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PARK Science

Integrating Research and Resource Management in the National Parks

National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science
Office of Education and Outreach

WILDFLOWER PHENOLOGY MONITORING

Research compares three modes of data collection for wildflower timing at Mount Rainier National Park: Traditional science, citizen science, and crowdsourcing

Also in this issue

- Coral spawning at Dry Tortugas
- Grand Canyon's busy corridor trail system and recreation management
- Disinfection techniques to contain white-nose syndrome
- Overcoming barriers to park and protected area careers
- STARFire: Integrating wildfire planning, budgeting, and operations
- Assessing trail drainage features

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From the Editor

Economy, efficiency, applicability

MANAGERS NEED RESEARCH APPLICATIONS THAT LEAD TO SUSTAINABLE and efficient solutions to resource management challenges in parks. This issue features a number of articles that test and present techniques with potential for widespread use.

We start with a look at phenology, a basic yet important means of monitoring the timing of events in the lives of plants and animals. This tool aids in understanding seasonal and climatic cues in nature and the related effects on park visitors and management. Our cover article from Mount Rainier offers a valuable scientific comparison of different methods for gathering data of this type, with findings that apply to efficiency, accuracy, cost, and choice.

Other timely articles describe the development of strategic tools that are useful for improving and sustaining certain park operations. For example, researchers present test results of a relatively simple field process for managers' use in assessing how well water bars and similar features divert runoff from trails. Also of note is STARFire, a scalable planning system that combines resource economics and fire science for the allocation of resources according to priority, risk, fuel treatment optimization, and overall program preparedness goals. Both tools could be employed potentially at hundreds of parks.

Reports of the further spread of white-nose syndrome in bats first to Washington State, then to Minnesota and Texas, were a disconcerting development during the preparation of this issue. This news emphasizes the importance of proper clothing and equipment disinfection for underground research and management activities. The article and procedural checklists presented on pages 50–62 describe techniques that will help prevent transmission of the nonnative fungus that causes this deadly disease in bats.

Timing is often a key element in securing employment, but it is not the only one. In the research report on pages 27–33, social scientists share students' perspectives on their prospects for working in park and protected area fields and those of professionals striving to advance their conservation-related careers. This article presents a few strategies that may be helpful to job seekers and hiring officials alike.

Finally, we feature a four-article section on the management of day use of the busy Grand Canyon corridor trails. The social sciences, including history, provide some of the tools necessary for understanding use types and levels, and possible solutions. Additionally, weather monitoring, strategic communications, and effective program design improve safety for visitors and park staff. These integrated programs provide critical information to managers considering their options for backcountry management plan revisions.

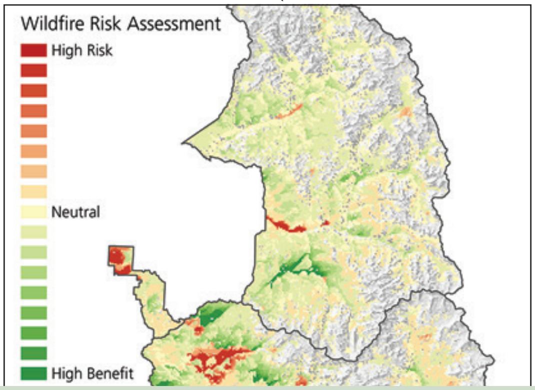
As always, this issue reflects the work of a huge family of researchers, resource managers, technicians, sponsors, partners, communicators, and other support staff. It tells a collective story of diversity in science applications with ever-evolving techniques for improving stewardship.

—Jeff Selleck, Editor

Contents

GLACIER NATIONAL PARK/COURTNEY RAUKAR

NPS/SEQUOIA–KINGS CANYON NATIONAL PARK



KAITLIN BURROUGHS, 2015

DEPARTMENTS

From the Editor 2
Economy, efficiency, applicability

FEATURES

Glacier's bat inventory and monitoring program: Using partners, collaborators, and volunteers to make it a success 5
Park biologists race the clock to learn as much as they can about bats before risks from white-nose syndrome and wind energy development alter bat populations and movements in and around Glacier National Park.
By Lisa Bate

Sex on the reef: Observations of coral spawning in Dry Tortugas National Park 13
A collaborative state and federal dive team observes the annual reproductive spawning event of protected corals in Florida's most remote park.
By Karen L. Neely and Tracy A. Ziegler

CASE STUDY

Monitoring wildflower phenology using traditional science, citizen science, and crowdsourcing approaches 17
Scientists and outreach coordinators from the University of Washington and the National Park Service compare several approaches to monitoring wildflower phenology at Mount Rainier National Park.
By Anna Wilson, Kevin Bacher, Ian Breckheimer, Jessica Lundquist, Regina Rochefort, Elli Theobald, Lou Whiteaker, and Janneke HilleRisLambers

RESEARCH REPORTS

Student and professional perspectives on park and protected area careers 27
The research study investigates student and professional perspectives on park and protected area careers, including five factors for success, five constraints, and two categories of opportunities for professional organizations to connect students with employers.
By Matthew H. E. M. Browning, Jennifer M. Thomsen, and Wonjun Choi

How professional organizations were critical to my career 32
By Matthew H. E. M. Browning

STARFire: Strategic budgeting and planning for wildland fire management 34
The system addresses key policy concerns by integrating risk analysis, fuels treatment, preparedness, and program analysis using the performance metric of return on investment in a scalable application.
By Douglas B. Rideout, Andrew G. Kirsch, Yu Wei, and Nicole J. Kernohan

Trail drainage features: Development and testing of an assessment tool 42
Researchers offer a reliable, empirically tested, field process for assessing trail drainage features and evaluating their effectiveness in making trails sustainable.
By Kaitlin Burroughs, Yu-Fai Leung, Roger L. Moore, and Gary B. Blank

ON THE COVER

A subalpine hillside radiates magenta from mountain Indian paintbrush *(Castilleja parviflora)* during peak wildflower season at Mount Rainier National Park, Washington. Phenological studies are increasingly important for understanding the effects of climate change on wildflower timing and its implications for wildlife, visitors, and park operations. The case study presented on pages 17–26 discusses trade-offs among three modes of gathering wildflower timing data.

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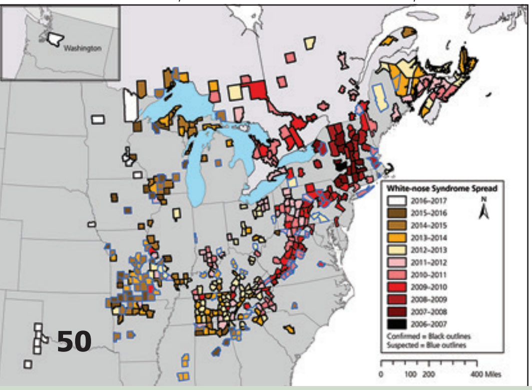

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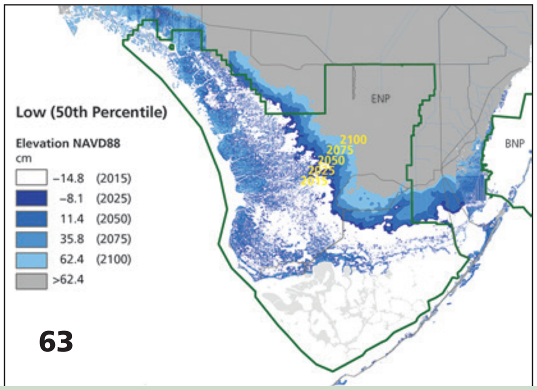

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UPCOMING ISSUES

Fall 2017
Seasonal issue. Includes timeline of NPS science and resource management milestones from 1916 to 2016. October release.
In production.

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- Access to back issues
- Manage your subscription
- Share comments with article authors
- Author guidelines
- Editorial style guide

STATE OF THE SCIENCE

White-nose syndrome decontamination procedures for backcountry subterranean projects **50**
With field protocols:
- Appendix I. Required equipment and explanations on use 57
- Appendix II. Fieldwork preparations 59
- Appendix III. Procedures prior to entering and after exiting a cave or mine 61
- Appendix IV. Procedures for full decontamination 62

A cave researcher summarizes the findings of developing, testing, and refining backcountry white-nose syndrome decontamination protocols.
By J. Judson Wynne

Sea level rise and inundation scenarios for national parks in South Florida **63**
A review of the science leads researchers to project sea level rise and inundation, trends in the frequency of nuisance flooding, recurrence intervals of storm surge, and impacts on infrastructure intended to provide useful information for managers and planners.
By Joseph Park, Erik Stabenau, and Kevin Kotun

IN FOCUS: MANAGEMENT OF GRAND CANYON'S POPULAR CORRIDOR TRAIL SYSTEM

Grand Canyon's corridor trail system: Linking the past, present, and future **74**
Grand Canyon National Park's corridor trail system tells the story of how human use and recreation have evolved amidst the park's vast backcountry.
By Elyssa Shalla

Understanding extended day use of corridor trails **84**
A social scientist discusses the impact of use levels on visitor experience along Grand Canyon National Park's most popular backcountry trails—those of the corridor—and summarizes visitor perceptions of various management interventions being considered to address them.
By Peter Pettengill

Canyoneering at Grand Canyon National Park:
Monitoring pockets of wilderness in the canyon corridor **91**
A backcountry ranger discusses the rise in popularity of canyoneering at the park and the management challenges resulting from this recreational activity.
By Matt Jenkins

Preventive Success!
Grand Canyon's response to search-and-rescue overload **99**
The rapid rise of search-and-rescue responses in Grand Canyon National Park leads to creation of the Preventive Search and Rescue team.
By C. J. Malcolm and Hannah Heinrich

Features

LITTLE BROWN BAT, COPYRIGHT KRISTI DUBOIS

Glacier's bat inventory and monitoring program

Using partners, collaborators, and volunteers to make it a success

By Lisa Bate

Abstract
Since its inception in 2010, biologists have continued to build and expand the bat inventory and monitoring program in Glacier National Park. We have now confirmed the presence of nine bat species in the park, adding three new species to the mammals list. Inventory work continues in hopes of confirming additional species. Year-round acoustic monitoring has confirmed the presence of bats overwintering in the park; research continues to determine whether or not bats use caves as hibernacula. Biologists use long-term acoustic monitoring to better understand bat migration paths and timing. Investigation into which buildings in the park support roosting bats has increased efficiency in environmental compliance reviews and will provide baseline data prior to arrival of white-nose syndrome.

Key words
bats, caves, collaborators, inventory, migration, monitor, partners, roost sites, species lists, volunteers, white-nose syndrome

THE DEVASTATING SPREAD OF WHITE-nose syndrome (WNS) in the eastern United States—and more recently infecting a new bat species (*Myotis yumanensis*) in Washington State (May 2016)—has given a new urgency to bat conservation in the West. As the disease continues to spread, the national parks in its path have stepped up their efforts to learn about and protect native bat populations. It is predicted that WNS will appear in Glacier National Park (Glacier) by 2026 (Rodhouse et al. 2016). Yet at Glacier (Montana), little was known about the park's bats until a combination of partners, collaborators, and volunteers came together in support of them.

In November 2010, Glacier wildlife biologists received a grant from the Glacier National Park Conservancy that allowed us to initiate a bat inventory and monitoring program at the park. So what did we do first? We headed to the caves! We knew we had caves in the park, but we did not know if their environments were conducive to supporting hibernating bats—or if bats even used them for hibernation. One problem: since Glacier's caves aren't generally a focus of management, none of our resources staff had ever been there. Fortunately, there's a local group that knows Glacier's caves well. The Bigfork High School Cave Club has mapped the interiors of Glacier's caves and knows them intimately. So with the help of five teenagers and their teacher in November 2010, we hiked, crawled, and climbed into three caves to install data loggers to record winter temperatures and humidity (fig. 1).

GLACIER NATIONAL PARK/LISA BATE (2)

Figure 1. Bigfork High School Cave Club member Brennen Shaw (right) inspects the data logger he helped deploy in one of Glacier's caves to record temperatures and humidity throughout the winter. (Above) Club members first guided the park biologist to caves in November 2010 to deploy data loggers. Pictured left to right are students Sandy Baker, Keegan Kelso, Eugene Germain, Matt Morgan, Brennen Shaw, and their teacher Hans Bodenhamer.

This partnership marked the true beginning of Glacier's bat inventory and monitoring program. Prior to this program, our knowledge about bats in Glacier was nearly nonexistent; no formal surveys had ever been conducted. We had visual records of only four bat species in our wildlife database, one of which was a single, road-killed individual. Of 11 potential species in Glacier, 6 were listed as Montana species of concern (SOC), or potential SOC (MNHP 2010).

We started with temperature and humidity recordings in the caves because we were so excited to start learning anything we could about bats in the park, but were months away from starting bat inventories using mist-netting and acoustic surveys. To accomplish the latter, we partnered with Waterton Lakes National Park in Canada (adjacent to Glacier and the other half of the Waterton-Glacier International Peace Park) to obtain the services of world-renowned bat biologist Cori Lausen. Cori, who has worked with bats for nearly two decades, is an expert in all aspects of bat ecology and survey techniques. We contracted to have her conduct two years' worth of summer mist-netting and acoustic surveys. Cori, however, was very clear that for the first year to be successful, she needed field assistants with at least some experience in bat surveys.

We didn't have that experience, so to prepare for Cori's arrival, we obtained in-kind matching funds from a number of agencies to provide park staff with training, consultation, and equipment. This project would not have been possible without this assistance from the Montana Natural Heritage Program; Montana Fish, Wildlife, and Parks; Bat Conservation International; and of course, the Bigfork High School Cave Club.

Finding the bats

Our main objective was to conduct a basic inventory of bat species in the park. Which species did we have? Which habitats did they occupy? Were they reproducing? What was the overall status of their health? We wanted this baseline information to better inform us of what the potential impact of white-nose syndrome might be, were it detected in Glacier, and to help us to make better decisions about bats in and around the park. Our second objective was to prepare our own staff to take over the bat inventories and initiate the monitoring phase of the program.

Glacier comprises more than 400,000 hectares (1 million acres), and we knew it would take time to conduct a thorough inventory of bats across the park. To sample a wide range of habitats, we adapted the Bat Grid protocol developed by biologists in the Pacific Northwest (Ormsbee 2007), which uses a grid cell of 10 km^2 (3.9 mi^2) as a sampling unit. Within each grid cell we used both visual and acoustic survey techniques to survey for bats. Mist-netting was our primary, visual technique; acoustic sampling was our secondary technique. Acoustic surveys allowed us to sample habitats not suitable for mist-netting, such as open, burned forests or meadows. It also allowed us to detect bats that typically forage higher aboveground than the nets can reach.

Surveying for bats is not like surveying for any other species: you can't hear them,

GLACIER NATIONAL PARK/COURTNEY RAUKAR

PARKS CANADA

Figure 2. (Left) Biologists Cori Lausen and Lisa Bate set up a triple-high bat net. (Right) Biologists Cori Lausen and Barb Johnston wear chest waders to deploy a water net in a pond where bats frequently forage.

GLACIER NATIONAL PARK/COURTNEY RAUKAR

GLACIER NATIONAL PARK/LISA BATE

Figure 3. A nearly invisible mist-net, set up across a trail, is shut and tied with flagging until bat emergence time to prevent "catching" late hikers or nontarget wildlife species. (Right) Monitoring crew used bat survey signs to alert visitors to nets deployed across trails or roads.

you can't see them. One of the first lessons was learning what the best conditions are for trapping. If a "trap night" coincides with a full moon, expect very few bats. If it is raining, cold, or windy, expect few bats. Bats choose to go into torpor rather than spend precious energy flying around on nights when insects aren't available. Bats use echolocation—they emit sound waves from their mouths, and use information from the sound waves that bounce back off flying insects—to locate and capture food at night. They also use echolocation to navigate in and around objects. Like humans, however, bats can see at night if there is enough ambient light. So, you have to plan strategically if you want to capture bats in mist-nets.

Cori showed us how to string nets at bends in trails and roads to surprise bats as they flew along these corridors. She would hide, or align, the poles with trees so they could not be seen. She showed us how to set nets over, or near, quiet water bodies (loud water noises interfere with bats' echolocation calls), and taught us how to tie three nets together to capture the high-flying bat species like the hoary. Wearing chest-high waders to access water nets was normal for trapping bats in Glacier (fig. 2).

As we set up each net in the daylight, we would tie them closed with flagging to prevent catching birds and to alert hikers on the trail. We also left signs alerting people to the presence of nets across the trails (fig. 3). Then just as it got dark, we ran around opening the nets all at once. This is called "emergence time" and was always the most hectic time, as the bats emerged from their daytime roosts to come out and feed. If there was a roost nearby, we could get slammed and catch 25–40 bats in a single net in just a few minutes. Things usually calmed down after the first hour and then we would begin the process of checking each net every 4–10 minutes. Any longer, and the bats could chew their way out. On a typical night, we would set up 7–10 nets about 0.8 km (0.5 mi) apart. The constant walking was a good thing, especially on slow nights; it kept us awake and warm.

Typically, we could not "hear" if a bat was caught in a net. Although little brown bats are notorious for their loud distress calls, most bats would hang quietly until we got there. When working with bats, you quickly learn that a high-quality flashlight is essential. It allows you quickly to determine whether or not a bat is in the net. It also allows you to move confidently at night in moose, mountain lion, and grizzly bear country. One night, while netting in a pond, we heard loud noises coming from multiple directions in the water. The flashlight revealed three huge (larger than our hands) western toads!

When we found a bat in a net we would remove it, place it into a clean cotton bag, and hold it in our jacket or nearby warm vehicle for one hour before processing. The one-hour wait was to give the bat time to defecate so as to obtain an accurate weight; bats can eat 50% of their weight in a foraging bout. For each captured bat we recorded: (1) bat number, (2) net number, (3) time and date of capture, (4) species (Ormsbee 2005), (5) sex, (6) reproductive status, (7) age, (8) tooth class (Christian 1956), (9) weight (g), (10) forearm length (mm), (11) presence or absence of a keel, which is a flap of skin on the tail by each foot (Ormsbee 2005), (12) whether or not a biopsy was taken, (13) whether or not an acoustic sample was taken, and (14) comments on overall health and condition. When finished, we would hold the bat up high until it flew off.

GLACIER NATIONAL PARK/CLAY MILLER GLACIER NATIONAL PARK/MICHAEL PROCTOR

Figure 4. Bat crew receives stock and boat support, respectively, from Glacier biologist John Waller and park ranger Brett Timm, who transport nets and processing gear to backcountry trap sites. Pictured from left to right are Graham Neale, Lisa Bate, Courtney Raukar, and Cori Lausen.

