17}_8\text{O}$ , and  $^{18}_8\text{O}$ . In this example the atomic number (elemental identity) is displayed at the lower left of the element symbol, while the mass number (isotope) is displayed at the upper left.

There are two basic types of isotopes.

**Radioisotopes** are unstable because of the extra neutron(s), and spontaneously release radiation in the form of particles and energy. This release, which is statistically predictable, can actually change the atom's atomic number, resulting in the production of a different element. **Stable isotopes**, by contrast, have a nucleus that is stable indefinitely. They do not emit radiation but persist alongside the other isotopes. All three of the naturally occurring oxygen isotopes are stable, for example, so they do *not* spontaneously release radiation and decay into other elements.

Different isotopes of the same element all take part in chemical reactions, but at slightly different rates. "Lighter" isotopes move around more easily than "heavier" ones. This differential movement is called **fractionation**, and it affects the ratio of isotopes present in any given sample of water, soil, rock, tissue, or air. Scientists can measure isotope ratios in a laboratory. They usually present isotope data as " $\delta$ " values (often called "del" values for the Greek letter "delta") in parts per mil (i.e., per thousand, ‰) relative to a standard reference sample. Samples may be described as either "depleted" or "enriched" in a given isotope (usually the heavier, less common one) relative

to the standard. For example, the Pee Dee Belemnite (*Belemnitella americana*), or "PDB," is a standard reference for carbon isotopes based on calcite crystals (calcium carbonate,  $\text{CaCO}_3$ ) found in fossils of this species collected from a specific locality in South Carolina. The international standard for nitrogen is atmospheric air, which is very well mixed around the globe.

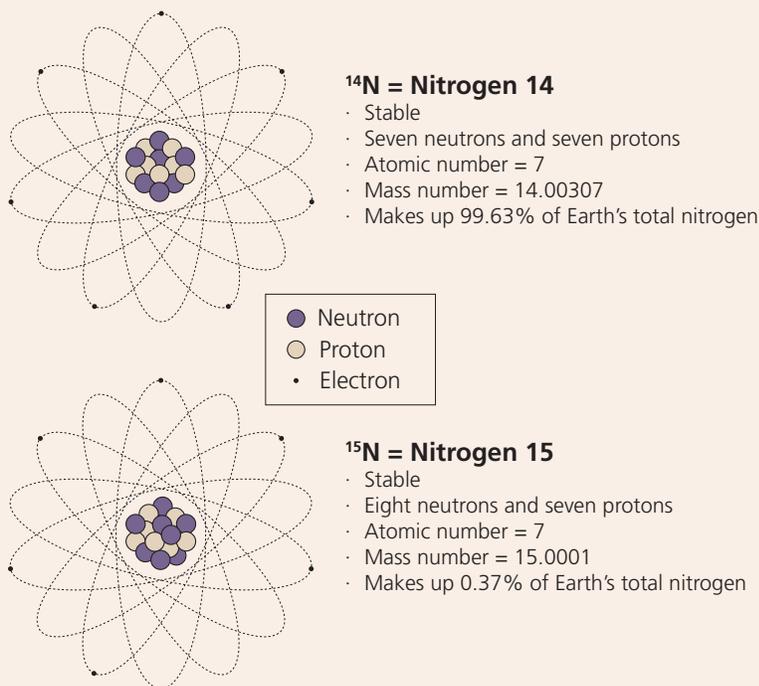
The science of isotopes—whether they are naturally occurring or created artificially in a laboratory—is well understood and widely applied in our world today (USGS 2007). Radioisotopes are widely used for energy sources in medicine and nuclear engineering as well as for "clocks" (like  $^{14}\text{C}$ , or carbon-14) for dating natural samples. Many people, however, are surprised to learn how many ways scientists use stable isotopes—especially in the natural sciences. First, scientists use isotopic ratios, which are also called "signatures" or "fingerprints," to characterize, classify, and constrain distinct sources for atoms in different samples. Second, scientists can measure fractionation under controlled conditions to make inferences about how samples are affected by specific processes such as evaporation or photosynthesis. Third, they can learn about complex changes through

space and time by carefully mapping stable isotopes or monitoring artificial isotope-labeled "tracers" in systems such as flowerpots, watersheds, fossils, tree rings, and sediment layers.

In the present study, nitric acid particles created from fossil fuel combustion contain isotopes of nitrogen and oxygen that differ from natural sources. Combustion temperatures and atmospheric reactions create distinct isotopic signatures that can be measured against background values to determine their origin. In this case, the article authors sampled nitrogen and oxygen isotopes of nitric acid deposition in Joshua Tree National Park and compared patterns to interpret two distinct areas where oxygen isotopes are a little heavier than natural "background" values. This finding is interpreted to reflect two artificial sources of the burning of fossil fuels.

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**Figure 1.** Two stable isotopes of nitrogen occur naturally. They have the same number of protons (i.e., atomic number = seven), but different numbers of neutrons (seven and eight). Scientists understand the ratio of nitrogen atoms in the atmosphere, and can compare measurements elsewhere to learn about physical and biological processes as well as the origin of nitrogen particles.