Our first year (2011) of surveys was intense; we trapped 19 of 21 consecutive nights. Cori, seemingly part bat herself, had no problem working all day—setting up mist-nets and detectors, opening and checking nets, removing and processing bats, closing nets, disinfecting everything, and then carrying all the gear back to the trucks for stowage. That first year, we saw a lot of sunrises because we would trap so late into the night. Thereafter, however, we adopted the protocol used by other Montana biologists, and were able to shut the nets down at 1 a.m. This proved to be far more sustainable, allowing us to be in our tents by about 3 a.m. With more sleep, we also found we were able to absorb much more of what Cori taught us.

We moved to a new location each night, trying to sample as many grid cells as possible. On the way to a new site and within the chosen grid cell, we would deploy two to three acoustic detectors to record bat calls for the night. In the first year, we only set up nets within 2 km (1.2 mi) of a road to maximize the number of trap nights. Beyond this distance we had to rely on horse, mule, and boat support because of the weight of the equipment and small size of our crew (three people) (fig. 4). In the second year, however, we began to trap at backcountry sites in hopes of increasing the diversity of bats caught.

Results

We have now confirmed the presence of nine bat species in Glacier National Park since we began surveys in 2011: the little brown, long-eared, long-legged, big brown, eastern red, silver-haired, and hoary bat, and California and Yuma myotis (fig. 5). Our detections of the eastern red bat, and the California and Yuma myotis, allowed us to add three new species to Glacier's mammals list. These detections also expanded the known range for each of these species. All of the species were confirmed through mist-netting except for eastern red bat. Just 4 km (2.5 mi) to the north, however, our acoustic documentation was corroborated with the capture of 13 eastern red bats in Waterton Lakes National Park (Lausen 2012).

Six of Glacier's nine bat species were found throughout the park. Two species—California and Yuma myotis—were only caught and detected west of the Continental Divide, which bisects the park. The eastern red bat was only detected east of the divide. The little brown bat was the most commonly found bat in the park (fig. 6). It is also considered the most common bat in Montana (Foresman 2012). The long-eared was the second most commonly found bat, followed by the hoary bat. The first time we saw and heard a hoary bat, we felt like biologists exploring in a remote country and discovering a new species unknown to the world. We had no idea that such a beautiful animal had been flying over our heads all our lives. None of us in Glacier had ever seen one. Their beautiful coats, large size, and unique

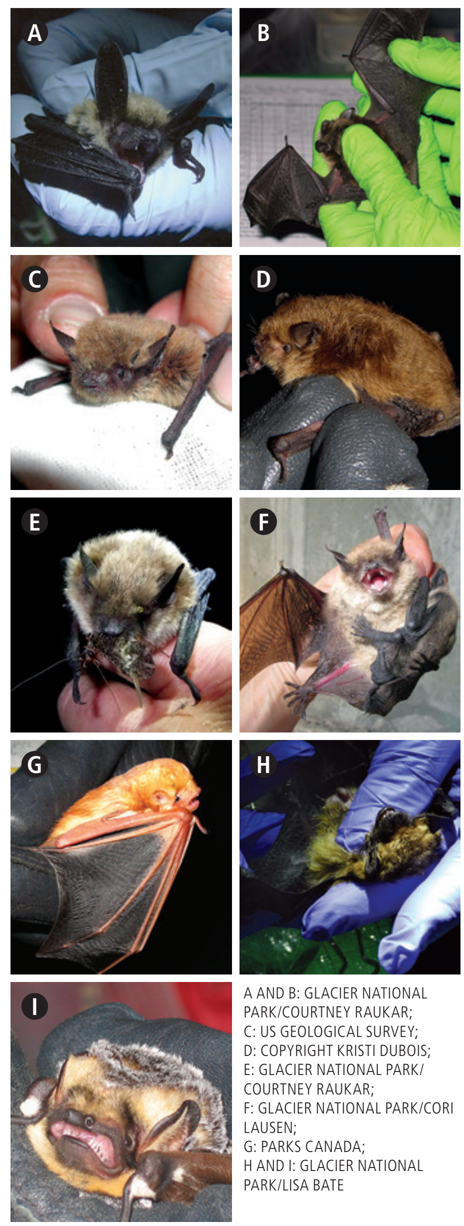

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Figure 5 (right). Nine bat species have been confirmed in Glacier since surveys began in 2011: (A) long-eared bat (*Myotis evotis*), (B) silver-haired bat (*Lasionycteris noctivagans*), (C) California myotis (*M. californicus*), (D) Yuma myotis (*M. yumanensis*), (E) little brown bat (*M. lucifugus*), (F) long-legged bat with pup (*M. volans*), (G) eastern red bat (*Lasiurus borealis*), (H) big brown bat (*Eptesicus fuscus*), and (I) hoary bat (*Lasiurus cinereus*).

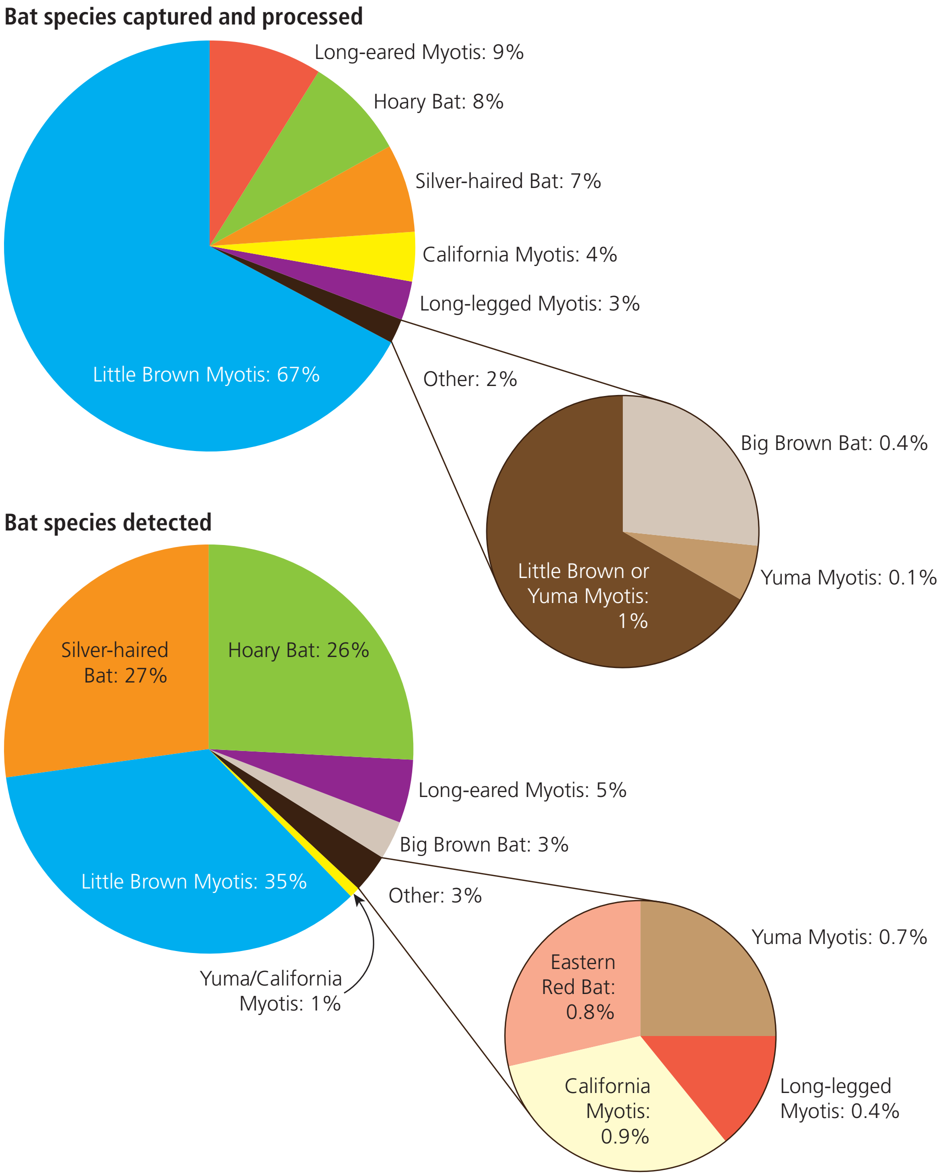

Figure 6. Percentage of bat species captured and processed (top) and detected (bottom) during acoustic surveys in Glacier National Park from 2011 to 2016 during warm-season months (May through September). Data reflect only those calls that could be identified to species.

GLACIER NATIONAL PARK/LISA BATE

Figure 7. Biologist Cori Lausen spreads the wing of the first hoary bat ever recorded in Glacier.

hissing and clicking sounds made every mosquito bite we had endured worth it, as this creature was new to us all (fig. 7)!

In 2013, as planned, all bat inventories were taken over by park staff and volunteers (ages 17 to 65). Since then, we have been able to trap six to eight nights per year, always pushing into new areas while returning to some sites for repeat sampling. Although most volunteers could not handle bats for safety reasons, they were instrumental in helping us set up nets, record data, and check nets for bats. One volunteer, a retired US Forest Service biologist, was the exception: his past experience with mist-netting and handling bats allowed us to set up double the usual number of nets in one evening, which typically resulted in our catching twice as many bats.

Over 61 trapping sessions from 2011 through 2016, we trapped and processed bats at 51 different locations throughout the park (fig. 8, next page). We processed a total of 1,064 individuals, catching about 15 bats per night. This included nights when we did not catch any bats (poor capture success seemed mainly to have been weather-related). None of the bats we processed showed signs of white-nose syndrome; in addition, soil samples from the caves tested negative for the fungus that causes the disease (Northup and Caimi 2014).

We recorded more than 70,000 bat passes (Glacier data files) during warm-season months (May–September) using acoustic detectors (fig. 8). Winter (October–March) acoustic monitoring efforts have detected bat activity at five different park sites, suggesting that bats do hibernate in Glacier. Poor recording quality prevented species identification, but we do know that the park has both low- (for example, big brown or silver-haired bat) and high-frequency (*Myotis* species) bats. We also now know that at least two of our caves have temperatures and humidity levels conducive to bat hibernation.

Changing technology

In April 2015, the northern long-eared myotis was listed federally as threatened under the Endangered Species Act because

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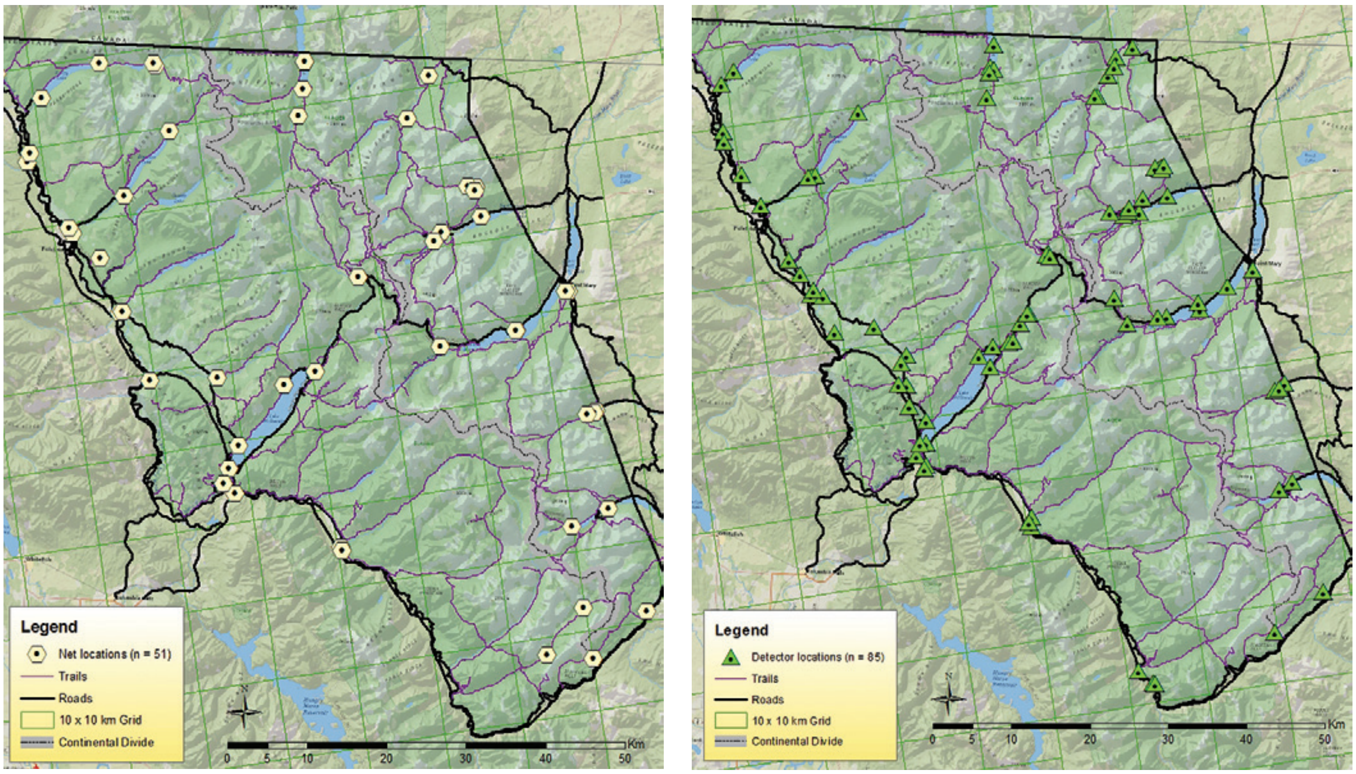

Figure 8. Locations of mist-netting (left) and acoustic detector (right) sites established throughout GNP during spring, summer, and fall months for bat inventory and monitoring project from 2011 through 2016 (Glacier National Park, Lisa Bate).

of risks from white-nose syndrome and wind turbines. Montana is included in the US Fish and Wildlife Service's range description for northern long-eared bats, but it is unknown if they reside, hibernate in, or migrate through Glacier National Park. We had already confirmed the presence of the eastern red bat, a species not expected in Glacier, and wondered if there could be other anomalies.

Documenting the exact range occupied by a threatened species is critical to its conservation. Species at the edge of their range may be more capable of adapting to climate change and other stressors like white-nose syndrome. To date, we have analyzed more than 70,000 bat call recordings from the park, but poor recording quality has limited the number of definitive classifications. Diagnostic echolocation calls for northern long-eared bats require the use of hardware that can record calls above 100 kHz. Two of the detectors we purchased in 2011 are not capable of recording above this threshold. However, with a grant received in 2016 from the NPS Natural Resource Stewardship and Science Directorate's Biological Resources Division, we have been able to replace these two obsolete detectors with high-quality ones and microphones to survey for this species. This new equipment is now providing higher-quality acoustic data on the presence, activity, migration, and hibernation patterns of all bat species in the park that are at risk from white-nose syndrome and wind turbines.

Bats in buildings

One important side benefit to this program has been increased efficiency in park operations relative to environmental law compliance activities. As our knowledge about bats in the park grew, so did the number of questions we received from park staff regarding bats. How do we get rid of bats in the attic? Can we re-roof this building in July? More than 900 buildings exist in Glacier National Park. Of the 733 owned by the park, nearly 400 are classified as historic. Most are in need of some repair, restoration, or remodeling, and have multiple entry points for bats. As a result, many of these buildings function as large "bat houses" (fig. 9).

The little brown bat is the most strongly associated with human structures in Glacier. It is also a species of concern because of its susceptibility to white-nose syndrome. Before any repair, restoration, or remodeling can begin, a compliance review has to ensure that native species

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A, B, AND BACKGROUND: GLACIER NATIONAL PARK/LISA BATE

Figure 9. Bats roost under siding of historic buildings (A), in bat boxes (B), in attics and barn lofts (C), and under bridges (not pictured) in Glacier. Boy Scouts construct the bat boxes as alternative roost locations. Park facility and integrated pest managers mount the boxes on park buildings that they then attempt to seal to prevent entry by bats.

will not be harmed or killed as a result of the work. Until 2015, staff limitations had allowed us to assess only 25 structures for bat use; of those, 16 (64%) were confirmed as roost sites, including maternity roosts. As the compliance list of proposed projects continued to grow, we realized we were not keeping up.

The solution? Forge another partnership. In 2015, a Jerry O'Neal National Park Service Student Stewardship Grant allowed us to hire a Montana State University student to help assess buildings for roosting bats over the course of the summer. The benefits were huge: by the end of summer, 579 buildings (park- and privately owned) had been inspected. Forty-three percent of the inspected buildings were found to contain at least one bat roost, with 451 total roost sites identified. Most roosts were in log cabins or in buildings with wood siding.

Having this information in hand has helped expedite the park's compliance review process. Now we can query the database to determine if the building had evidence of roosting bats and needs to be rechecked, or if there was no potential for roosting bats (e.g., no loose siding, tin roofs, or small openings), which allows us to move forward with a project. The Montana Natural Heritage Program has used these data as the foundation for their own database on bat roost sites in Montana, which will allow biologists to better assess potential impacts of white-nose syndrome, should it arrive here.

Bats in caves

After three years of winter monitoring, we had confirmed bats overwintering in Glacier National Park (via solar-powered acoustic detectors), but still had to determine if they hibernate in park caves. Additionally, we had collected bat guano for genetic testing to identify bat species, but had found no bats in caves during winter. Results from DNA tests have confirmed that little brown bats use at least one of Glacier's caves.

Poia Cave, Glacier's largest cave, is about 1.6 km (1 mi) long, with many hidden cracks and crevices. Visitors are allowed access with a permit. Although few people visit Glacier's caves, it would only take one person, wearing gear that had been contaminated in a cave where white-nose syndrome was present, to introduce the disease to the park. Knowing when bats were using Glacier's caves would tell us if they needed increased protection.

With additional funds provided by the Biological Resources Division, we purchased two data roost loggers. In September 2016—again with help from the Bigfork Cave Club and other volunteers—we deployed the data loggers in two park caves. This equipment is capable of monitoring for extended periods, eliminating the need to deploy solar collectors susceptible to avalanche loss and allowing us to avoid dangerous and difficult wintertime bat surveys. We expect these units to monitor for bats for up to six months. In the spring, we will return to the caves and replace the batteries. This will allow us to monitor year-round in the caves to gain a better understanding of when bats are using these natural structures.