# Rocky Mountain Science Centennial

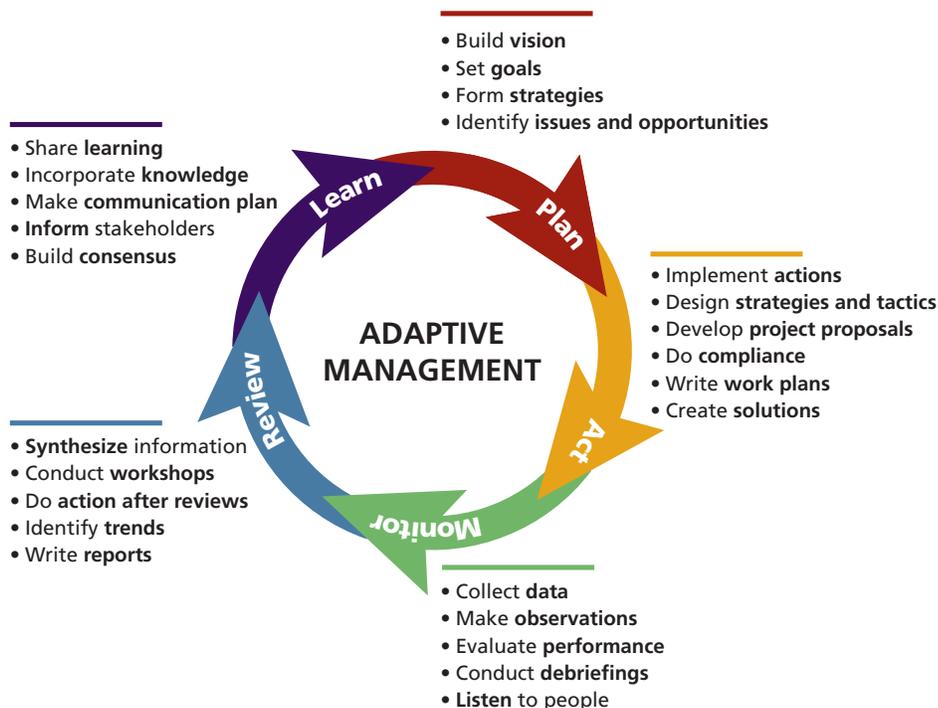
## Honoring the past and celebrating the present: 100 years of research at Rocky Mountain National Park

By Isabel Ashton, Ben Baldwin, Ben Bobowski, Scott Esser, and Paul McLaughlin

### IN THE FIRST 30 YEARS OF PARK

history, naturalists from the park, other federal agencies, academic partners, and citizens were inspired to catalog and describe what the American public had decided to protect and preserve for future generations. For instance, in 1917 Dr. Willis Lee published “The Geological Story of Rocky Mountain National Park” and in 1933 Ruth Nelson published “Plants of Rocky Mountain National Park.” In the following decades, similar works appeared about subalpine lakes, glaciers, plants, birds, conifer distribution, and mammals. By the 1960s, research began to address specific management questions. As an example, in the 1960s and 1970s, Beatrice Willard investigated the effects of road construction and visitor trampling on alpine tundra (fig. 2), which altered the way the park manages its alpine resources and visitor use. Sporadic research by NPS staff, other agencies, and academics continued through subsequent decades, but it lacked a clear agency mandate and the administrative support required to ensure an integration of research and park management (see Hess 1993 for a more thorough discussion).

The National Parks Omnibus Management Act of 1998 (Public Law 105-391, 112 Statute 3497) and the subsequent Natural Resource Challenge initiative (NPS 1999) had a huge impact on Rocky Mountain. The Omnibus Management Act directed park units to utilize the “highest quality science and information” in decision making (Section 202). A year later, the Natural Resource Challenge provided funding for a dedicated research administrator and, in



NATIONAL PARK SERVICE

**Figure 1.** This adaptive management framework was recently developed and adopted in-house by the Resource Stewardship Division at Rocky Mountain National Park to assist with the decision-making process. Research and the dissemination of science to the public play key roles in the monitoring, reviewing, and learning process.

2000, funding was provided for the creation of the Continental Divide Research Learning Center (<http://www.nps.gov/rlc/continentaldivide>) as part of the NPS Research Learning Center Network (<http://www.nature.nps.gov/rlc>). The purpose of the network is to bring “science to parks and park science to the public.” At the same time, the Cooperative Ecosystem Studies Unit (CESU) Networks were also established by the Challenge. The Rocky Mountain CESU (<http://www.cfc.umt.edu/cesu>) provided the park with a mechanism for partnering with and funding academ-

ics and other federal agencies on science, technical assistance, and education projects. With better administrative, logistical, and political support, many researchers were attracted to work in Rocky Mountain. On an annual basis, the park now issues an average of 120 research permits, with researchers working in the park on a diversity of topics including social science, archaeology, plant and animal species, wetlands, alpine tundra, and the spread of exotic species.

### Abstract

In 2015, Rocky Mountain National Park (Colorado) celebrated 100 years of protecting high-elevation ecosystems and wilderness character while providing visitors access to inspiring wild places. We took this centennial year as a time of celebration and a time for reflection on the strengths and weaknesses of our resource stewardship program. While the mountains within the park have changed relatively little over the past century, our approach to integrating science into park and wilderness management has changed dramatically. It is only recently that we have had the capacity to embrace adaptive management (fig. 1) and work with partners to effectively use science to inform policy and management actions.

### Key words

history, research, research learning centers, resource management, Rocky Mountain National Park

Our current challenge has not been the park's or our partners' capacity for research, but rather synthesizing and communicating the vast amount of science information to park management and the public. The park has worked to communicate science to a range of audiences through research briefs, lecture series, ranger programs, short videos, publications, and Web content. One of our most successful strategies to foster research and communication has been to hold two-day research conferences during which staff, students, and researchers are encouraged to share their work with the public. Recently, the park has tried a new approach to synthesizing research efforts in a Natural Resource Vital Signs Report (Franke et al. 2015). This short collection of articles provides another example of our science communication program.

In the following four articles, we provide a few vignettes of the success stories from



NPS PHOTO

**Figure 2.** Dr. Beatrice Willard uses toothpicks to mark plants for her alpine tundra research in 1961 at Rocky Mountain National Park. She continued monitoring her plots for more than 40 years and her research was used to guide visitor management in the tundra. The plots are now listed in the National Register of Historic Places.

the last 100 years of research and science in Rocky Mountain National Park. In the first vignette, Therese Johnson and colleagues explore how a foundation of science allowed the park to move forward on an elk and vegetation management plan. Next, Kathy Tonnessen shows the strong link between science and management as it relates to air quality. The author highlights the efforts across park boundaries to build collaborations with industry and regulators to reduce nitrogen deposition in Rocky Mountain. Mark Fiege then surveys environmental history at Rocky Mountain and its connections to science. His work serves to remind us that history and science are integrally linked, and that it is necessary to explore the past to understand the present condition of the park. Finally, Ben Bobowski provides the conclusion and describes opportunities for the future of science in Rocky Mountain.

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# The role of science through a century of elk and habitat management at Rocky Mountain National Park

By Therese L. Johnson, Linda C. Zeigenfuss, N. Thompson Hobbs, and John A. Mack

**O**VER THE PAST CENTURY ELK (*Cervus elaphus*) management in Rocky Mountain National Park has evolved along with NPS policy, social values, and an improved understanding of the role of elk in the ecosystem. Science has played an important part in shaping management approaches through the application of monitoring and research (Monello et al. 2006).

Early settlers indicated that elk were once abundant in the Estes Valley, but by the 1880s they were locally extirpated by market hunting. Elk were translocated from Yellowstone National Park by the Estes Park Protective and Improvement Association and the U.S. Forest Service to reestablish a population in 1913–1914, prior to park establishment. The elk population grew quickly in the absence of hunting by humans and predation by both gray wolves (*Canis lupus*) and grizzly bears (*Ursus arctos horribilis*), significant predators that had been extirpated. Studies conducted in the 1930s and 1940s found shrubs and aspen on the elk winter range were heavily browsed. Range conditions were deteriorating, motivating the park to reduce the population through direct control by shooting or relocating elk from 1944 to 1968. After 1968, as social values changed and support for control programs declined, direct control was replaced by “natural regulation,” a hands-off approach that allowed elk numbers to increase to ecological carrying capacity (Wright 1992; Monello et al. 2006). The park and its partners recognized, however, that hunting outside the park was necessary to help fulfill the role of extirpated predators.

Monitoring through the 1980s documented an increase in the elk population, but suggested that the use of key range areas had stabilized; thus there was no need for direct control at that time (Stevens 1980).

By the early 1990s, elk had not been actively managed in the park in more than two decades. Conflicts between people and elk increased and habitat conditions declined, causing managers to question the appropriate population size and management approach. Scientists conducted more than 40 studies to better understand the elk population, its influence on other resources, and long-term ecosystem sustainability. This work included a

## Key words

elk, population modeling, resource management, restoration, vegetation monitoring

joint NPS–USGS research initiative that focused on collecting key data to provide a strong scientific basis for management planning (Singer and Zeigenfuss 2002). Research results suggested that a combination of extirpation of predators, land and water development, and past land uses contributed to (1) an overabundant, highly concentrated, and less migratory elk population; (2) declines in beaver (*Castor*



**Figure 1.** National Park Service and Colorado State University scientists collect biological samples and affix a radio-collar on an anesthetized elk in Rocky Mountain National Park in January 2008.

*canadensis*); (3) hydrologic changes; and (4) loss of aspen (*Populus tremuloides*) and willow (*Salix* spp.) habitats that supported high biodiversity. After population control ended, the winter elk population initially increased, gradually stabilized, and then fluctuated around an estimated carrying capacity of 1,000 (Lubow et al. 2002). Ecosystem modeling predicted that under natural conditions with wolves present the winter population would fluctuate between 200 and 800, allowing willow and aspen to persist (Coughenour 2002).

### Elk and vegetation management plan

The robust body of research allowed the park to lead an interagency team in developing an Elk and Vegetation Management Plan (USDOI 2007) from 2004 to 2007. Elk that use the park are part of a regional migratory population, making interagency cooperation essential. Ecosystem modeling was used to evaluate a range of management alternatives by predicting the habitat conditions and elk population size expected to result from each alternative if it were selected. Social science research found strong public support for taking action to reduce the population and restore vegetation, but no agreement on the approach (Stewart et al. 2004). The final plan called for using a combination of conservation tools, including temporarily fencing up to 600 acres (243 ha) of habitat, culling, and vegetation restoration methods to restore a natural range of variability in the elk population and vegetation conditions.