Looking to the future we are eager to continue building upon Glacier's bat inventory and monitoring program with additional support from the Biological Resources Division. Our goals are to complete the "Bats in Buildings" project, expand inventories into additional grid cells, and continue with our long-term acoustic monitoring at select sites in Glacier. Volunteers are eager to help and are already committed. Where else do they get to trek up and over a mountain ridge, belly crawl into a cave to see a magical waterfall, see and hear the hissing and clicking sounds of a hoary bat, and encounter mountain goats, bighorn sheep, grizzly bears, and the rare Canada Lynx along the way!

Acknowledgments

This project has been made possible with generous grants from the Glacier National Park Conservancy and the NPS Natural Resource Stewardship and Science Directorate's Biological Resources Division. Additional funds were provided by the Jerry O'Neal National Park Service Student Fellowship Grant. Thanks to our collaborators: Bryce Maxell, with the Montana Natural Heritage Program, and Kristi DuBois, with Montana Fish, Wildlife, and Parks, for technical support, advice, and training. Jason Corbett, with Bat Conservation International, provided advice on cave surveys and mine closures. Thanks to conservation biologist Barb Johnston and retired biologist Cyndi Smith of Waterton Lakes National Park for collaboration and support. Special thanks to retired division chief of Science and Resources, Jack Potter, for recognizing the importance of this program. Thanks to Glacier staff John Waller, Dawn LaFleur, Courtney Raukar, Clay Miller, Susan Clothier, James Waddell, Jack Polzin, Jim Willis, Brett Timm, and Jason Griswold for their support and assistance with the program. Volunteers Gerard Byrd, Karen Chickering, Anne Zavadil, Hans Bodenhamer, and the Bigfork High School Cave Club assisted in placement of roost and data loggers in caves and collection of soil samples. Special thanks to retired biologist Lewis Young, whose continued volunteer support makes it possible to put up twice as many nets every year. Cheyenne Stirling inspected buildings for bat roost sites. And very special thanks to numerous other park staff, volunteers, and family without whose help this program would only partially exist.

References

Christian, J. 1956. The natural history of a summer aggregation of the big brown bat, *Eptesicus fuscus fuscus*. American Midland Naturalist 55(1):66–95.

Foresman, K. R. 2012. Mammals of Montana. Mountain Press, Missoula, Montana, USA.

Lausen, C. 2012. Waterton Lakes National Park bat survey. Unpublished Report. Birchdale Ecological, Ltd., Kaslo, British Columbia, Canada. Available from Waterton Lakes National Park, Waterton, Alberta, Canada.

MNHP (Montana Natural Heritage Program). 2010. Montana Field Guides: Bats. Accessed January 2010. http://fieldguide.mt.gov/displaySpecies.aspx?family=Vespertilionidae. Montana Natural Heritage Program, Helena, Montana, USA.

Northup, D., and N. Caimi. 2014. Service-wide investigation of *Geomyces destructans* (a.k.a. *Pseudogymnoascus destructans*) in National Park Service caves. Final Report. Prepared under the Rocky Mountains Cooperative Ecosystem Studies Unit, Task Agreement P12AC11090, Cooperative Agreement H2370-09-4001. Northern Arizona University, Flagstaff, Arizona, USA.

Ormsbee, P. 2005. Key to Idaho, Montana, and South Dakota bats. Unpublished document. US Forest Service, Willamette National Forest, Eugene, Oregon, USA. Available at ftp://nris.mt.gov/Maxell/Bat_Presentations_Materials/MT_Bat_Species_Morphological_Key_2015.pdf.

———. 2007. Bat grid draft protocol. Unpublished document. Appendix E *in* J. Kesling, C. Abel, and L. Schwabe, primary authors. 2008. Malheur River wildlife mitigation project (BPA project 200002700): 2008 annual report. Bonneville Power Administration, Portland, Oregon, USA. Available from https://digital.library.unt.edu/ark:/67531/metadc929401/.

Rodhouse, T. J., T. E. Philippi, W. B. Monahan, and K. T. Castle. 2016. A macroecological perspective on strategic bat conservation in the U.S. National Park Service. Ecosphere 7(11):e01576. doi:10.1002/ecs2.1576.

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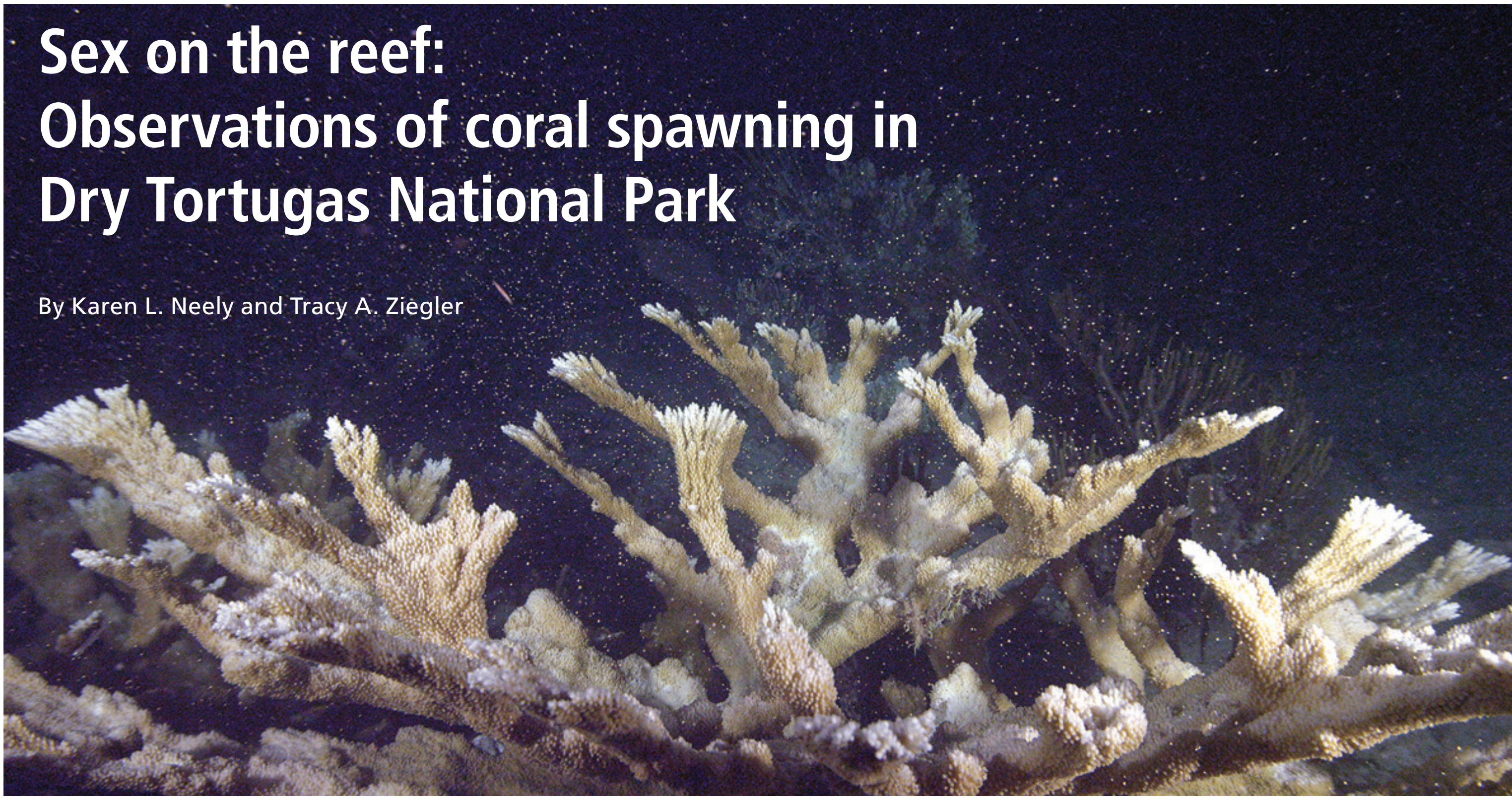
PS

Sex on the reef: Observations of coral spawning in Dry Tortugas National Park

By Karen L. Neely and Tracy A. Ziegler



NPS/BRETT SEYMOUR

A colony of elkhorn coral (*Acropora palmata*) releases thousands of egg-sperm bundles into the water column.

Abstract

In Florida's remote Dry Tortugas National Park, coral reefs are an important management priority. Reproduction of coral species is difficult to monitor, however, and the reproductive potential of coral colonies at the park has been a matter of concern for several years. Two threatened species, elkhorn coral (*Acropora palmata*) and pillar coral (*Dendrogyra cylindrus*), were targeted for observation during their predicted annual spawning event in August 2014. Over a three-night period, both species were observed releasing gametes in near synchrony with observations at other sites in the Florida Keys. That these organisms are capable of being reproductive within the park provides hope for the future of these threatened species in the region.

Key words

coral reefs, coral spawning, Dry Tortugas National Park, endangered species

MANAGEMENT OF CORAL REEFS IS A high priority for many national parks within tropical and subtropical areas; examples include Virgin Islands National Park, National Park of American Samoa, Biscayne National Park (Florida), Kaloko Honokōhau National Historical Park (Hawaii), and Dry Tortugas National Park (Florida). The coral reef ecosystems these parks protect are often small in area but hugely important for their biodiversity, ecosystem services, and aesthetic value (National Park Service 2010). Coral reefs, however, are in serious decline worldwide. Within the well-studied Caribbean, the coverage of hard corals on reef environments has declined from approximately 50% in the 1970s to approximately 10% today (Gardner et al. 2003). The causes are many and varied, but include storm damage, altered ecological interactions, poor water quality, elevated water temperatures, pollution, and sedimentation. These stressors in turn contribute to more proximal causes of death like increased algal competition, higher disease incidence, and heat-related coral bleaching (Pandolfi et al. 2005).

These decadal-scale declines are increasingly worrisome and increasingly well documented. Pockets of resilient reef communities and restoration projects provide beacons of hope for the interim survival of these systems, but what of longer-scale trends based on natural propagation of species? Reproduction of coral colonies frequently occurs asexually through broken fragments growing into new colonies, but for many coral species, sexual reproduction—and the resultant benefits of genetic recombination—is limited to a once-a-year opportunity (Szmant 1986).

Reproductive strategies

In the Caribbean, that once-a-year opportunity occurs during the warm-water months of August and September. Being stationary organisms, coral reproduction relies upon the release of gametes—sperm, eggs, or a combination of the two—into the water column. Some species (about 50% of Caribbean species and 15% worldwide) are "brooders," meaning that eggs are held within the coral polyps, and only sperm is released with the hope of drifting over an egg-bearing individual. In these brooders, fertilization is internal, and the coral release larvae that are ready to settle and grow into adults. Other coral species (about 50% of Caribbean species and 85% worldwide) are "broadcast spawners" (Baird et al. 2009). Within these species, both eggs and sperm are released and externally fertilized in the water column to form larvae that drift in search of places to settle. For these broadcast spawners to reproduce successfully, individual corals must synchronize gamete release with their neighbors. An individual that spawns even an hour later than those around it will have a near-zero chance of successful fertilization (Levitan et al. 2004). Each species depends on environmental cues to time gamete release, such as water temperature, lunar cycle, time of sunset, and chemical signals from surrounding individuals (Levitan et al. 2011). Though the exact mechanisms governing each individual's timing are not fully known, a successfully reproducing population can launch millions of gametes into the water column within minutes.

These gametes and the coral larvae they produce are the next generation of reef-building corals. They can recruit locally to repopulate the reefs from which they spawned and create new genetic combinations that may be resistant to present and future threats. They can also flow downstream to help repopulate more distant reefs and introduce new genotypes to other regions (Jones et al. 2009). Due to the location and oceanographic features of Florida's remote Dry Tortugas National Park, both processes are of the utmost importance to both local and regional populations.

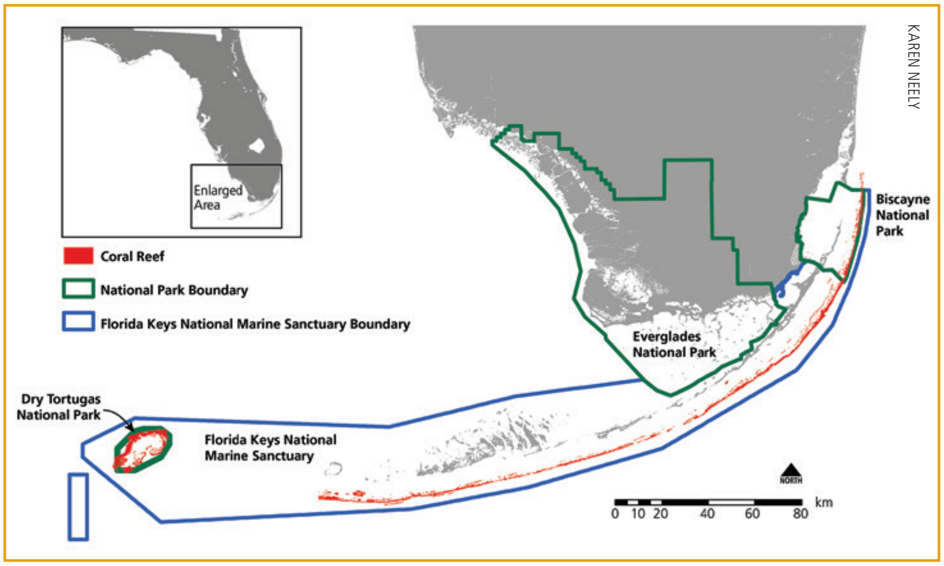


Figure 1. The coral reefs of Dry Tortugas National Park lie 60 km (37 mi) west of the main Florida Reef Tract. Numerous agencies manage the marine resources of the region.

Importance of Dry Tortugas coral populations

The Florida Reef Tract is the world's third largest barrier reef (following those in Australia and Belize) and the only coral reef in the continental United States (fig. 1). It stretches like a protective shield from the southern tip of Florida down the Florida Keys, terminating past Key West (Florida Fish and Wildlife Conservation Commission 2015). Tracing this trajectory across deeper waters for another 60 km (37 mi) leads to one more set of coral-rich islands: the Dry Tortugas. This region, which expanded in 1992 from a national monument protecting the 1840s–era Fort Jefferson into a national park that is 99% submerged, is host to a variety of marine life-forms, including numerous corals, sea turtles, and other species listed under the Endangered Species Act (ESA). The location of the Dry Tortugas makes reproduction of any marine species here important. The islands' remoteness means that populations rely heavily on local recruitment for the next generation. Their position at the upstream end of the Florida Current also makes them a potential source of gametes for the rest of the Florida Reef Tract (Domeier 2004).

Dry Tortugas reefs have been regularly monitored since 1999. The National Park Service South Florida/Caribbean Inventory and Monitoring Network (http://science.nature.nps.gov/im/units/sfcn) and the State of Florida's Coral Reef Evaluation and Monitoring Program (http://ocean.floridamarine.org/FKNMS_WQPP/pages/cremp.html) both document coral cover, species diversity, and coral health on an annual basis. Though far from many human influences, the remoteness of these waters does not make them immune to the decline of reef systems. Twenty-five percent of sites have shown significant coral decline since 1999 (Ruzicka et al. 2014). Of the nearly 40 species of coral documented within Dry Tortugas National Park, 7 are listed as threatened under the Endangered Species Act (http://www.nps.gov/drto/learn/nature/tespecies.htm). Researchers selected two of these, elkhorn coral (*Acropora palmata*) and pillar coral (*Dendrogyra cylindrus*), for spawning observations (fig. 2).

KAREN NEELY (2)

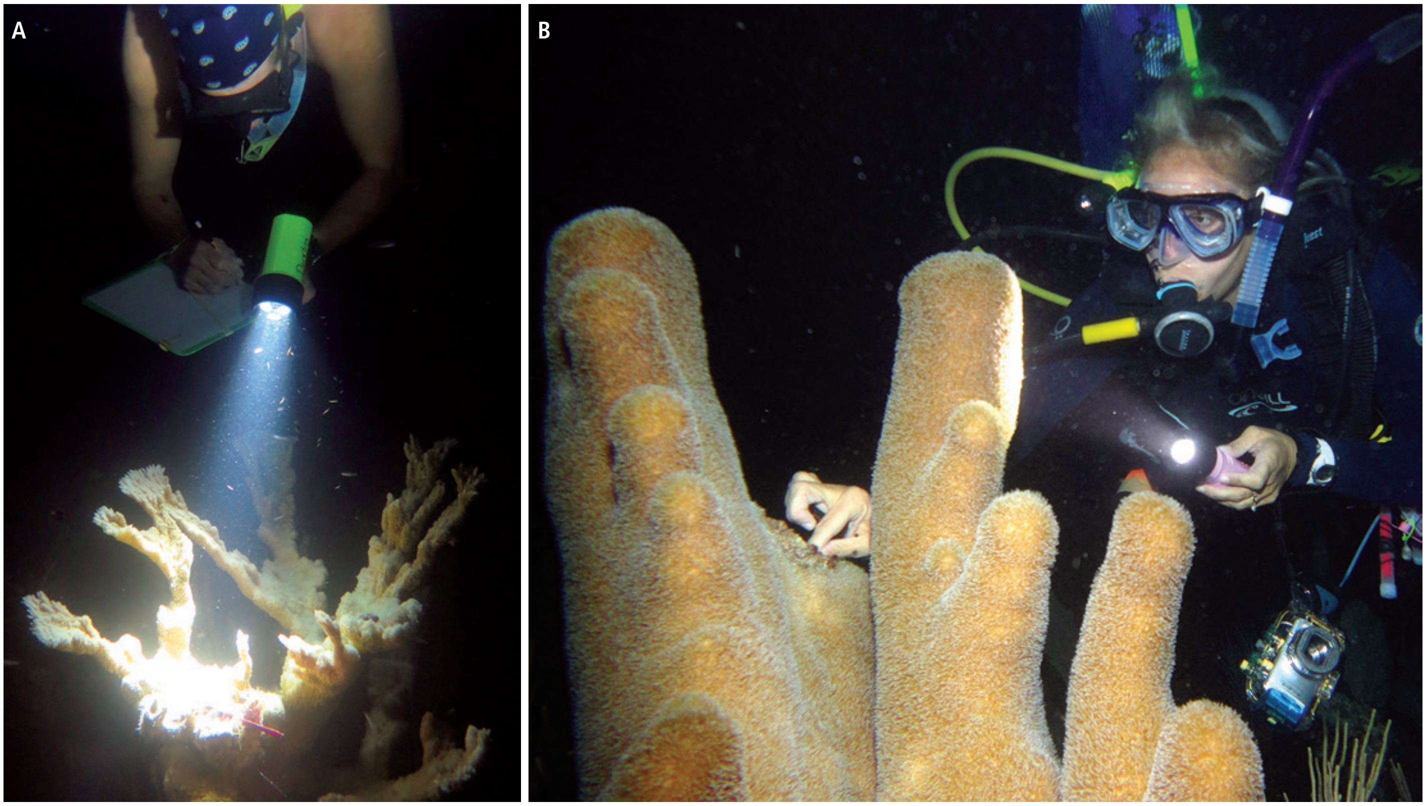


Figure 2. Researchers from Dry Tortugas National Park and Florida's Fish and Wildlife Research Institute observe and document the spawning of (A) *Acropora palmata* and (B) *Dendrogyra cylindrus*, both ESA-listed coral species.