Implementation of the 20-year plan began in 2008, and science has continued to inform the park's adaptive management strategies. To begin restoration, temporary elk enclosure fences were constructed to protect approximately 228 acres (92 ha) of aspen and willow habitat from browsing. A total of 130 female elk were culled during winter in 2009–2011 to achieve and maintain a low-end population objective. Of these, 79 elk were used for research to develop a live test for chronic wasting



**Figure 2.** Rocky Mountain National Park staff measure willow plants on the elk winter range in Rocky Mountain National Park during summer 2013.

disease in elk and to test a fertility control agent for potential future use (fig. 1). The need to cull is evaluated annually based on several factors, including population data, predictive modeling that estimates expected population size, projected hunter harvest outside the park, and potential culling scenarios in the park, including no reduction. In the past four years culling has not been needed.

An interagency workshop was recently held to support adaptive management by summarizing current science and evaluating progress toward management objectives. Vegetation monitoring from 2008 to 2013 found that average willow height increased 29% and willow cover increased 20% across the winter range, with progress made primarily inside fences (fig. 2). Distribution of aspen stem sizes reflected a shift toward recruitment of younger trees, and sapling recruitment increased from 13% to 26% of sampled sites, again nearly all inside fences (Zeigenfuss and Johnson *in press*). Elk population monitoring found

that an elk range shift occurred in 2002–2012 with more elk wintering outside the park, and that since plan implementation began in 2008, elk winter range densities have decreased and migration off the winter range during summer has increased (unpublished data from Colorado Parks and Wildlife, the National Park Service, and the U.S. Geological Survey). A five-year declining trend in the park winter population continued during 2013–2014, with an estimated average of 185 elk using the park (Hobbs 2014).

Research and monitoring continue to provide a strong scientific basis for management decisions and interagency collaboration as the park enters the next phase of implementation. We used results from 2013–2014 research that evaluated experimental willow establishment using cuttings and seeding (Kaczynski and Cooper 2014) to guide broader-scale willow planting in 2015. Current collaborative work among the National Park Service, Colorado Parks and Wildlife, and Colo-

*The need to cull is evaluated annually based on several factors, including population data, predictive modeling that estimates expected population size, projected hunter harvest outside the park, and potential culling scenarios in the park, including no reduction. In the past four years culling has not been needed.*

Colorado State University is investigating many dimensions of elk management, including (1) potential population-level effects of chronic wasting disease, (2) adult female survival rates and mortality sources, (3) landscape-scale elk movements, (4) substantial changes in regional elk distribution, (5) frequency of cross-boundary movements, and (6) further development of population survey methods. Ultimately, maintaining the critical link between science and adaptive management will play a key role in promoting long-term ecosystem health and sustainability.

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# High elevations under threat from nitrogen deposition: Air quality monitoring, research, and management at Rocky Mountain National Park

By Kathy Tonnessen

## Key words

cooperation, critical loads, nitrogen deposition, nitrogen deposition reduction plan, Rocky Mountain National Park

## ROCKY MOUNTAIN NATIONAL PARK

was created 100 years ago “to preserve the high-elevation ecosystems and wilderness character of the southern Rocky Mountains” for the benefit and enjoyment of present and future generations (NPS 2013). It is home to protected alpine, subalpine, and montane ecosystems, but research has revealed that these ecosystems are sensitive to various forms of human disturbance, particularly the deposition of air pollutants. This form of pollution includes rain, snow, particles, and gases containing nitrogen (especially ammonium and nitrate) that cause acidification and nutrient enrichment of streams, lakes, vegetation, and soils. Nitrogen air pollution also contributes to haze in the park, which reduces visibility and obscures scenic views. Additionally, nitrogen oxides are components of ozone, a secondary pollutant that can affect human health and natural ecosystems. However, the focus of this discussion is nitrogen deposition in rain and snow and how it affects park ecosystems. This is a story of how state and federal agencies, and university researchers have partnered to collect air quality information and craft a policy approach to help protect the park’s air quality and high-elevation ecosystems from the threat caused by nitrogen deposition.



**Figure 1.** The wet deposition monitoring collectors at Loch Vale watershed are part of the National Atmospheric Deposition Program and the National Trends Network.

## History of air pollution research and regulation in Rocky Mountain

In 1977, National Park Service managers were given an affirmative responsibility to protect air quality–related values in “Class 1” parks under the Clean Air Act amendments of 1977 (Public Law 95-95, 91 Statute 685). Once the park and its partners began to collect air quality information, park managers grew increasingly concerned about regional air pollution and specifically the effects of nitrogen deposition on high-elevation ecosystems. A national 10-year assessment (1980–1990) of the effects of nitrogen deposition on aquatic ecosystems by the National

Acid Precipitation Assessment Program provided the backdrop for this concern (NAPAP 1990).