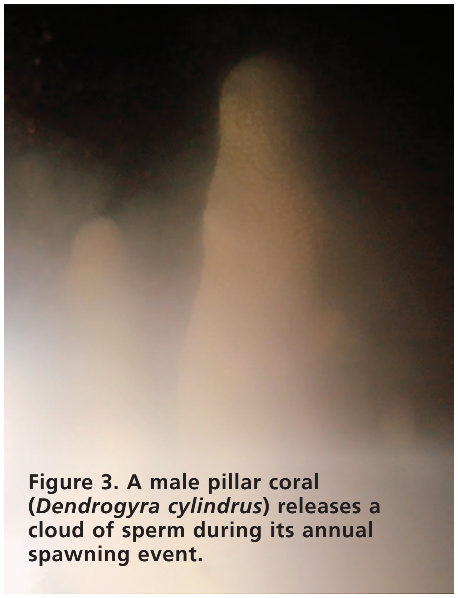
The two species are of interest for several reasons. Both have a single, small, clumped population in the park, making the reproductive success of those individuals indispensable for natural population recovery. Both are also the targets of Florida Fish and Wildlife Research Institute monitoring programs that have looked at individual colony health for 10 (*A. palmata*) and 5 (*D. cylindrus*) years. In addition, though the species are both broadcast spawners, they have slightly different sexual strategies. *A. palmata* is hermaphroditic, meaning eggs and sperm are released together in packed bundles that break apart at the surface where they mix with those of other individuals. In contrast, *D. cylindrus* is gonochoric, meaning colonies are either male or female. In this case, both male and female colonies must be present within a population for successful fertilization.

Pockets of resilient reef communities and restoration projects provide beacons of hope for the interim survival of these systems, but what of longer-scale trends based on natural propagation of species?

New observations

Until recently, logistical difficulties prohibited observations of spawning within Dry Tortugas National Park. It was unknown whether these populations were reproductive and whether they would spawn in synchrony with the rest of the Florida Reef Tract. A collaborative team composed primarily of National Park Service and Florida Fish and Wildlife Research Institute divers selected a five-night window in August 2014 to hover over the target species. The window was identified based on previous years' phenological spawning observations elsewhere in the region, with each species expected to follow a pattern of gamete release determined by the number of nights since the full moon and the number of hours after sunset (Fogarty et al. 2012; Neely et al. 2013).

Bathed in the warm waters and under the glow of the recent full moon, the divers waited. Two nights after the full moon, colleagues 270 km (170 mi) away in Key Largo announced *D. cylindrus* spawning success. The Dry Tortugas group waited with bated breath until, 30 minutes later, the observed colonies followed suit (fig. 3). The process and time lag were repeated the next night with *D. cylindrus*. And the following night,



KAREN NEELY

Figure 3. A male pillar coral (*Dendrogyra cylindrus*) releases a cloud of sperm during its annual spawning event.

four nights after the full moon, *A. palmata* did the same (photo, page 13), synchronized with the date of their Key Largo conspecifics, but with a 30-minute lag. As the gametes were released, divers recorded the timing of each spawn, the reproductive output of each colony, and, for *D. cylindrus*, the gender of each individual. Though the team was pleased to find reproductively active colonies, they were concerned to discover that all of the nine *D. cylindrus* colonies in the Dry Tortugas were male.

Conclusion

The spawning observations pose just as many questions as they provide answers. Are the gametes successfully fertilizing and settling? Can these clumped individuals seed other areas of the park to increase population size? How will genetic diversity affect reproductive potential now and in the future? And from a management perspective, should measures such as transplantation of "nursery-raised" corals be used to supplement the natural processes to promote species' survival? These questions demonstrate that there is still much to learn, but certainly knowing the corals are making the most of their once-a-year opportunity is a good start.

Acknowledgments

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References

Baird, A. H., J. R. Guest, and B. L. Willis. 2009. Systematic and biogeographical patterns in the reproductive biology of scleractinian corals. Annual Review of Ecology, Evolution, and Systematics 40:551–571.

Domeier, M. L. 2004. A potential larval recruitment pathway originating from a Florida marine protected area. Fisheries Oceanography 13:287–294.

Florida Fish and Wildlife Conservation Commission. 2015. The unified Florida Reef Tract map. Accessed 30 September 2015 from http://ocean.floridamarine.org/IntegratedReefMap.

Fogarty, N. D., S. V. Vollmer, and D. R. Levitan. 2012. Weak prezygotic isolating mechanisms in threatened Caribbean *Acropora* corals. PLoS ONE 7(2):e30486. doi:10.1371/journal.pone.0030486.

Gardner, T. A., I. M. Côté, J. A. Gill, A. Grant, and A. R. Watkinson. 2003. Long-term region-wide declines in Caribbean corals. Science 301:958–960.

Jones, G. P., G. R. Almany, G. R. Russ, P. F. Sale, R. S. Steneck, M. J. H van Oppen, and B. L. Willis. 2009. Larval retention and connectivity among populations of corals and reef fishes: History, advances and challenges. Coral Reefs 28:307–325.

Levitan, D. R., N. D. Fogarty, J. Jara, K. E. Lotterhos, and N. Knowlton. 2011. Genetic, spatial, and temporal components of precise spawning synchrony in reef building corals of the *Montastraea annularis* species complex. Evolution 65:1254–1270.

Levitan, D. R., H. Fukami, J. Jara, D. Kline, T. M. McGovern, K. E. McGhee, C. A. Swanson, and N. Knowlton. 2004. Mechanisms of reproductive isolation among sympatric broadcast-spawning corals of the *Montastraea annularis* species complex. Evolution 58:308–323.

National Park Service. 2010. Explore water: Discover the beauty and value of coral reefs in your national parks. Accessed 30 September 2015 from http://www.nature.nps.gov/water/coralreefs/.

Neely, K. L., K. S. Lunz, and K. A. Macaulay. 2013. Simultaneous gonochoric spawning of *Dendrogyra cylindrus*. Coral Reefs 32:813. doi:10.1007/s00338-013-1034-0.

Pandolfi, J. M., J. B. C. Jackson, N. Baron, R. H. Bradbury, H. M. Guzman, T. P. Hughes, C. V. Kappel, F. Micheli, J. C. Ogden, H. P. Possingham, and E. Sala. 2005. Are U.S. coral reefs on the slippery slope to slime? Science 307:1725–1726.

Ruzicka, R., V. Brinkhuis, M. Colella, J. Kidney, C. Bradshaw, N. Sheridan, K. Lunz, J. Morrison, L. Bartlett, K. Macaulay, and K. Neely. 2014. Long-term monitoring and assessment of selected coral reef sites in the Dry Tortugas National Park. 2011–2012 Final Report. Fish and Wildlife Research Institute and Florida Fish and Wildlife Conservation Commission, Saint Petersburg, Florida, USA.

Szmant, A. M. 1986. Reproductive ecology of Caribbean reef corals. Coral Reefs 5(1):43–53.

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PS

Case Study

UNIVERSITY OF WASHINGTON/ANNA WILSON

Monitoring wildflower phenology using traditional science, citizen science, and crowdsourcing approaches

Figure 1. Phenology refers to the seasonal timing of important biological events, which are frequently cued by climate. For example, the seasonal timing of flowering for montane wildflowers like yellow glacier lily (*Erythronium grandiflorum*) is closely tied to the date of snow disappearance at Mount Rainier National Park.

By Anna Wilson, Kevin Bacher, Ian Breckheimer, Jessica Lundquist, Regina Rochefort, Elli Theobald, Lou Whiteaker, and Janneke HilleRisLambers

CLIMATE CHANGE IS LIKELY TO HAVE DRAMATIC consequences for national parks and surrounding ecosystems. Monitoring important biological processes that are sensitive to climate is therefore critical to help inform management strategies allowing national parks to observe and potentially adapt to climate change impacts. The National Park Service already has significant programs in place, such as the Inventory and Monitoring Network Program (http://science.nature.nps.gov/im/monitor/) and the Climate Change Response Program (https://www.nps.gov/orgs/ccrp/index.htm), but scientists and managers continue to explore approaches for accurately and efficiently monitoring processes of interest. A spectrum of options is available depending upon resources and program goals. On the one hand, a few highly trained and credentialed experts can generate high-quality data from a small area that conform to strict data protocols—this is the "traditional" approach often taken by professional scientists. However, other approaches exist that can be more advantageous. For example, engaging visitors to aid in data collection (a citizen scientist approach) may greatly expand the volume of data collected while simultaneously fostering public understanding, investment, and support for the resulting management actions (Dickinson et al. 2012; Theobald et al. 2015). Alternatively, a large amount of information on the spatial or temporal distribution of organisms may already exist in photo databases (e.g., Hurlbert and Liang 2012; Bakkegard and Davenport 2012), which can be leveraged as a low-cost method to monitor biological processes of interest (a crowdsourcing approach).

In this article, we describe these three approaches, which we have used to monitor the relationship between climate factors like the timing of seasonal snow disappearance and the timing of wildflower reproduction ("wildflower phenology") at Mount Rainier National Park (figs. 1 and 2, next page). Our goal is to provide a case study for national park staff and other resource managers interested in initiating wildflower phenology monitoring programs of their own. Wildflower phenology is a particularly important process to monitor, because it is strongly driven by climatic factors (fig. 1) (Fitter and Fitter 2002; Inouye 2008). This

UNIVERSITY OF WASHINGTON/NATASHA LOZANOFF

Figure 2. Wildflower phenology is studied by documenting the seasonal progression of wildflower species through their phenophases, which involves documenting the timing of reproductive life stages like flower buds, flowers, maturing fruit, and dispersing seed. Four phenophases of white avalanche lily (*Erythronium montanum*) are pictured here—the four monitored by our citizen scientists. Two additional phenophases were monitored through our professional scientist approach (leaf-out and leaf senescence [leaf fall]), while our crowdsourcing approach only captured the flowering phenophase. This series of photos (as well as comparable ones for each of the 10 focal species) was included in the species identification booklet provided to MeadoWatch volunteers.

UNIVERSITY OF WASHINGTON/JANNEKE HILLERISLAMBERS

Figure 3. Peak wildflower season at Mount Rainier National Park, generally in July–August, is a large draw for visitors. Different wildflower species bloom on different schedules and in different habitats, creating a mosaic that is constantly changing. These schedules are shifting with climate change, but not all species of wildflowers—or wildlife—respond in the same way. This creates challenges for wildlife, park managers, and visitors alike.

means that changes in wildflower phenology are likely to indicate ongoing biological responses to climate change (Parmesan 2006). Additionally, the timing of wildflower phenology is crucial both to the plants themselves and to the life cycle of organisms that depend on flowers, fruits, or seeds for resources (e.g., pollinators and frugivores or preferential fruit eaters). Long-term monitoring of wildflower phenology could therefore help identify the plants and animals likely to be affected significantly by climate change, especially given the possibility of phenological mismatches, where plants fall out of sync with their pollinators or consumers (e.g., McKinney et al. 2012; Robbirt et al. 2014). Wildflower meadows are also a large attraction for visitors (fig. 3); consequently, shifts in wildflower phenology could also influence national park visitor experience and visitation patterns (Buckley and Foushee 2012).

Three approaches to monitoring wildflower phenology at Mount Rainier National Park

How could wildflower phenology be monitored in national parks? The timing of reproductive life stages, or phenophases, of different species is of particular interest (fig. 2). We describe the three approaches we used for estimating the timing of these wildflower phenophases at Mount Rainier National Park (fig. 4, page 20). The first is a professional scientist approach (data collected by a graduate student); the second is a citizen scientist approach (data collected by volunteers participating in our citizen science program MeadoWatch—http://www.meadowatch.org); and the third is a crowdsourcing approach with data extracted from geo-located, date-stamped photos uploaded to a photo-sharing website and database (Flickr). Each of these had trade-offs associated with balancing the data characteristics, resources required, and outreach potential, which we discuss below (summarized in table 1).

Professional scientist approach

One of our team members (Elli Theobald, a graduate student at the University of Washington) has studied wildflower phenology at 70 sites distributed across a 1,350-foot elevation gradient (fig. 5, page 21). Permanent research sites were carefully chosen to be representative of the surrounding landscape. For four summers, Theobald visited these sites weekly, identifying the relative abundance of each of six phenophases (fig. 2). She monitored the phenology of all animal-pollinated plant species (47 species), representing the vast majority of the plant community within these sites. Each site was also instrumented with microclimate sensors, resulting in accurate estimates of snow duration at each site.

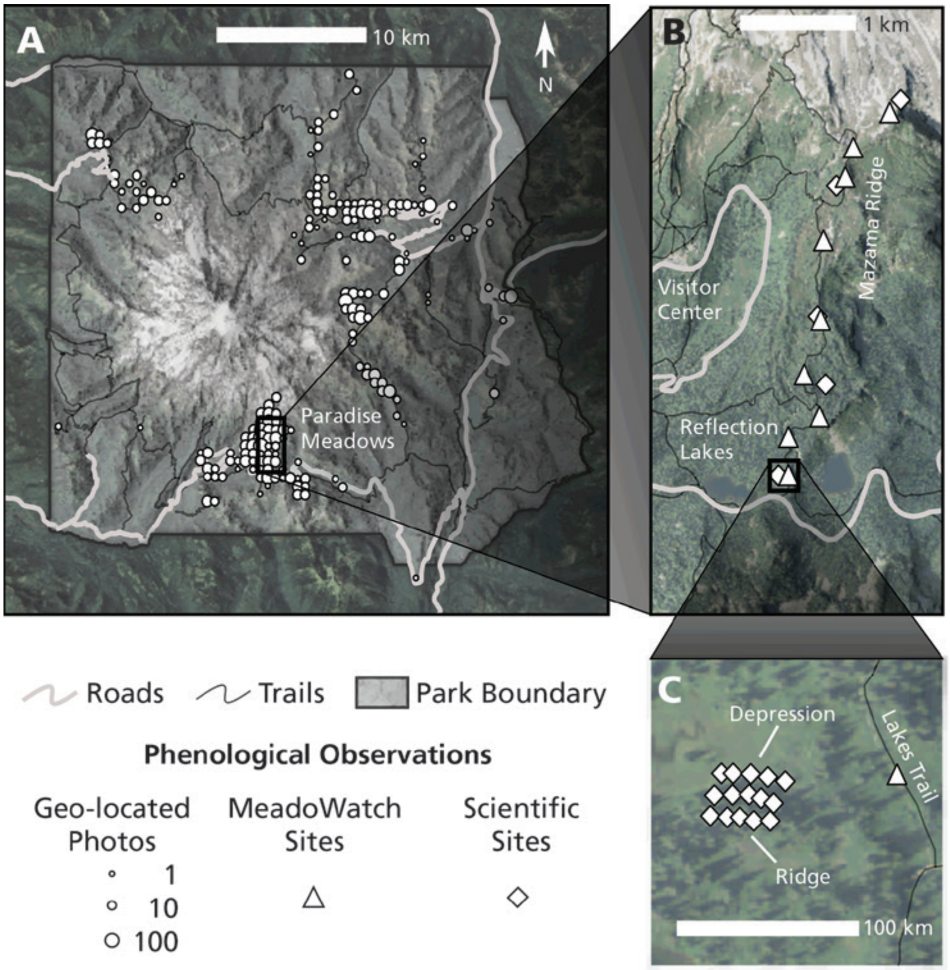
The main advantage of this approach was that the data provided very detailed descriptions of the onset, duration, and peak dates of the six phenophases monitored relative to snowmelt for the majority of wildflower species in this system (fig. 6, page 21). However, there were several downsides to this approach relative to the other two. First, the geographic scope of sites we monitored was limited by the ability of one person to access them frequently while collecting data (fig. 4). Second, the collection of detailed data on such a broad suite of species and on nonflowering phenological stages required the professional scientist to have advanced, technical botany skills, particularly at the onset of the study. Third, collecting these data was relatively expensive, requiring salary for the scientist to conduct fieldwork and manage and analyze data. Fourth, the inherent outreach potential of this

Abstract
Monitoring wildflower phenology in national parks allows for detection of the biological impacts of climate change. Here, we compare three modes of data collection we employed at Mount Rainier National Park to monitor wildflower phenology: (1) a professional scientist approach with observations collected by credentialed experts (agency scientists and those traditionally employed by academic institutions), (2) a citizen scientist approach with observations collected by trained volunteers, and (3) a crowdsourcing approach with observations extracted from online photo databases. All three approaches have their advantages and disadvantages with regard to data characteristics (e.g., quality and quantity), outreach opportunities, and resources required to initiate and maintain each type of program. For example, professional scientists were able to collect the most detailed phenological data of the three approaches (e.g., multiple reproductive stages for more than 40 species), but this approach also required more technical skills to initiate and maintain and provided few opportunities for outreach. Per personnel hour, the citizen scientist approach generated more data than the professional scientist approach and provided the greatest opportunity for outreach, but was limited to presence/absence of easily identified species located at fewer study sites that could be easily accessed by volunteers. Crowdsourced data were least costly to acquire and most spatially extensive, but also provided the least detailed information on wildflower phenology and required personnel to have the most technical computing skills of the three approaches. Moreover, this approach is likely only feasible for abundant wildflower species in heavily visited portions of national parks. We suggest that the best approach to monitoring wildflower phenology in national parks (and other public lands) will depend on program goals (including data requirements, time frame, outreach goals, and partner/funder goals), available resources (including funding, staff, and volunteer capacity), and park characteristics (e.g., proximity to urban areas, visitation).