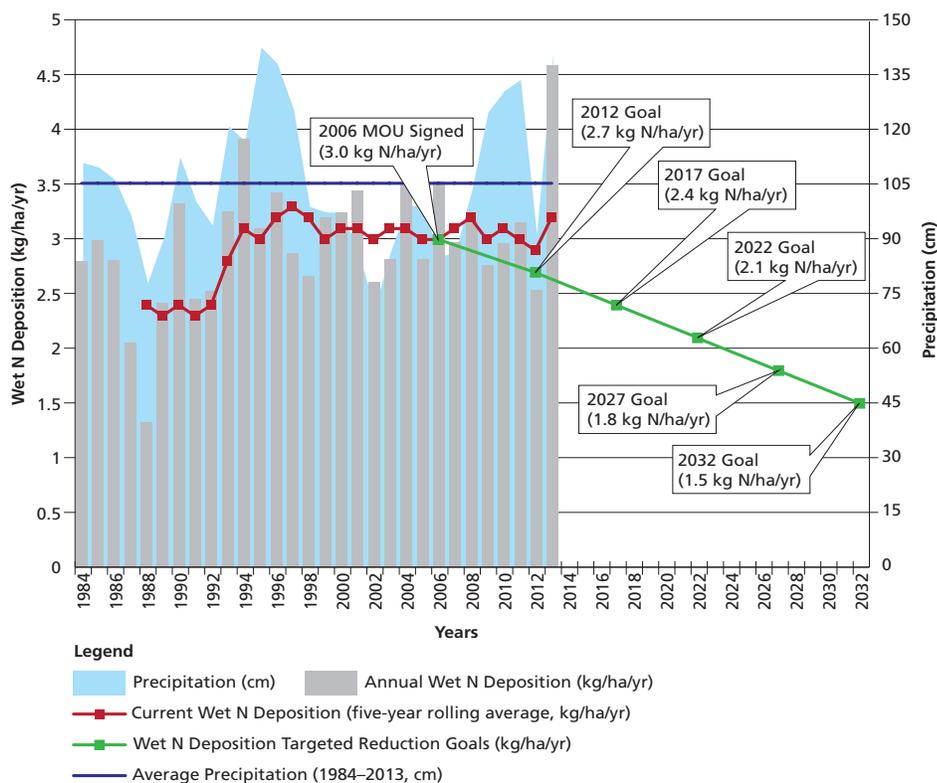
The National Park Service developed a research site in the park in 1982 to determine the effects of nitrogen deposition on a representative, high-elevation watershed ecosystem in the Colorado Front Range. Loch Vale watershed, which is located on the east side of the park in the alpine-subalpine backcountry at an elevation of 10,364 feet (3,159 meters), was equipped with research instruments more than 30 years ago (Baron 1992). Researchers have come to this watershed to monitor atmospheric nitrogen deposition

in addition to climate, snowpack, stream-flow, water chemistry, aquatic biota, soil chemistry, soil hydrology, and glaciers, with an emphasis on how atmospheric nitrogen deposition is affecting ecosystem processes at a watershed scale. Shortly after the watershed study began, the National Park Service installed a National Atmospheric Deposition Program/National Trends Network wet deposition monitoring site at Loch Vale watershed, Rocky Mountain National Park, to complement this ecosystem-level research (National Atmospheric Deposition Program 2014; fig. 1, previous page).

Once every week the National Park Service and its cooperators collect rain and snow samples at this site for chemical analysis.

The park and its partners are committed to maintaining this long-term monitoring of wet deposition and have invested in the data collection for more than 32 years. The Loch Vale watershed study has evolved through time to include the current cooperative work among the U.S. Geological Survey, the National Park Service, and Colorado State University.

The persistence of the park and its research partners in collecting decades of data at Loch Vale has been key to understanding air quality effects in the park, and has allowed Rocky Mountain National Park to work with regulatory agencies to implement a long-term strategy to further define and then reduce atmospheric nitrogen deposition. Atmospheric transport research finds that emissions come from fossil fuel burning, auto emissions, crop production, and livestock production (Thompson et al. 2015; Benedict et al. 2013). Data collected in the park show that soils, water, vegetation, and diatom communities have been altered by increased nitrogen availability over the last 65 years (Baron 2006). The concept of “critical loads” of pollution, below which significant ecosystem effects do not occur, has been applied to data collected at Rocky Mountain National Park (Baron 2006). The estimated critical load for wet nitrogen deposition for alpine lakes in the Loch Vale watershed is 1.5 kilograms/hectare/year



**Figure 2.** Wet nitrogen deposition and precipitation at Loch Vale in Rocky Mountain National Park are compared with the Nitrogen Reduction Plan targeted reduction goals (Morris et al. 2015).

(kg/ha/yr) or 1.3 lb/ac/year. With these critical load estimates in hand, the Colorado Department of Public Health and Environment, the National Park Service, and the U.S. Environmental Protection Agency signed a memorandum of understanding (MOU) in 2006 and then developed the Rocky Mountain National Park Nitrogen Deposition Reduction Plan in 2007 (Colorado Department of Public Health and Environment et al. 2007). This partnership established a long-term goal for nitrogen wet deposition at Loch Vale of 1.5 kg/ha/yr (1.3 lb/ac/yr) by 2032, with proposed five-year milestones of nitrogen deposition reduction along a gradually declining linear path (fig. 2).

The Nitrogen Deposition Reduction Plan suggests that future nitrogen emission reductions will result from other control measures already in process (e.g., regional haze regulations). The 2007 plan suggests voluntary strategies to reduce nitrogen emissions,

including possible measures to curb automobile emissions, reduce factory emissions, and implement agricultural best practices. A Nitrogen Deposition Contingency Plan was developed in 2010 to describe how the agencies should respond if the interim milestones are not achieved (Colorado Department of Public Health and Environment et al. 2010). This contingency plan calls for the following: (1) tracking of wet deposition of nitrogen compounds in Rocky Mountain National Park, (2) description of the process for triggering the development of contingency measures, (3) development of a list of potential contingency measures, and (4) provision for public outreach. It is important to note the language added to the MOU regarding imposition of additional nitrogen emission controls:

Nothing contained in this plan requires any entity, other than the above-mentioned agencies, to take any actions, or

requires any entity to make enforceable emission reductions but does contemplate that the Colorado Air Quality Control Commission Subcommittee may be presented with future proposals to adopt enforceable requirements to reduce nitrogen deposition in the Park.