Key words
citizen science, climate change, crowdsourcing, outreach, phenology, volunteers

Table 1. Data characteristics, outreach opportunities, and resources needed for wildflower phenology monitoring at Mount Rainier National Park

Category	Component	Professional Scientist	Citizen Science	Crowdsourcing
Data characteristics	Accuracy and complexity	Most accurate and precise data for highly complex data collection protocols	Simple to moderately complex data collection protocols with accuracy and precision depending on volunteer training	Simple data with accuracy that varies depending on technology (camera GPS accuracy)
	Data quantity	~1,000 site-date observations/year; 47 species, 6 phenophases	~1,700 site-date observations/year; 10 species, 4 phenophases	~1,000 photos/year; 8 species, 1 phenophase
	Site selection	Intentional, potential to access remote, hazardous, and sensitive sites	Variable, depending on volunteer capacity	Haphazard, generally near developed areas, easy access sites often visited
	Geographic scope	Number of sites limited by personnel, time for travel, and collection of detailed data	Variable, depending on volunteer capacity	Potential for greatest spatial coverage
Outreach	Inherent opportunities	Low: limited to interactions with the professional scientist (~1–2 weekly)	High: constrained only by the quantity of volunteers (~40–85 annually)	Low (none): dependent on whether photographers uploading photos visit the specific monitoring project website (unknown)
Resources required	Personnel (initiation)	Master's or PhD level for project design (50% effort for 3 months minimum)	Master's or PhD level for project design (50% effort for 3 months minimum)	Master's or PhD level to extract information from databases (50% effort for 2 weeks minimum)
	Personnel (maintenance)	Master's or PhD level for collecting data, or to supervise and train personnel (BS level) to collect data (50–100% effort for 3 months/year)	Seasonal project manager (BS level); (50% effort for 3 months/year); volunteers willing to spend 1–3 days collecting data each summer (no salary)	Lab assistant (AS or BS level) to categorize photographs; (100% effort for 2 weeks/year); photographers willing to share photos on photo websites
	Personnel (training)	Extensive botany knowledge, experimental design (master's or PhD level)	Botany knowledge, communication skills (BS level)	Programming skills (master's or PhD level), botany knowledge (AS or BS level)
	Supplies	Data sheets, field guides	Species identification booklets and data sheets (one/volunteer)	None
	Volunteer training	None	Orientation: data collection, and species and phenophase identification	None



(A) Crowdsourcing*
4,790 photos
8 species
1 phenophase
No microclimate sensors
5 years of data
Presence data collected
457 photographers

(B) Citizen Science*
Nine 1 m^2 plots
10 species
4 phenophases
9 microclimate sensors
1 year of data
Presence/absence data
About 40 citizen scientists

(C) Professional Scientist
Seventy 1 m^2 plots
47 species
6 phenophases
70 microclimate sensors
4 years of data
Phenophase abundance data
1 professional scientist

*For more information visit http://www.meadowatch.org

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Figure 4. Locations of wildflower phenological data collected in Mount Rainier National Park, 2009–2013. Circle sizes (on A) are proportional to the number of geo-located, date-stamped photos used for the crowdsourcing approach to monitoring wildflower phenology. MeadoWatch volunteers visited nine sites (triangles) located along Mazama Ridge (B), representing our citizen science approach. A professional scientist collected data at nearby sites (diamonds) in permanent monitoring plots stratified by topography (B, C).

data collection approach was limited to chance field encounters between her and visitors during data collection.

Citizen scientist approach

In 2013, we (members of the HilleRisLambers laboratory at the University of Washington and staff at Mount Rainier National Park) founded MeadoWatch, a citizen science program that engages volunteers to collect wildflower phenology data. The program is ongoing, and data presented here are from 2013 when volunteers monitored 10 focal wildflower species at nine sites along a 3-mile (one-way) hiking trail (figs. 4 and 7). Sites cover a relatively small area of Mount Rainier National Park because all must be accessible to volunteers visiting the park for a day. We recruited citizen scientists with e-mails to organizations with like-minded phenology monitoring goals (e.g., Audubon, the Mountaineers, the Washington State Native Plant Society) and via the Mount Rainier volunteer blog, which yielded 41 volunteers participating in 2013.

During a mandatory two-hour orientation, we provided citizen scientist volunteers with an overview of climate change impacts on plant phenology and detailed training on methods to locate our sampling sites, identify four reproductive phenophases of focal wildflower species (fig. 2), and collect data. Citizen scientist volunteers received data sheets and a booklet to bring on their hike with directions to the sites, focal wildflower species, and phenophase descriptions.

During their hike, citizen scientists recorded the presence or absence of each focal species' phenophase at each site, and ranked the phenophases present from most abundant to least abundant (within species). As with the professional scientist approach, all sites were instrumented with microclimate sensors, allowing for accurate estimates of snow disappearance. We collected data sheets at the end of summer, and entered and analyzed the data at the University of Washington. One trained staff person (Anna

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Figure 5. Graduate student Elli Theobald gathers phenological data on a weekly basis at Mount Rainier National Park during the summer months.

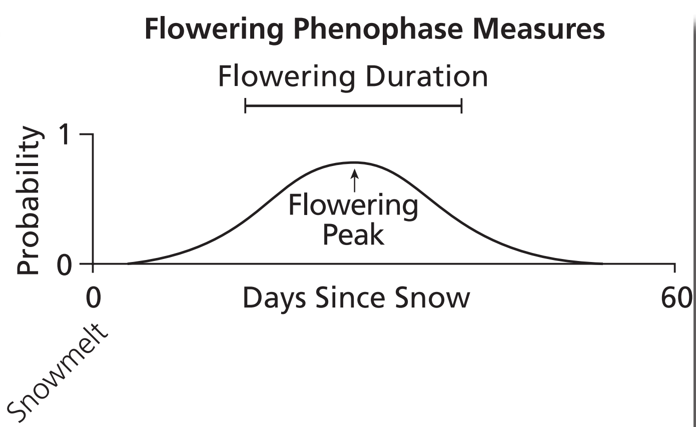

Figure 6. Data collected by our graduate student can be used to estimate the peak timing and duration of each of the six phenophases she monitors (green leaves, buds, flowers, fruits, seeds, senescing vegetation). Flowering is shown here.

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UNIVERSITY OF WASHINGTON/ELLA SEELY

Figure 7. MeadoWatch volunteers Weedy McCauley and Karen Davis survey one of nine sites to document the presence and absence of four phenophases of 10 focal wildflower species (buds, flowers, fruits, seeds).

Wilson) recruited and coordinated volunteers, worked closely with national park staff to arrange waivers and entrance to the park, maintained sampling sites, and managed the resulting data.

The citizen scientist approach had both advantages and disadvantages relative to the other two approaches (table 1). First, data generated by MeadoWatch citizen scientists provided greater temporal resolution (daily) on wildflower phenology than the professional scientist data (weekly). Additionally, MeadoWatch provided the greatest inherent outreach potential of the three approaches, with more than 40 members of the public engaged in the first year of data collection (increasing to more than 85 as of 2016). We assume our citizen science volunteers gained knowledge of climate change, wildflower phenology, and the scientific process (e.g., Evans et al. 2005; Jordan et al. 2011), although we did not explicitly quantify this. However, we also note drawbacks to this approach, primarily related to data characteristics. Data were not as detailed as those collected by professional scientists, a design choice motivated by our assumption and verified by surveys of our volunteers that citizen scientists may not all have the expertise necessary to identify cryptic phenophases (e.g., emerging leaves) or the time to quantify the abundance of phenophases. The spatial coverage of sites was also low relative to sites monitored with the professional scientist approach and covered by crowdsourcing approaches (fig. 3). Both factors likely contributed to estimates of wildflower phenology from the citizen science approach that were more uncertain and, in some cases, different from those estimated by professional scientists (figs. 8 and 9, next pages).

Crowdsourcing approach

Our third approach used geo-located, date-stamped photos from a photo sharing website (Flickr, http://www.flickr.com) as observations of wildflower phenology (similar to those shown in figs. 1 and 3). A graduate student with advanced computing and quantitative skills (Ian Breckheimer) developed a computer script to extract photos taken within the Mount Rainier National Park boundary from the Flickr photo database, and this generated a data set of 4,790 photos taken over a five-year period (2009–2013). Undergraduate lab assistants (trained in species identification of commonly photographed species by Breckheimer) then determined if photos contained flowers of eight focal wildflower species (682 of the 4,790 pictures). Those without focal wildflowers were noted and used as “absences” in analyses developed by Breckheimer that standardized for photographer “effort,” which varied spatially and temporally. Focal wildflower species captured were fewer in number than those monitored both by the professional scientist and citizen scientists, and limited to those species that were frequently photographed (likely driven by their showiness and abundance). Additionally, photos only provided information on the flowering phenophase (fig. 2), since other phenophases were not frequently photographed or were difficult to identify in photos.

We found several advantages to this approach, including the low up-front costs and minimal time required to generate a multiyear data set that covered a much larger geographic area than either of the other approaches (fig. 4). For example, undergraduate lab assistants could extract information from thousands of photos taken over multiple years in much less time than that spent by the professional scientist or volunteer coordinator in just one wildflower season. However, there were also disadvantages to this approach. We had no control over where and when photos were taken, which meant that quantifying the timing of peak flowering (the day a particular species is most likely to be flowering) and how long flowering continues (i.e., flowering optima and duration; fig. 6) required relatively sophisticated statistical approaches to accommodate large variation in the distribution of photos over space and time. This also meant we could not link exact measures of snow duration from microclimate sensors to each data point as we did with professional scientist and citizen scientist generated data and so had to rely on estimates of snow disappearance date from models instead. Finally, this approach also lacked the outreach potential of MeadoWatch, since we did not interact personally with these photographers.

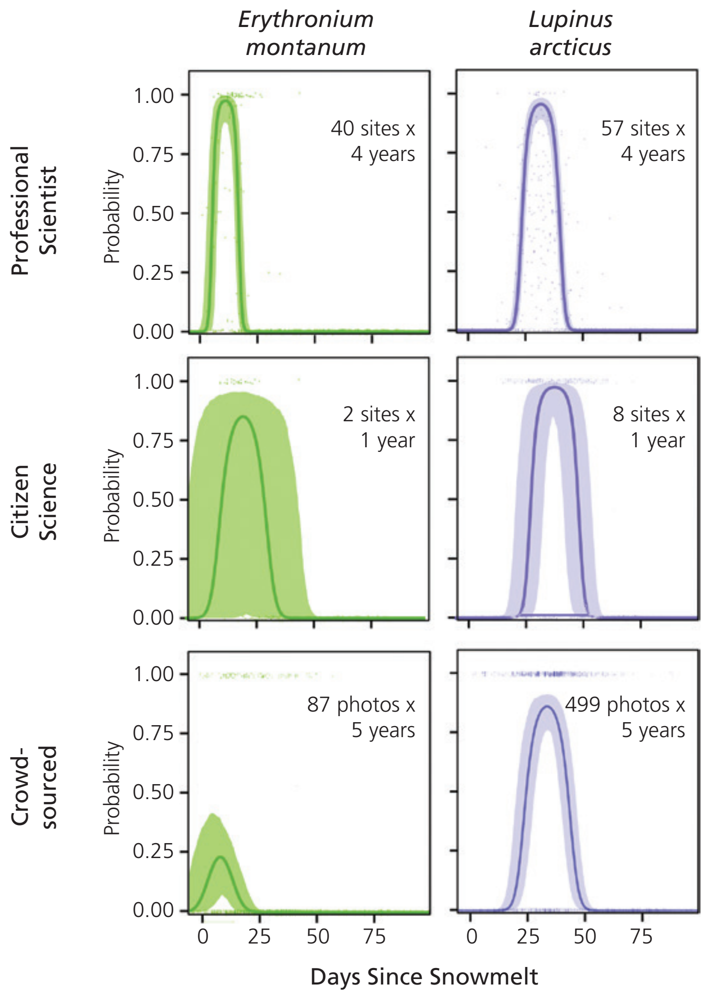

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Figure 8. Flowering phenology curves for the white avalanche lily (*Erythronium montanum*, green) and Arctic lupine (*Lupinus arcticus*, purple) demonstrate that all three approaches provide largely similar estimates of flowering phenology for two species, when data quantity are sufficient. The x-axis measures days since snowmelt; the y-axis measures the probability of flowering within a plot (for professional and citizen scientist data) or the probability of appearing in a representative photo (for crowdsourced data). Solid lines represent the best estimate, while shading represents the 95% uncertainty interval. The width of the credible intervals reflects the number of years of data, number of locations, and relative information content of the data. Low sample size decreases certainty, and thus increases credible intervals for citizen science monitoring of *E. montanum*, sampled in just 1 year and only 2 locations. See text in “Discussion” for more detailed data comparisons. Full data sets will be made available in upcoming publications, which will be available through links on the MeadoWatch website (www.meadowatch.org).

Discussion

The three approaches we employed for monitoring wildflower phenology provided us with a largely consistent understanding of wildflower phenology in our system (figs. 8 and 9). Specifically, all approaches captured variation among species in the timing of peak flowering relative to snowmelt as well as in flowering duration (fig. 9), providing similar species rankings (i.e., distinguishing early- from late-flowering species and short- from long-duration flower-

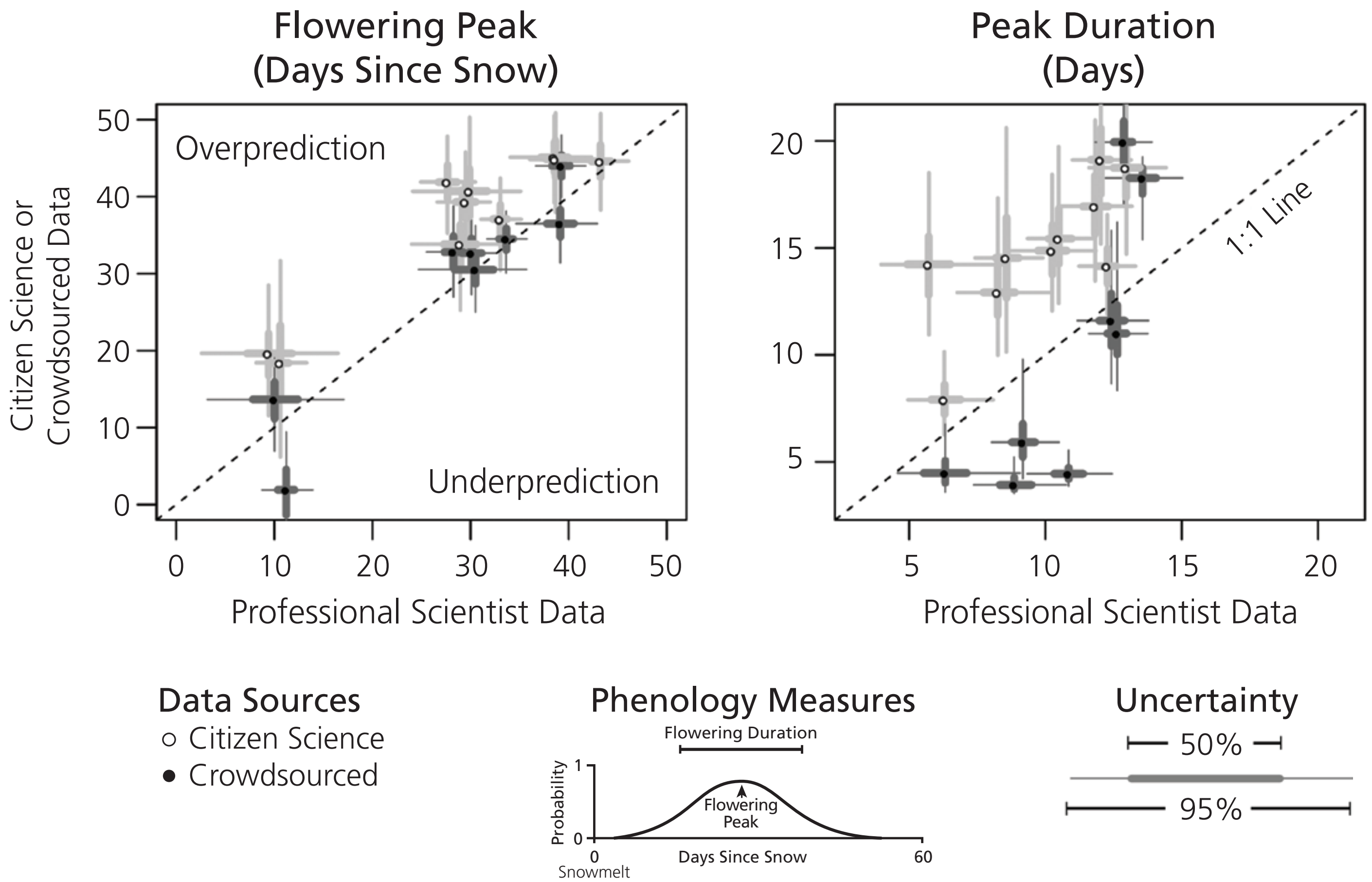

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Figure 9. Peak flowering relative to snowmelt (left panel) and flowering duration (right panel), as estimated from data collected by professional scientists (x-axis) versus data collected by citizen scientists (white circles) and data crowdsourced from geo-located, date-stamped photos (black circles) on the y-axis. Each dot represents one of the 10 (for citizen science–derived data) or eight (for crowdsourced data) wildflower species in common between the two approaches being compared. The dashed diagonal line is a 1:1 line, indicating where the citizen science and crowd sourcing estimates would lie when identical to the professional scientist estimates for the same species. Data for this analysis were from 2013, a year when all three methods were used at Mount Rainier National Park. Despite differences in parameter estimates, all three approaches provide a similar picture of the progression of flowering after snowmelt at our site, as well as relative differences among species in flowering duration. See text in "Discussion" for more detailed data comparisons.

ing species). However, species-specific estimates of peak flowering dates and flowering duration did vary among the three approaches (duration more than peak flowering—fig. 9). In some cases, these differences could be attributed to differences in data quantity (e.g., *Erythronium montanum* curves estimated from the citizen science approach—fig. 8). However, these differences (2–15 days—fig. 9) were much smaller than spatial and temporal variability in the main climatic driver of wildflower phenology, snowmelt duration (>30 days). Thus, our understanding of how the progression of flowering would vary between years and locations (within the 100-day growing season), or over time, would be similar for data generated by the three approaches. Approaches also differed in type of phenology data they generated, the resources they required, and their inherent educational potential (table 1). Some of these differences arose due to the design choices we made; however, we believe other differences are inherent to these approaches (Dickinson et al. 2012). Here, we summarize these differences, and discuss the design choices we made or could have made to optimize data quality and quantity, minimize cost, and maximize outreach potential for each of these different approaches.

Comparing data characteristics

We believe that a professional scientist approach will generally yield the most detailed and highest quality data relative to the two other approaches, while the citizen science and crowdsourcing approaches have the potential for generating the highest volume of data (given similar resources in terms of personnel time and supplies). The differences in data quality and complexity among the three approaches arise for a few different reasons. Professional scientists generally have more specialized training, allowing them to collect data for more species and more phenophases than citizen scientists (who generally do not have a botanical back-

Changes in wildflower phenology are likely to indicate ongoing biological responses to climate change.

ground or experience collecting scientific data) or a crowdsourcing approach (where data collection opportunities are limited by photographers' preferences). For example, one graduate student could annually collect data on more than 40 species and six phenophases (representing the professional scientist approach), whereas volunteers participating in our citizen science program MeadoWatch monitored 10 species and four phenophases; crowdsourced photos from Flickr provided data on just one phenophase (flowering) for 8 species. Another factor is measurement error caused by misidentification (or lack of observation) of phenophases, which is presumably lower for phenology data generated by professional scientists than for crowdsourced data (given uncertainty in species identity from photos) and, in some cases, data collected by citizen scientists. Mandatory species identification training and resources like the species identification booklets we provided to volunteers during orientation can minimize measurement error.

Although data generated by professional scientists may be of higher quality, this advantage might be offset by the higher volume of data that citizen scientist and crowdsourcing approaches can generate, especially if those programs persist over many years. For example, our professional scientist spent a similar amount of time visiting each of her sites weekly (representing one observation per site per week) as our citizen scientist volunteer coordinator spent coordinating data collection from 15–20 volunteers in a week (representing 15–20 observations each week at a smaller number of sites). This meant that our MeadoWatch volunteers generated data with higher (approximately daily) frequency. Similarly, in just one year, our graduate student and several undergraduate lab assistants spent less time generating a much more spatially and temporally extensive data set through the crowdsourcing approach than either the professional scientist or volunteer coordinator spent leading data collection efforts for one summer. Flickr photos allowed us to "go back in time" given that we had access to photos uploaded in previous years. However, the high data-volume potential of citizen science programs and crowdsourcing approaches is contingent on the supply of motivated volunteers and high park visitation rates, which (at Mount Rainier National Park) is likely tied to the proximity of metropolitan areas (e.g., Seattle, Tacoma, Olympia). For less highly visited natural areas, these approaches may not yield the same volume of data, although recruitment efforts can increase the volunteer base and encourage more visitors to upload their photographs to online photo databases like Flickr or iNaturalist (http://www.inaturalist.org) as they did in our case.

Comparing costs required for initiation and maintenance

The resources needed to initiate and maintain wildflower phenology monitoring programs in terms of personnel were similar for the professional scientist and citizen scientist approaches, but much lower for crowdsourcing. All three approaches required at least part-time staff to collect data (professional scientist approach); recruit, train, and organize volunteers (citizen scientist approach); or extract, classify, and analyze wildflower photos (crowdsourcing approach). However, the number of hours required to classify photos (for the crowdsourcing approach) was not only lower, but could be conducted at any time of year. Because personnel are likely the highest expense associated with any wildflower phenology monitoring effort in a national park over long time periods, this is an important advantage of the crowdsourcing approach. Costs for personnel can potentially be reduced by capitalizing on additional funding sources, as we did. For example, Elli Theobald (representing the professional scientist approach) received a Graduate Research Fellowship (from the National Science Foundation), and we secured two federal grants to support the volunteer coordinator for MeadoWatch.

The three approaches we employed also differed in the optimal skill sets possessed by the personnel employed, because of the differing methods used. For example, the professional scientist approach required that the graduate student have a greater knowledge of botany and experimental design than personnel associated with our citizen science program or the crowdsourcing approach. On the other hand, communication skills were key to interacting with volunteers effectively (as in our citizen science program), but they were not necessary to collecting wildflower phenology data in the field or extracting information from the Flickr photo database (our professional science and crowdsourcing approaches, respectively). Finally, programming skills (to extract photograph metadata from online databases) and a more sophisticated statistical background were essential for processing and analyzing the nonstandard data gleaned from the Flickr photos. These skills were not as critical for our graduate student or MeadoWatch volunteer coordinator, because more mainstream statistical methods could be used to give accurate estimates of wildflower phenology for these data sets (fig. 6).

Comparing inherent outreach potential

The three approaches we used for monitoring wildflower phenology differ greatly in their potential for outreach to park visitors, with the citizen scientist approach most effective at doing so. For example, MeadoWatch, explicitly designed to engage members of the public, reached more than 40 volunteers in its first year (>85 as of 2016)—far more than the professional scientist and crowdsourcing approaches. Of course, crowdsourcing does have the potential to engage many park visitors, particularly if photographers are engaged while visiting the park, as opposed to their photos being used long after they were uploaded and without their knowledge. Although scientists often share their research results with the public or engage in outreach outside of data collection, we argue that traditional monitoring programs (i.e., the professional scientist approach) are generally constrained in their outreach capacity (as compared to the other two approaches). This is because only a few trained personnel are involved in collecting data, in contrast to citizen science and crowdsourcing approaches, which tend to engage as many volunteers as possible and frequently involve repeated interactions.

Conclusion

These three approaches all represent viable alternatives for monitoring wildflower phenology, but differ in data quality and requirements, amount and type of resources required for initiation and maintenance, and the inherent outreach opportunities provided (table 1). Thus, the choice of approach will depend on the goals for establishing a wildflower phenology program and resources available. Based on these considerations, we make the following recommendations for those wishing to initiate and potentially maintain a long-term wildflower phenology monitoring program.

A **traditional professional scientist** approach is likely the best option when (1) data accuracy is paramount (perhaps for policy mandates, legal reasons, or sensitive resource areas), (2) personnel with the technical expertise are available to collect data (either because of reliable funding sources or existing partnerships), and (3) data collection by volunteers is not otherwise feasible (due to low capacity or high safety risks). While this approach lacks inherent outreach opportunities, funding for outreach programs could be built into budgets and partnerships (as encouraged by many federal agencies) to ensure that the information gained from data collection can be provided in forms and venues suitable for interpretive staff and visitors.

A **citizen scientist approach** may be the best option when outreach is an important goal, especially if it is equal in importance to the scientific goal of data collection. In fact, wildflower phenology is already monitored in several national parks through citizen science efforts (e.g., the A.T. Seasons Phenology Program along the Appalachian Trail and the California Phenology Project, both in partnership with the USA National Phenology Network—https://www.nps.usanpn.org/). This approach requires the following resources: (1) an on-the-ground, at least part-time volunteer coordinator to work with scientists on developing appropriate protocols, training volunteers, and coordinating logistics, (2) a dedicated volunteer base, and (3) minimal funding for volunteer recruitment and supplies (e.g., training materials). Additionally, suitable monitoring locations must be easy to access by visitors, with focal species and phenophases easily identified by volunteers with limited plant identification skills (e.g., minimally acquired after relatively short training sessions). At Mount Rainier we continue monitoring wildflower phenology through the MeadoWatch citizen science project, giving us valuable data on wildflower phenology (of great scientific interest) while engaging more than 85 volunteers (as of 2016) in research on climate change (valuable and rewarding outreach for both the University of Washington scientists and their NPS partners).

Crowdsourcing phenological data from geo-located, date-stamped photos stored in online databases may be the best option when (1) personnel to collect phenological data or coordinate volunteers in summer months are unavailable, (2) long-term budgets for the program are uncertain (since this is the only approach that can provide multiple years of data with less than one year of effort), and (3) areas of interest are located in heavily visited portions of national parks, generating a large number of photos. The proliferation of smartphones and cameras with GPS capabilities, combined with the ability to share and store biodiversity observations via social media (e.g., iNaturalist) will likely make crowdsourcing of photos an increasingly viable option (Newman et al. 2012).

Of course, any of these approaches could be modified or combined to overcome some of the individual drawbacks. For example, crowdsourcing could be coupled with on-site outreach programs and social media campaigns to increase interaction with volunteers, thereby increasing outreach potential. Such on-the-ground supplemental programs would simultaneously inform and inspire national park visitors while increasing data quantity. Alternatively, the professional scientist approach could be combined with the citizen science approach, which could simultaneously increase data quality (if volunteers experience difficulty identifying phenophases) and quantity (by increasing the number of observers). However, given that we found quantitative differences in estimates of phenological timing between monitoring approaches (fig. 9), we recommend against using different approaches in different years (or switching approaches) to detect long-term trends. Clearly, there are many possibilities for creating and maintaining successful monitoring programs that simultaneously address scientific questions while incorporating citizen science or crowdsourcing approaches (Bonney et al. 2009; Dickinson et al. 2012).

We believe that the citizen science and crowdsourcing approaches to collecting scientific data represent viable alternatives to traditional monitoring programs, while simultaneously supporting the NPS mission to protect resources and provide for meaningful visitor experiences (Theobald et al. 2015). These approaches also align with recent calls for NPS staff to engage the next generation of conservation scientists and increase public understanding of science (NPS 2014, pp. 10 and 15; OTAG 2016). If continued over many years, these approaches can be used to monitor the impacts of climate change on wildflower phenology while getting the full benefit of the inherent opportunities for public engagement. At the same time, data collected using these approaches can serve as “canaries in the coal mine” to identify locations and trends of concern where managers can then focus limited resources and further investigation by professionals.

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References

Bakkegard, K. A., and L. J. Davenport. 2012. *Nephila clavipes* (Araneae: Nephilidae): A model species for monitoring climate change in the southeastern United States. Southeastern Naturalist 11:551–566.

Bonney, R., C. B. Cooper, J. Dickinson, S. Kelling, T. Phillips, K. V. Rosenberg, and J. Shirk. 2009. Citizen science: A developing tool for expanding science knowledge and scientific literacy. Bioscience 59:977–984.

Buckley, L. B., and M. S. Foushee. 2012. Footprints of climate change in US national park visitation. International journal of biometeorology 56:1173–1177.

Dickinson, J. L., J. Shirk, D. Bonter, R. Bonney, R. L. Crain, J. Martin, T. Phillips, and K. Purcell. 2012. The current state of citizen science as a tool for ecological research and public engagement. Frontiers in Ecology and the Environment 10:291–297.

Evans, C., E. Abrams, R. Reitsma, K. Roux, L. Salmonsen, and P. Marra. 2005. The Neighborhood Nestwatch program: Participant outcomes of a citizen-science ecological research project. Conservation Biology 19:589–594.

Fitter, A., and R. Fitter. 2002. Rapid changes in flowering time in British plants. Science 296:1689–1691.

Hurlbert, A. H., and Z. Liang. 2012. Spatiotemporal variation in avian migration phenology: Citizen science reveals effects of climate change. Plos One 7:e31662.

Inouye, D. W. 2008. Effects of climate change on phenology, frost damage, and floral abundance of montane wildflowers. Ecology 89:353–362.

Jordan, R. C., S. A. Gray, D. V. Howe, W. R. Brooks, and J. G. Ehrenfeld. 2011. Knowledge gain and behavioral change in citizen-science programs. Conservation Biology 25:1148–1154.

McKinney, A. M., P. J. CaraDonna, D. W. Inouye, B. Barr, C. D. Bertelsen, and N. M. Waser. 2012. Asynchronous changes in phenology of migrating broad-tailed hummingbirds and their early-season nectar resources. Ecology 93:1987–1993.

National Park Service. 2014. A call to action: Preparing for a second century of stewardship and engagement. National Park Service, Washington, DC, USA. Available at https://www.nps.gov/calltoaction/PDF/C2A_2014.pdf.

Newman, G., A. Wiggins, A. Crall, E. Graham, S. Newman, and K. Crowston. 2012. The future of citizen science: Emerging technologies and shifting paradigms. Frontiers in Ecology and the Environment 10:298–304.

Outreach Technical Advisory Group (OTAG). 2016. Science communication framework. National Park Service, Natural Resource Stewardship and Science, Washington, DC, USA.

Parmesan, C. 2006. Ecological and evolutionary responses to recent climate change. Annual Review of Ecology Evolution and Systematics 37:637–669.

Robbirt, K. M., D. L. Roberts, M. J. Hutchings, and A. J. Davy. 2014. Potential disruption of pollination in a sexually deceptive orchid by climatic change. Current Biology 24:2845–2849.

Theobald, E. J., A. K. Ettinger, H. K. Burgess, L. B. DeBey, N. R. Schmidt, H. E. Froehlich, C. Wagner, J. HilleRisLambers, J. Tewksbury, M. A. Harsch, and J. K. Parrish. 2015. Global change and local solutions: Tapping the unrealized potential of citizen science for biodiversity research. Biological Conservation 181:236–244.

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PS

Research Reports

Student and professional perspectives on park and protected area careers

By Matthew H. E. M. Browning, Jennifer M. Thomsen, and Wonjun Choi

Abstract
Young adults interested in park and protected area careers may feel discouraged because of the perceived difficulty in entering these careers. Simultaneously, park and protected area professionals may experience increased pressure and urgency to recruit qualified young adults because of the high number of baby-boomer retirements. Although both groups may believe they know some strategies for young adults to transition into these careers, they may not know the broad range of perspectives and ideas held by young adults and professionals at large. One such possible strategy is for organizations working with park and protected area professionals to facilitate the development and recruitment of young adults and, in particular, undergraduate and graduate students, who may be particularly competitive for job openings. Our study attempts to document the perceptions and current constraints facing students when entering park and protected area careers as well as how professional organizations might help them overcome these constraints. Using data collected from a career workshop at the 2015 George Wright Society conference, we present five factors that can influence students' success in the job market, five constraints that might prevent students from being successful, and two categories of opportunities for professional organizations to help students effectively pursue these careers. We believe our findings support students, recruiters, and hiring organizations through strengthening connections and outlining strategies to address some of the key issues facing park and protected area professionals in the 21st century.

Key words
job placement, park and protected area careers, professional organizations, student chapters, student employment

THE NATIONAL PARK SERVICE (NPS) AND SIMILAR bureaus and agencies are experiencing two overlapping constraints in job recruitment. First, young adults are having greater difficulties with securing jobs than people of other ages. Recent data from the US Bureau of Labor Statistics describe how unemployment rates for individuals in their early 20s are approximately 200% higher than those for individuals in their late 30s and 40s (BLS 2015). Thus, the many factors influencing job placement success for this generation of recent graduates have led to the highest peak in millennials making less than $25,000 per year in the past 25 years (Stahl 2015). The number of students seeking and earning advanced degrees has also significantly increased by more than 150% in recent years (NCES 2015), which further inflates job competition. This high level of job competition may be particularly strong in park and protected area fields that have experienced relatively flat budgets or budgets that have increased at a rate that has not kept up with the increased costs of labor. Such issues have prevented areas administered by the National Park Service, like the Blue Ridge Parkway, from filling more than 70 vacant positions since the early 2000s (Eilperin 2012). According to the NPS Office of Relevancy, Diversity, and Inclusion, only 4% of current NPS employees are 29 years old or younger (K. Reyes, workforce data analyst, NPS, e-mails with first author, 2 March 2016) while more than 20% of the US labor force is in this same age bracket and is gainfully employed (BLS 2015).

The second challenge regarding job recruitment is related to the large, impending turnover of employees due to baby-boomer retirements. This demographic, which consists of people born between 1946 and 1964, comprises 33% of today's workforce (BLS 2015). As senior employees, however, these baby-boomers are disproportionately represented in upper management positions. Nearly 21% of all NPS managers were eligible to retire by the end of 2016. In contrast, only 15.8% of the nonmanagerial NPS employees could retire in the same timeframe (K. Reyes, workforce data analyst, NPS, e-mails with first author, 2 March 2016). These

MATTHEW H. E. M. BROWNING

Figure 1. The career workshop at the George Wright Society 2015 conference brought together students and professionals interested in discussing park and protected area careers. These groups had the opportunity to answer questionnaires, which provided data documenting perceptions of park and protected area careers.

upper-level vacancies will simultaneously require internal readjustments as well as a host of new hires during a transition that will play out over the course of many years. The challenge is for agencies to plan ahead strategically for both coherence and continuity during this transition. As such, employers must focus on recruiting a large number of new employees with high leadership potential for rapid advancement. Recent graduates also need to set lower expectations for their first job. For example, while many recent graduates may have the skill set for higher-level positions, they may be best served by obtaining seasonal or temporary positions (Doyle et al. 1999). Students may be more receptive to this route if they have an understanding that the employer supports rapid upward mobility.

These two constraints provide a great opportunity for professional organizations such as the George Wright Society to help recent graduates be successful in entering park and protected area careers. Professional organizations might extend career services offered by higher education institutions (e.g., career workshops, education courses, practice interviews, and career fairs) but also informal networking opportunities to connect young adults with potential employers. For example, the International Association for Society and Natural Resources (IASNR) has a Student Affairs Committee and a "students" tab on their website for announcements, mentoring opportunities, and student-driven events at their annual forums to further collaboration and professional development. Similarly, the George Wright Society (GWS) offers an annual Park Break program that promotes a weeklong immersion experience for students to engage with professionals in the field around real-world issues in park and protected area management. Such opportunities would help young adults learn about employers' expectations, prepare for the job application process, and build a professional social network. Additionally, these opportunities would help employers identify and recruit future young professionals qualified for their agencies with the appropriate skill set to be successful in their career (Sharp and Doucette 2014).

To gain a better understanding of these dynamics, we hosted a workshop and developed questionnaires to gather perspectives on park and protected area careers from both students and career professionals. Our three specific goals were to understand (1) what factors are needed for students to be successful in pursuing careers, (2) what constraints prevent students from obtaining and advancing in their careers, and (3) how professional organizations might simultaneously help students in their career pursuits and agencies in their recruitment of these students. We focused largely on currently enrolled undergraduate and graduate students, because we believed this cohort might be particularly competitive for related job openings. Furthermore, this cohort would be likely to fulfill agency needs for new employees with leadership potential. Professionals were also included in the study to offer their perceptions from the agency and organizational points of view.