—Colorado Department of Public Health and Environment et al. 2007

The first nitrogen deposition milestone, set for 2012, was a five-year rolling average of 2.7 kg/ha/yr (2.4 lb/ac/yr) (Morris et al. 2015). The five-year average of 2.9 kg/ha/yr (2.6 lb/ac/yr) for 2008–2012, however, did not meet the goal. The 2013 monitoring and tracking report for wet nitrogen deposition at Rocky Mountain National Park notes an even higher five-year rolling average from 2009 to 2013 of 3.2 kg/ha/yr (2.9 lb/ac/yr), though this measurement was likely biased by large precipitation events in April and September 2013 (Morris et al. 2015). The partners agreed that current strategies need to have sufficient time to show effectiveness by the next milestone in 2017.

To aid in reducing ammonia emissions from farms and feedlots along the Front Range, the Colorado Department of Public Health and Environment, the National Park Service, Colorado State University, Texas A&M University, the Natural Resources Conservation Service, and the Colorado Livestock Association have designed a Web site that introduces the pilot project called the Rocky Mountain National Park Early Warning System (<http://www.rmwarningsystem.com/EarlyWarnings.aspx>). This Web site provides real-time information on weather conditions that would allow for the transport of agricultural emissions of ammonia from eastern Colorado upslope to Rocky Mountain National Park. This Web site recommends short-term management strategies to reduce ammonia emissions from animal and crop production. Use of online tools is voluntary at this time and should assist agricultural producers in reducing air emissions that result in increased nitrogen

deposition in the park. Agricultural producers can use best management practices to reduce ammonia emissions from feedlots and dairy farms, and during fertilizer applications. However, Colorado regulators are limited by state law in requiring emission controls on agriculture (Porter and Johnson 2007). Another resource available to the agriculture industry is the Rocky Mountain National Park Agricultural Subcommittee, which was formed in 2006 to collaborate with the three agency partners and to provide recommendations for ammonia reduction strategies.

This air quality program at Rocky Mountain National Park represents a long-term commitment to protect the park's ecosystems by using research, monitoring, and modelling to influence resource management in cooperation with agency partners and industry. This case study can be used as a model for other parks of how to link science to effective resource management through partnerships.

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# Nature, history, and environmental history at Rocky Mountain National Park

By Mark Fiege

## HISTORIANS AND SCIENTISTS ENJOY

surprises—that part of the story that is unexpected and unpredictable. Surprises are reminders that life is uncertain and that inquiry is a process of questioning conventional assumptions. So here is a surprise: Rocky Mountain National Park, that alpine gem in Colorado, is a historical park. It is true that Rocky Mountain is not the same kind of park as Gettysburg National Military Park or Little Bighorn Battlefield National Monument. It is true that the park’s enabling legislation of 1915 calls for “the preservation of the natural conditions and the scenic beauties thereof” (Rocky Mountain National Park Act, 38 Statute 798). It also is true that Rocky Mountain visitors come to experience bugling elk, waterfalls, wildflowers along Trail Ridge Road, Longs Peak, aspen in fall colors, and much more. And yet, none of these wonderful truths about a magnificent park negates another irreducible reality that is no less wondrous: Rocky Mountain National Park is a historical park.

For scientists, the park’s history is an open secret. Much research on the park addresses site-specific issues such as the number of elk, the decline of willows, the absence of beavers, the chemical condition of water flowing from a lake, or the deposition of sediment in a valley. Accordingly, researchers necessarily ask historical questions: What happened here? What caused this? What conditions prevailed in the past? Scientists, furthermore, explicitly recognize their work as historical. David Cooper, whose consultations with park staff on wetlands and alpine flora go back decades (e.g., Kaczynski and Cooper 2014), insists that historical questions should be among the first that a researcher asks. Jill Baron, who has collected more than 30 years of data on nitrogen deposition at Loch Vale (e.g.,

Baron 2006), likes to quote William Cronon that ecology is a historical science. This focus on floral, faunal, and geological history merges with ancient human history in the discipline of archaeology. Bob Brunswig has surveyed hundreds of archaeological sites dating back to when the Pleistocene glaciers and ice fields began their retreat (Brunswig 2007).

For their part, environmental historians who work in Rocky Mountain National Park are better equipped than ever to recognize the history, human and nonhuman, in the park’s nature. Much as ecology has become more historical, scholarly history has become more ecological (Fiege 2011). Like ecologists, environmental historians understand change in terms of numerous variables interacting over time, albeit with more emphasis on the human role. How did human history shape forests, streams, and wildlife? How did people’s experience of the landscape shape their history? Like ecologists, environmental historians also seek to understand change through multiple spatial and temporal scales. The concept of “the long now,” for example, connects past, present, and future in a single analytical frame (Robin et al. 2013).