Methods

The George Wright Society conference is a biennial event and one of North America's premier interdisciplinary conferences on protected areas. It is attended by anywhere from 350 to more than 1,000 professionals (700 in 2015), of which approximately 50% are federal agency employees and as many as 100 are students (D. Harmon, executive director, GWS, e-mail to first author, 27 January 2016). At the 2015 GWS conference in Oakland, California, we organized a two-hour career-focused workshop (fig. 1). This workshop brought together 55 students and approximately 30 professionals to discuss different conservation careers, such as jobs with the National Park Service and other land management agencies, nonprofit organizations, and universities. Four "career sectors" related to the management of park and protected areas were discussed: governmental agencies, academic, nonprofit, consultant, and corporate. During the session, students rotated among groups of professionals to discuss the biggest challenges and opportunities of working in each of these sectors in addition to strategies for navigating challenges and being successful in a park and protected area career more broadly. The session was followed by an informal networking opportunity at a nearby restaurant.

We developed questionnaires to collect diverse perspectives on obtaining careers in park and protected areas. These questionnaires consisted primarily of open-ended questions, each of which focused on the three specific components of our study (factors for success, career constraints, and professional organization opportunities to assist students). The questionnaire prompts and formatting were initially pilot tested with 15 park and protected area professionals from universities and governmental agencies and 16 undergraduate and graduate students from two US universities. These students were majoring in human dimensions of natural resources, recreation or parks management, or environmental sciences. Based on feedback from the pilot test, the questionnaires were further refined before submission and approval by the University of Illinois at Urbana-Champaign's Institutional Review Board. We used the refined questionnaires for our survey of students and professionals at the GWS career workshop.

The two questionnaires were interrelated; one targeted current students seeking employment, while the other focused on professionals working in various agencies and organizations. We asked student respondents what career sector(s) they were most interested in entering, and we asked professionals what sector best described their current employment. We also asked all respondents about the top three ways graduate students could be successful in the career sector they indicated earlier, as well as

Table 1. Representation of parks and protected area career sectors in survey sample

Sector	Number of Respondents	
	Students' Interests	Professionals' Careers
Agency Federal, state, or local governmental agency	21 (66%)	3 (30%)
Academic University/college faculty or staff	12 (38%)	2 (20%)
Nonprofit Nonprofit organization (other than higher education)	11 (34%)	2 (20%)
Consultant For-profit company or organization	11 (34%)	2 (20%)
Corporate For-profit company or organization	8 (25%)	1 (10%)
Total	32[a]	10

[a] Some student respondents indicated more than one sector. As such, the total number of students is lower than the sum of students interested in each sector.

the top three constraints facing graduates interested in that same sector. Professionals were asked how each of these challenges had changed since they started working in that career sector. Last, we asked all respondents how the George Wright Society and other professional organizations could help graduate students be successful in these career sectors.

Participation in the study was voluntary and individuals could complete the relevant questionnaire at the beginning of the session or through a web-based version after the session. We received responses from 33 students and 10 professionals (51% response rate). We then studied the responses for words and phrases that represented themes within each of our three study components (e.g., "experience" and "social connectivity" were themes identified within the "factors for success" component). Last, we calculated the frequencies with which each theme was present in each group of respondents' (students' and professionals') answers.

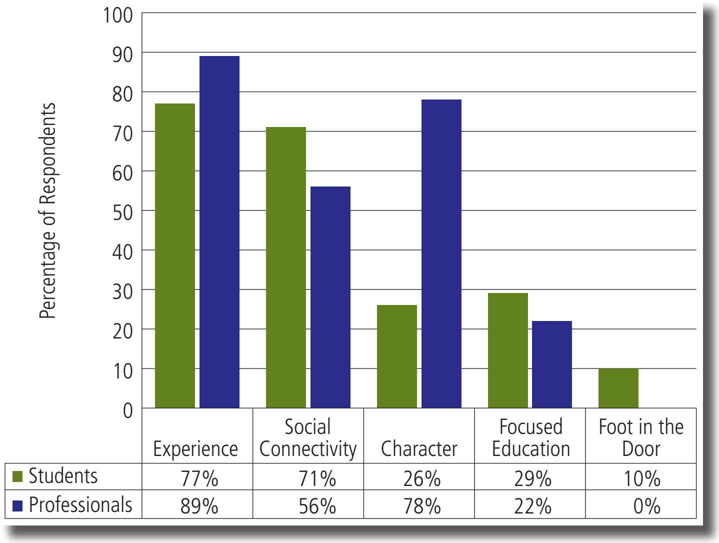


Figure 2. The percentage of students and professionals who pointed out different factors for success in parks and protected area careers.

Results

Career sectors

Agencies or bureaus were the most frequently cited desired or current employers for both professionals and students, followed by academic institutions, nonprofit organizations, consultants, and corporations (table 1). Nearly 33% of student respondents (n = 10) indicated interest in multiple employers. Of the 21 students who cited the "agency" career sector, 5 indicated they were also interested in the nonprofit sector, and 3 indicated additional interest in the academic sector or consultant roles.

Career perspectives

Students and professionals had similar perspectives on park and protected area careers. The themes derived from survey responses resulted in five factors for success, five constraints, and two categories of opportunities for professional organizations (see tables 2 and 3, next page).

Respondents discussed some themes more than others. The majority of students perceived experience and social connectivity as factors for success (fig. 2). More than half of professionals also discussed these two factors in addition to character traits such as determination, flexibility, and commitment to public service. A majority of both groups cited bureaucratic systems, particularly as they relate to hiring processes and organizational cultures, as significant constraints (fig. 3, page 31). A majority of students cited competition—both the sheer number of other highly qualified job

Table 2. Types of perceptions about park and protected area careers

Component	Theme	Findings
Factors for Success	Experience	Work. Volunteering. Internships. Research projects.
	Social Connectivity	Networking. Having a professional network. Collaborating. Building a strong relationship with an academic advisor. Being a team player.
	Expertise	Being an expert in a field. Earning advanced degrees. Attending relevant workshops and conferences. Gaining specific skills such as research methods. Writing and publishing papers. Using GIS. Writing grant applications. Teaching courses.
	Character	Determination. Hard work. Flexibility. Self-motivation. Planning. Collegiality. Commitment to public service. Capitalization on new opportunities. Ability to deal with bureaucracies. Interdisciplinary capabilities.
	Foot in the Door	Internships that are explicitly tied to more successful job applications. Entry-level jobs. Pathway programs. Using career service offices.
Constraints	Lack of Opportunities	No jobs. No funding.
	Bureaucratic Systems	Difficulty navigating USAjobs.gov. Getting past "gatekeepers." Finding job opportunities, in particular "that first job." Navigating shifting management paradigms. Understanding nontransparent hiring processes. Not knowing "the right people." Lack of knowledge about an agency's culture. Lack of social network.
	Academic and Professional Demands	Too much information to know. Lack of time in school. High advisor standards. Low or no pay for internships and entry-level positions. Needing to frequently move when pursuing degrees and advancing in careers.
	Personal Issues	Student debt. Difficult work/life balance. Minority/international student status. Inability of (or lack of interest in) adapting to new environments or geographic locations. Difficulty finding "the right fit" with an employer. Lack of clarity about career goals. Feeling torn between purely academic research and applied research. Having to accept lower-level positions despite sufficient levels of education and experience.
	Competition	Increasing pressure for advanced degrees. More people having doctorate degrees. Increasing need for publications. Flooded and highly competitive job markets. Increasing need for diverse skill sets. Not adequately distinguishing oneself from other candidates. Overcoming assumptions from others about one's age and/or abilities.
Opportunities for Organizations	Indirect Support	Posting job opportunities. Providing networking opportunities. Connecting students with mentors (e.g., faculty affiliate groups or formal mentor programs). Promoting peer networks (e.g., student chapters or social opportunities at conferences).
	Direct Support	Research projects. Grants. Internships. Scholarships. Publication forums. Workshops on federal application processes. Career panels. Other types of training programs.

Table 3. Frequency of reporting different perceptions about parks and protected area careers

		Number of Respondents	
Component	Theme	Students	Professionals
Factors for Success	Experience	24 (77%)	8 (89%)
	Social connectivity	22 (71%)	5 (56%)
	Focused education	9 (29%)	2 (22%)
	Character	8 (26%)	7 (78%)
	Foot in the door	3 (10%)	0 (0%)
Constraints	Lack of opportunities	17 (55%)	1 (11%)
	Bureaucratic systems	17 (55%)	6 (67%)
	Academic and professional demands	14 (45%)	7 (78%)
	Personal issues	9 (29%)	3 (33%)
	Competition (also inability to self-promote)	8 (26%)	6 (67%)
Opportunities for Professional Organizations	Indirect support	19 (79%)	4 (57%)
	Direct support	12 (50%)	4 (57%)

applicants with whom they would have to compete and the difficulty of distinguishing oneself against these other applicants—as a constraint. A majority of professionals cited academic and professional demands as a constraint. Indirect provision of experiences and facilitation of professional support were mentioned as two opportunities for professional organizations by majorities of students and professionals, respectively (fig. 4).

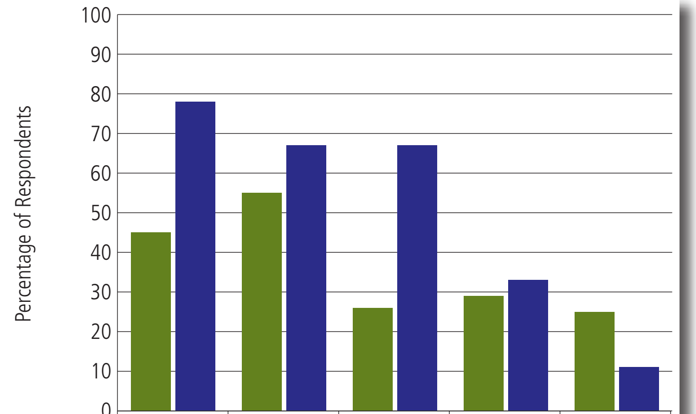
Professionals provided qualitative feedback revealing that some constraints had become more severe since they started in their specific career sector. Five professionals indicated that the lack of opportunities or number of qualified applicants had increased. Two respondents mentioned that agencies were implementing "pathway" programs to overcome some of these constraints. Professionals reflected that some other constraints had not changed over time, including personal issues, professional demands, and difficult systems.

Discussion and conclusion

Our study of attendees at the 2015 GWS conference career session found that students and career professionals were generally in alignment on what factors contributed to career success, what types of career constraints existed, and what opportunities were available for professional organizations to assist students in pursuing park and protected area careers. Experience (e.g., jobs, internships, volunteering, and research projects) and social connectivity (e.g., networking) were frequently discussed by both groups of respondents, while focused education (e.g., being a content expert and knowing specific skills) and "getting a foot in the door" were less frequently discussed. On the other hand, the majority of professionals believed character traits were important factors, but the majority of students did not. These findings suggest that students should focus on those factors that potential future employers believe to be important when obtaining jobs (e.g., work/volunteer experience and networking) in addition to leadership training that builds character traits desirable by potential employers.

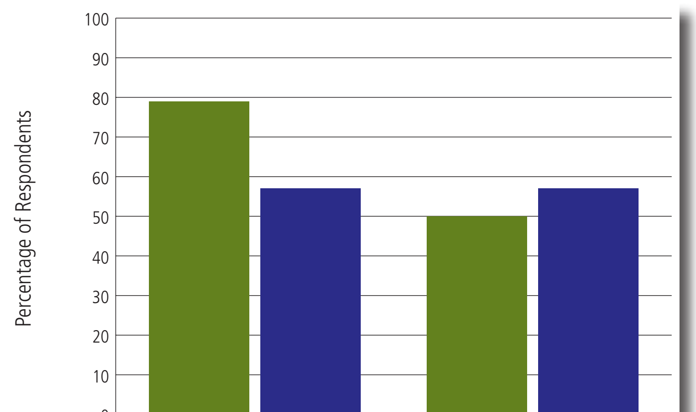
The majority of students and professionals identified that bureaucratic systems and professional or academic demands (e.g., low pay for entry-level jobs and relocation) were constraints for students pursuing careers. Lack of jobs and lack of funding opportunities were also identified by a majority of students, but few professionals mentioned these as constraints. These findings reinforce the notion that securing a job is a difficult professional and personal journey, and suggest that students may have a more accurate perspective on the number of jobs available to them than potential employers (e.g., BLS 2015).

We also discovered that many students have interests in multiple career sectors related to park and protected areas, such as agency, academic, and nonprofit jobs. This finding may be related to students' perceived career constraints. Students may want to



	Academic and Professional Demands	Bureaucratic Systems	Competition	Personal Issues	Lack of Opportunities
Students	45%	55%	26%	29%	25%
Professionals	78%	67%	67%	33%	11%

Figure 3. The percentage of students and professionals who pointed out different challenges or constraints to park and professional area careers.



	Indirect Support	Direct Support
Students	79%	50%
Professionals	57%	57%

Figure 4. The percentage of students and professionals who pointed out two types of opportunities for organizations to assist students in pursuing park and protected area careers.

apply to a greater diversity of jobs, because they perceive there is a lack of job opportunities and that a "shotgun approach" might increase their chances of receiving at least one job offer. In other words, students may feel like they cannot be overly selective with the specific career sector they enter or which employer they would work for. Students also appear deterred by the job application processes associated with bureaucratic systems (http://usajobs.gov, in particular). Students may also want to maximize how many job options they have because of the substantial demands associated

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with any particular position (e.g., initial job offers and advancement opportunities may require moving frequently or moving to undesirable locations).

Our respondents identified a number of ways that professional organizations might help students be successful in pursuing park and protected area careers. Both students and professionals discussed professional organizations directly and indirectly providing students with support through such means as work experience, mentoring, and focused education opportunities. A small number of student respondents also discussed peer networks, such as student chapters, as a way to help them in their careers. These findings suggest that professional organizations can help students in ways that might require extensive investments (e.g., internships, research funding, and training), but also in other ways that require less cost (e.g., connecting students with mentors, providing networking opportunities, and posting job opportunities).

The ability to generalize our findings is limited by our sampling frame (e.g., undergraduate and graduate students and professionals capable of traveling to this particular conference, and those who were able—and inclined—to attend this particular workshop), small sample size, and limited response rate. As such, we recommend that future researchers use more diverse and representative samples of students and professionals to offer greater ability to generalize findings. We also recommend that future researchers quantitatively investigate the extent to which these perceived factors for success and career constraints are actualized in the job market.

More generally, our study suggests different issues for current and future park and protected area professionals to target when advancing in their careers and recruiting qualified job applicants. We encourage further discussion on how agencies, universities, and professional organizations can help young professionals activate those factors for support to enter their careers—as well as to negotiate possible career constraints.

Acknowledgments

We would like to thank the George Wright Society staff and board of directors for their support of our career workshop and accompanying research study. We would also like to thank all the career professionals who agreed to come to our workshop, many of whom were not already attending the conference and thus went out of their way to attend this particular event.

References

Doyle, K., S. Heizmann, and T. Stubbs. 1999. The complete guide to environmental careers in the 21st century. Island Press, Washington, DC, USA.

Eilperin, J. 2012. National parks face severe funding crunch. The Washington Post. Accessed 19 February 2016 at https://www.washingtonpost.com/national/health-science/national-parks-face-severe-funding-crunch/2012/08/19/959da5b0-e7ab-11e1-a3d2-2a05679928ef_story.html.

National Center for Education Statistics (NCES). 2015. The condition of education 2015. Institute of Education Sciences, US Department of Education, Washington, DC, USA. Accessed 19 February 2016 at https://nces.ed.gov/pubs2015/2015144.pdf.

Sharp, R., and N. Doucette. 2014. Preparing the next generation of protected area employees: Opportunities for students, agencies, and universities. Proceedings of the 2013 George Wright Society Conference on Parks, Protected Areas, and Cultural Sites, Hancock, Michigan, USA.

Stahl, A. 2015. The 5.4% unemployment rate means nothing for Millennials. Forbes Magazine. Accessed 19 February 2016 at http://www.forbes.com/sites/ashleystahl/2015/05/11/the-5-4-unemployment-rate-means-nothing-for-millennials/#738d293357d4.

US Bureau of Labor Statistics (BLS). 2015. Labor force statistics from the current population survey. Accessed 19 February 2016 at http://www.bls.gov/cps/home.htm.

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How professional organizations were critical to my career

BY MATTHEW H. E. M. BROWNING

I RECENTLY GRADUATED FROM A DOCTORAL PROGRAM and spent nine months in a job search. I also helped develop the graduate student career workshop at the 2015 George Wright Society conference that we describe in the accompanying research report published on these pages of *Park Science.*

I found that most of the study results matched my personal experience. I was interested in multiple career fields (nearly one-third of student respondents also indicated interest in multiple career sectors), and I ended up applying to jobs in all five career fields identified in the study. Simultaneously, I worked to gain experience, advanced education, social connections, and "a foot in the door," and I felt all of these helped me write competitive job applications.

One study finding—the perceived lack of jobs—did not match my experience. I believed there was a relative abundance of job openings during the time I searched (June 2014 to February 2015), and I ended up applying for 18 openings, all of which had something to do with human dimensions of natural resources. Eleven of these were academic positions (9 of which were tenure-track), 4 were agency jobs (1 of which was a permanent position), 1 was corporate, 1 was nonprofit, and 1 was with a small firm, effectively an independent consultant. I also identified another 17 jobs during my search for which I could have applied but chose not to. Again, all of these focused on human dimensions of natural resources. My doctoral advisor was as surprised and happy at these opportunities as I was, saying, "I've never seen so many openings in our field."

My biggest surprise from the study, however, was how closely the opportunities for professional organizations to help graduate students enter park and protected area careers matched my experience. I've been heavily involved in two nonprofit organizations during my graduate studies: the Children and Nature Network (C&NN) and the George Wright Society (GWS). Both of these organizations have been extremely generous in helping me pursue my career, and I believe I can attribute much of my career trajectory to the opportunities they've provided me.

Our study found that organizations could provide five types of opportunities for students: directly providing experience, indirectly providing experience, facilitating professional support, promoting peer networks, and offering focused education. Both C&NN and GWS contributed to each of these fields substantially. The Children and Nature Network provided me in-person trainings, webinar continuing education sessions, internship opportunities, research studies, a publication forum, and a strong peer network of "Natural Leaders" with similar interests and values to mine. Their professional support was

BRIAN STAUFFER, UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN NEWS BUREAU

Matthew Browning

also outstanding. Their former CEO served on my PhD committee, and their board members and partner agencies sponsored my initiatives, hired me for research projects, wrote recommendation letters for me, and sent me "insider information" on job openings. The George Wright Society was equally helpful. They offered me in-person trainings and conference workshops, research project opportunities, a publication forum, wonderful mentorship from the executive director and board, and a seat on the board of directors reserved solely for graduate students. I'm positive that both of these organizations also indirectly enhanced my ability to find a meaningful career in ways I have yet to identify.