An environmental historian working in the park soon discovers affinities with scientists. A conversation with David Cooper about tree trunks and animal bones at the bottom of a subalpine bog evokes shared feelings of wonder that such traces of a lost world could survive into the present. As the biogeographer Jason

## Key words

environmental history, interdisciplinary research, “the long now,” resource management, Rocky Mountain National Park

Sibold holds forth on wildfire history as revealed in burn scars on trees (e.g., Sibold et al. 2006), he poses questions about the potential of archival documents to yield additional insight into the subject. During a discussion of alpine lake sediments, Jill Baron emphatically affirms the historian’s observation that in geological time, the birth of the lake some 14,000 years ago just happened. Sometimes the affinities come to light on backcountry trips. Snowshoeing through the silence and shadows of an 800-year-old grove of subalpine fir, the historian remarks that the trees are medieval. “Yes!” Baron replies, and she reveals that she once considered majoring in medieval studies.

A range of recent projects addresses Rocky Mountain National Park’s historical nature and suggests the potential of environmental history to augment the work of scientists in support of management. A study of climbing on Longs Peak explains changes in mountaineering in relationship to shifting environmental conditions, thereby providing knowledge essential to the management of crowds in a designated wilderness area (fig. 1; Alexander and Moore 2010). Histories of invasive exotic plants document their spread and

*Like ecologists, environmental historians understand change in terms of numerous variables interacting over time, albeit with more emphasis on the human role.*



**Figure 1.** Climbers ascend the historical north face cable route of Longs Peak around 1960.



**Figure 2.** Participants in the “Parks as Portals to Learning” workshop in 2014 hold a site-based discussion on the environmental history of Moraine Park.

the results of efforts to control them, thus informing the decisions of park staff responsible for protecting native species (e.g., Blankers 2014). The Parks as Portals to Learning partnership unites park staff with Colorado State University faculty and students in a workshop that will interpret the historical human presence, including elk and vegetation management, in Moraine Park (fig. 2). Soon to be offered in book form, the lecture “Elegant Conservation” shares a concept of resource stewardship grounded in environmental history methodology (Fiege 2015). In February 2010, park staff, scientists, and historians traveled on snowshoes through the Kawuneeche Valley, located on the west side of the park. The outing was unusual not only because of its inclusion of historians, but also because the purpose of the trip was to see evidence of ecological disturbance and to discuss how history might help the park manage and interpret the valley. The eventual product of that outing was a detailed study of the valley’s environmental history (Andrews 2015).

To recognize Rocky Mountain National Park as a historical park is to imagine a better future for it and other parks. At Rocky Mountain, environmental historians can continue to offer knowledge and skills useful to management and interpretation (e.g., Higgs et al. 2014). They can assist scientists in the formulation of research questions.

They can provide documentary evidence to help answer those questions and to convey scientific findings. They can narrate the great story of how the park landscape and all that it contains came into being and changed over time. And as skilled writers and communicators, they can offer stories about scientists and science to the public.

Most importantly, acknowledging that all national parks are historical can help the National Park Service realize the potential of two visionary documents, *Imperiled Promise* (Whisnant et al. 2011) and *Revisiting Leopold* (National Park System Advisory Board Science Committee 2012). Both assert that the agency’s traditional distinction between nature and culture, and natural and cultural resources, has outlived its usefulness. Among other problems, this simplistic division leads natural resource managers to think about history primarily in terms of the conflict-oriented compliance required by cultural resource law. Because of its commonalities with ecology and other natural sciences, however, environmental history is positioned to bring history into parks in a manner that bridges the classic “two cultures” divide.

Looking ahead to Rocky Mountain National Park’s second century and the 2016 celebration of the National Park Service centennial, an alternative future is within reach. In that time to come, visitors will

experience Rocky Mountain’s natural wonders, but they also will have the opportunity to discover how park resources got there in the first place, and how people perceived and managed those marvelous things. Thus equipped, visitors will be able to look forward and imagine the conditions under which the park still might inspire wonder—or not—in the years ahead.

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PS

## Inspiring the future: The next 100 years of research and learning at Rocky Mountain National Park

By Ben Bobowski

#### Key words

adaptive management, biosphere, citizen science, environmental history, science literacy

**AFTER A CENTURY OF RESEARCH** and resource stewardship in Rocky Mountain National Park, we have learned from our successes and mistakes. We know better than ever that the way forward is through persistent investment in science and people to build understanding and coalitions of support for difficult decisions that lie ahead of us. We have learned that science literacy among park staff, citizen scientists, visitors, and communities cannot be taken for granted. We appreciate better that concepts of adaptive management and organizational learning can be difficult to understand and implement. The sooner we embrace these concepts as integral to our management, however, the more successful we can be. We have learned that inclusiveness and integrating the public—from youth to retirees—into our work make us a more resilient organization. We know that to conserve species and

systems in the park we must work with others beyond park borders to include landscapes and continents far from our daily experience. To understand a way forward with clarity we will benefit significantly by discovering the history of how we arrived at where we are today.

The area we know as Rocky Mountain National Park has been used by people for more than 10,000 years as a place of *re-creation*. It became a park because the people thought it was worth protecting. As we look toward the future we will be most successful if we embrace the idea that the biosphere is forever intertwined with the ethnosphere. As ambassadors of science and stewardship, we have endless opportunities to inform the values that drive the protection of Rocky Mountain and to make a difference.

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PS

# Field Moment

Gulf Island National Seashore  
19 October 2014, 1:12 a.m.

## Turtle T.H.i.S.

A team of youth volunteers with Teens Helping in the Seashore, or “Turtle T.H.i.S.,” uses a photometer to measure ambient nighttime light levels near sea turtle nests at Gulf Islands National Seashore, Florida. The green laser beam helps the researchers target specific points for analysis. The red lights illuminating the work area are less disturbing to sea turtles and also preserve the team’s night vision because of their relatively short wave length.

This program, which was formed in 2014 through a partnership with the National Park Foundation, the U.S. Geological Survey, and the NPS Natural Sounds and Night Skies Division, is part of a multifaceted sea turtle conservation effort along 160 miles (257 km) of undeveloped beaches that grace Gulf Islands. Four species of federally protected sea turtles nest at the park, including the loggerhead sea turtle (*Caretta caretta*), the green sea turtle (*Chelonia my*

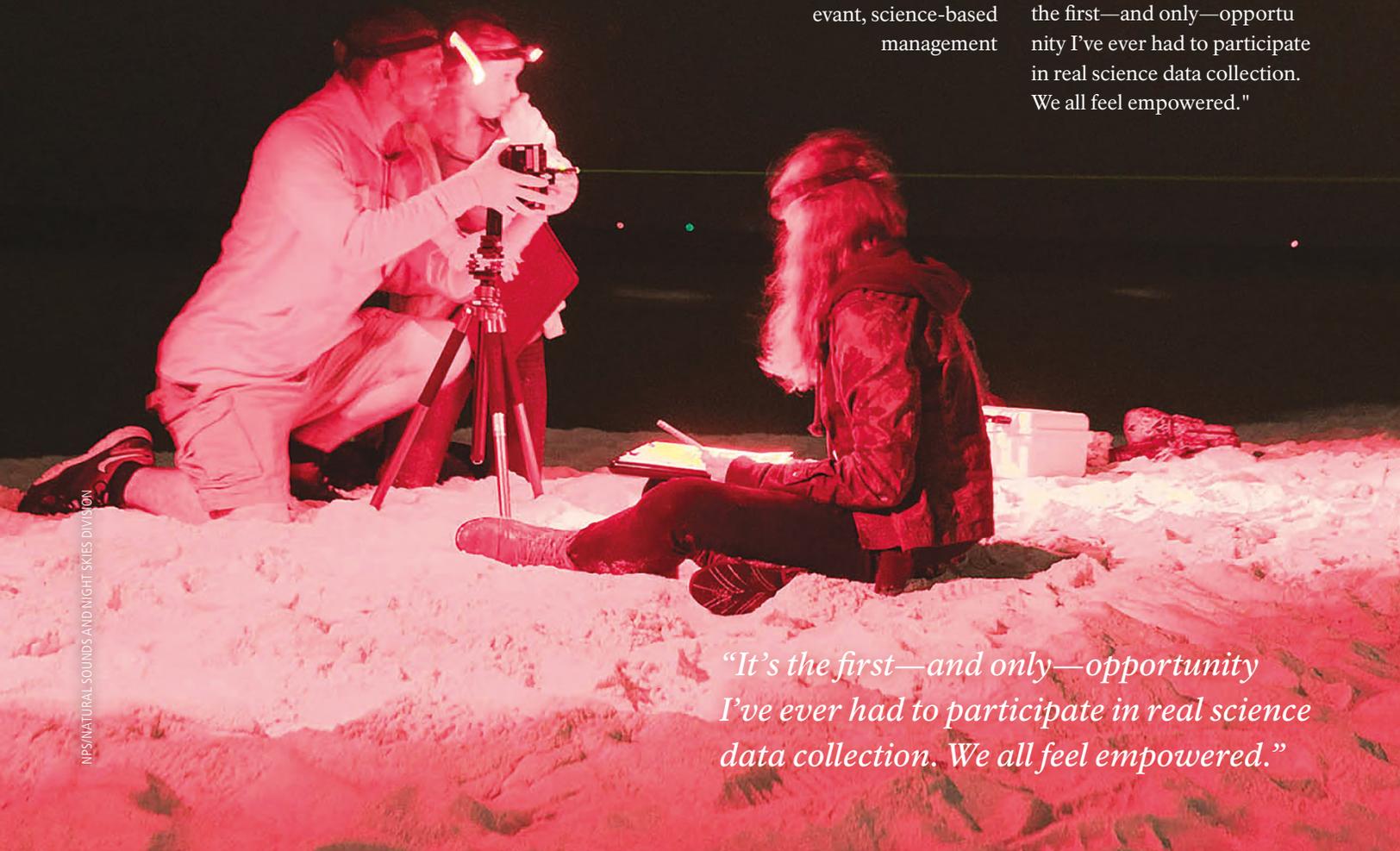
*das*), the leatherback sea turtle (*Dermochelys coriacea*), and the Kemp’s Ridley sea turtle (*Lepidochelys kempii*).

The goals of the project are to (1) document night sky brightness, which is one of the primary factors having a direct impact on sea turtle nesting, hatchling disorientation, and hatchling survival; (2) have students learn about the ecology of nesting and hatching sea turtles; and (3) provide NPS managers and community leaders with data to make relevant, science-based management

decisions for the conservation of nesting sea turtles.

The project engages approximately 200 youth from local schools and colleges—including these students from Escambia High School in Pensacola, Florida—to help with data collection, management, analysis, and outreach. This photograph captures in an instant just how deeply the Turtle T.H.i.S. project engages the volunteers. Another student intern (not shown) reflected on the program, saying, “It’s the first—and only—opportunity I’ve ever had to participate in real science data collection. We all feel empowered.”

*“It’s the first—and only—opportunity I’ve ever had to participate in real science data collection. We all feel empowered.”*





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