I'm greatly indebted to these two organizations, and I see their offerings to be unequivocally correlated with my career. However, I believe that I was able to capitalize on their offerings partly because I remained focused on being aware of these opportunities and on putting together competitive applications for these opportunities. Some of my fellow graduate students were not as focused on working with professional organizations as I was. As such, I see a great potential for organizations to further connect students with meaningful careers. I believe the key will be increasing awareness of and participation in career opportunities from diverse groups of students, not just those who already prioritize working with, and taking advantage of, the opportunities provided by professional organizations.

STARFire: Strategic budgeting and planning for wildland fire management

By Douglas B. Rideout, Andrew G. Kirsch, Yu Wei, and Nicole J. Kernohan

Abstract
University researchers and program analysts at the US Department of the Interior (USDOI) have collaborated to produce the STARFire spatial strategic budgeting and planning system. As the first system of its kind, it addresses concerns expressed by the USDOI Office of Policy Analysis, the National Cohesive Strategy, and the US Government Accountability Office. The system relies on fire behavior, fire probabilities, valuation, and cost information to support four analysis modules: risk analysis, fuel treatment optimization and prioritization, preparedness, and program analysis and budgeting. The system also uses the unique nonmarket and nonmonetized valuation system known as MARS (Rideout et al. 2008) to express values as rates of substitution across the system to facilitate consistent comparisons of alternatives. The system was developed to be scalable and has been applied at the planning unit scale as well as state and regional scales.

Key words
budgeting, Bureau of Land Management, Department of the Interior, economics, fuels treatment, GIS, National Cohesive Wildfire Management Strategy, National Park Service, planning, spatial planning, preparedness, return on investment, scale

LENGTHENING FIRE SEASONS (WESTERLING ET AL. 2006), increasing fuel loads (USDOI and USDA 2014), flat budgets, and a growing wildland-urban interface have increased the complexity of wildland fire issues facing the National Park Service and other land management agencies. The National Cohesive Wildland Fire Management Strategy was initiated in 2009 (USDOI and USDA 2014) to address these and other wildfire management challenges across the United States. The strategy was completed in 2014 and identifies key goals of restoring and maintaining fire-resilient landscapes while considering "wildfire risk, values at risk, and appropriate response to wildfire at different temporal and geographic scales." In addition to balancing wildfire management decisions between these objectives, the US Government Accountability Office (GAO, formerly the US General Accounting Office) continues to recommend that land management agencies improve the cost-effectiveness of fire programs with better accountability for spending (GAO 2002, 2005, and 2009). Similarly, the Cohesive Strategy (USDOI and USDA 2014) recommends performance measures and metrics for assessing the accomplishment of its outlined goals. The complexities of providing such metrics are highlighted in a report by the USDOI Office of Policy Analysis (2012). This analysis stresses that "[o]ne of the greatest challenges with comparing costs and benefits [of wildfire] is in characterizing everything in terms of a common metric, such as dollars, especially as nonmarket goods and services are often difficult to quantify and monetize."

A collaborative effort, initiated about 2008, among the National Park Service, Colorado State University, and other USDOI bureaus (the Bureau of Land Management and the US Fish and Wildlife Service) led to the development of the spatial budgeting and planning system called STARFire to address this suite of wildfire management issues. STARFire was initially designed to address resilient landscapes by accounting for diverse landscape values (including nonmarket values), ecosystem condition, and management costs. As such, STARFire enables planners and managers to evaluate the risks of wildland fire while restoring and maintaining resilient landscapes in a cost-effective manner.

The inputs (management costs, burn potential, and fire-affected values) support calculations for STARFire's performance metric of return on investment (ROI). This metric is tightly integrated within STARFire to support efficiency in data acquisition, storage, and system computations. This enables STARFire to support comparisons across management programs and accommodates analysis at varying geographical scales. For example, STARFire can be applied at individual parks (or planning units) or expanded to address regional- and national-level analyses. At the park level, STARFire's ROI computation can account for, compare, and defend management decisions while supporting appropriation requests. At the national scale, STARFire provides efficient decision support for federal agencies to allocate money received from the Congress. Additionally, STARFire can prioritize expenditures to different locations across the country while identifying how that money would be spent to promote return on investment on fire management. It can quantify return on investment for planning alternatives and assess the impact of budget increases/decreases across fire programs. In particular, STARFire provides decision support and performance accountability for wildfire risk, fuel treatment programs, and preparedness programs.

STARFire's analysis modules include the following:

Wildfire Risk Assessment—identifies where wildfire is expected to produce the most loss (considering all values) and where it can generate the greatest ecosystem benefit.

Landscape Value Added from Wildfire Management Activities—calculates the expected present value added to the landscape through management activities. For instance, this quantifies the potential to add value by conducting a fuel treatment or by engaging in protection through preparedness programs. This intermediate product is used to integrate the Fuel Treatment and Preparedness modules.

Fuel Treatment Analysis and Locator—aids fire planners in locating and prioritizing fuel treatments that reduce hazards or improve the ecosystem condition to provide the highest return on investment across the landscape. Optimal treatment locations can be modeled by STARFire or input by the analyst to be evaluated and prioritized.

Preparedness Analysis—preparedness is about getting ready for the fire season with crews and equipment, and STARFire models the return on investment across a range of potential preparedness budgets and values at risk.

Interprogram Analysis—STARFire analyzes the program balance between fuels and preparedness. Managing this balance, while including the interactions of these parameters, is a key element necessary for efficient management and budgeting.

The STARFire system and each of its analysis modules were created and programmed through a series of research agreements under the Colorado Plateau unit of the Cooperative Ecosystem Studies Unit (CESU) Network. Additional funding has been provided by the McIntire-Stennis research program at Colorado State University and by the Joint Fire Science program.

STARFire enables planners and managers to evaluate the risks of wildland fire while restoring and maintaining resilient landscapes in a cost-effective manner.

The STARFire analyses

Each STARFire module is supported by a set of common inputs, including fire-affected values, management costs, fire history, and burn probabilities. The landscape is rasterized for analytical purposes using a consistent cell size. Fire-affected values consider the entire spectrum of values, including property, infrastructure, and nonmarket goods and services such as critical habitat and watershed condition. Fire-affected values are defined spatially and their associated values are estimated using a structured elicitation process known as MARS (Marginal Attribute Rates of Substitution) (Rideout et al. 2008). This process requires convening a set of subject-matter experts with responsibility for managing the natural and ecological resources and for planning and managing fire at the site. During the elicitation process, experts identify and define the set of fire resources that are positively and negatively affected by fire. They then estimate the magnitude of the fire effect on resource value relative to each of the other resources in the value set (per cell). These values are also elicited by fire intensity and by ecosystem condition. These are defined economically as "rates of substitution" and kept in a nonmonetized internal currency in the analysis but can be easily converted and expressed in dollars (Rideout et al. 2008). The currency's numeraire is highly valued property that is common across all areas to facilitate comparisons across the full range of values and across planning units; it is expressed in units occasionally dubbed WUIcoin, short for Wildland Urban Interface coin. For example, each planning unit has developed housing or its equivalent. A comparison of independently elicited values among several national parks (Rideout et al. 2012) demonstrates a remarkable consistency in the relative protection of and improvement in values of national park resources.

By introducing cost information and comparing it with values and probabilities, we are able to use expected return on investment as a single performance metric. The metric supports the direction given by the Government Accountability Office and addresses the challenge identified in the 2012 policy analysis document of comparing disparate values introduced in nonmarket valuation. The ROI metric enables efficient comparisons among management programs and among planning units within an agency. It also facilitates potential comparisons among agencies (with disparate values and missions) and across national programs. Fire behavior (generated from FlamMap or similar) and fire history information is used to estimate burn and ignition probabilities. The fuel models and fire behavior modeling parameters can be adjusted to model alternative scenarios such as longer fire seasons and increased fire loading. Fire behavior modeling outputs are static and vary by cell, are calculated for each burnable cell on the landscape, and are stored for use. Probabilities are then applied in two separate approaches: the first is to assess wildfire risk and the second is to assess the potential to add value on the landscape from wildfire management activities such as fuels treatment and preparedness budgeting. These analysis modules are described further later in this article.

STARFire analysis modules

Wildfire Risk Assessment

This module can help managers visualize the appropriate response to wildfire anywhere on the landscape, and it can also be used to support post-fire reviews. STARFire builds a custom fire footprint based on conditional burn and spread probabilities for each ignitable cell on a gridded landscape (Rideout et al. 2008). Conditional probabilities refer to burn probabilities estimated given an ignition. Combining the probabilistic footprint with the fire-affected value information, STARFire estimates the expected net benefit of the fire footprint and stores it back at the ignition cell. The resulting output (fig. 1) quantifies the expected value of wildfire risk and benefit for each burnable cell on the landscape. The red cells indicate expected net loss and the green cells indicate expected net benefit from fires originating in that cell. A cell may be colored red because it contains a highly valued resource that would be damaged if burned. A cell may also be colored red because, if it ignites, it has the potential to burn into a sensitive value based on fire spread and the cell's probabilistic fire footprint.

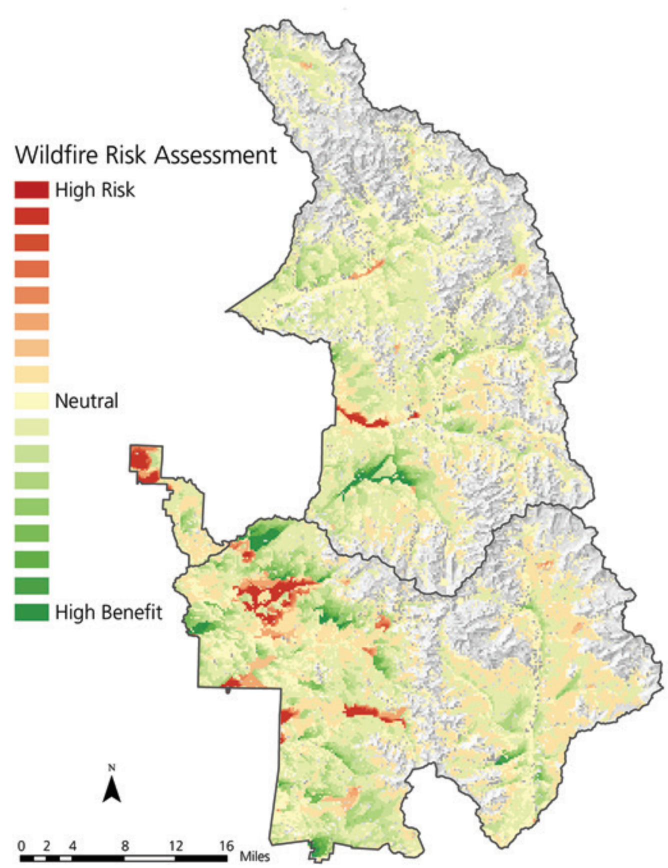
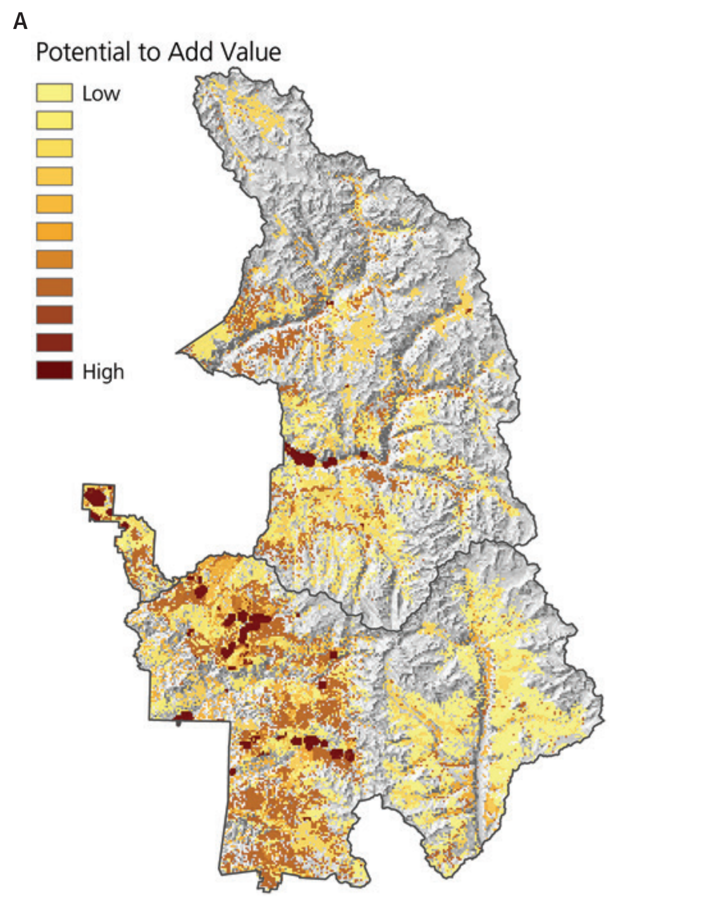


Figure 1. Wildfire risk assessment at Sequoia and Kings Canyon National Parks.

Landscape Value Added from Wildfire Management Activities

STARFire calculates the potential to add value from wildfire management activities (fig. 2, panel A, facing page) by combining the burn probability information, fire behavior, and the fire-affected value information. Burn probabilities are calculated for each cell on the landscape using fire behavior information and ignition probability information (generated from the fire history). The potential value added on each cell is given by the loss (benefit) of it burning and its probability of burning. Measuring the expected value added (VA) across the landscape enables the integration of STARFire program components such as fuels treatment and preparedness budgeting. In addition to assessing the potential to add value to a particular landscape, the measurement enables comparisons across planning units. For example, figure 2, panel B, demonstrates how the potential to add value from fire management activities can be compared across national parks (or other planning units) using the common currency of WUIcoin, described earlier.

The Landscape Value Added analysis is an intermediate product that is used to quantify the expected benefit of varying levels of fuels treatment and preparedness by budget level. It can also be used to support future analysis modules such as postfire rehabilitation. Currently, fuel treatment and preparedness programs are the two management approaches used to facilitate resilient landscapes and mitigate fire risk. The measurement of expected value added shows where the greatest value can be obtained through



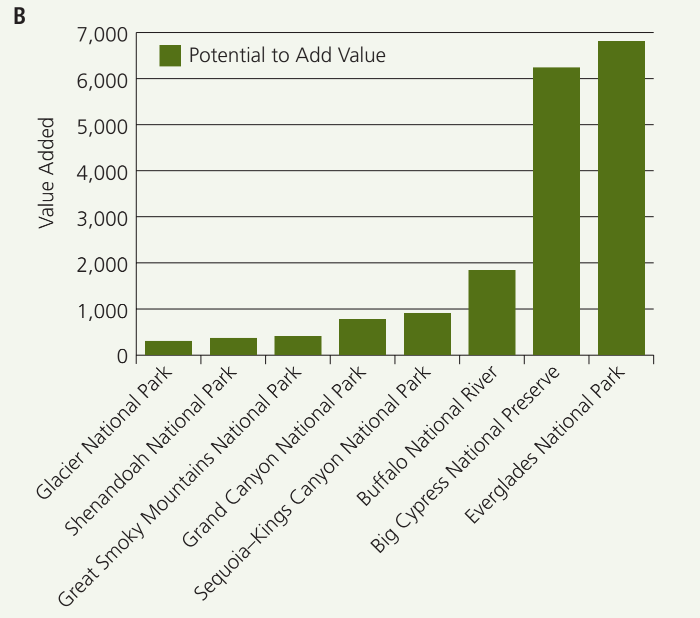


Figure 2. STARFire measures the potential to add value to a landscape or planning unit from fire management activities as displayed in the panels at left (A) and above (B). Panel A shows the potential to add value from wildfire management activities measured in STARFire's internal currency. Panel B compares the potential to add value at eight different national parks. (Data are shared online in a linked table.)

fire management activities and is used to support the following two modules.

Fuel Treatment Analysis and Locator

Land management agencies use fuel treatments to reduce hazardous fuels and to improve ecosystem condition, and these benefits often occur jointly. Guided by return on investment as a performance measure, STARFire optimizes and prioritizes fuel treatment locations to account for these effects and management costs (Rideout et al. 2014). The management costs often include considerations such as cover type, ecosystem condition (maintenance vs. restoration), treatment type, accessibility, and region. STARFire can identify optimal fuel treatment locations on the landscape based on return on investment, or alternatively, it can apply user-defined treatment schedules. To quantify the effect of the fuel treatment on the landscape, post-treatment fire behavior data are estimated (using FlamMap or something similar) by updating the fire modeling landscape to reflect the effects of the treatment (e.g., updated fuel models). The altered fire behavior (fire intensity, rates of spread, and spread direction) is then used to adjust STARFire's use of fire-affected values and burn probability calculations. The value added by the treatment plan is assessed by comparing post- and pretreatment surfaces. This quantifies the amount of value added to the landscape from hazard fuel reduction and the expected benefit from the completed treatment. Figure 3, panel B (page 39), shows the STARFire recommended fuel treatment locations for three different acreage budgets. Panel A (next page) shows the value added from alternative budget levels. The results allow land management agencies to demonstrate the return on investment from their fuel treatment programs and how budget declines can reduce the value of the landscape.

Preparedness Analysis

In planning and budgeting for preparedness, the National Park Service and other land management agencies are interested in the dual importance of reducing wildfire risk to highly valued resources (via initial attack) and the management of beneficial wildfire (BWF) for resource improvement or ecological restoration. Beneficial wildfire has been discussed under several aliases, such as “appropriate management response” and “wildland fire use.” To manage these dual purposes, agencies employ a similar set of resources, including crews, equipment, and planning. STARFire provides the unique ability to allocate a single “preparedness” budget to these dual purposes and assess how much value added and return on investment each component contributes (Rideout et al. 2016). For the risk reduction component, STARFire compares fire spread rates with arrival times for deployed resources using principles of diminishing returns and standards for initial attack success (Rideout et al. 2016). For the management of beneficial wildfire, STARFire uses diminishing returns to relate the preparedness budget with the expected value of benefit that incorporates the singular concept of relating BWF program size with program budget. Program size, for a given budget, is also uniquely related to the distance that any potential BWF cell is to a cell containing a valuable resource to protect, under the assertion that cells close to protection resources are more complex and costly to manage for beneficial wildfire (Rideout et al. 2016). Figure 4 (facing page) shows the amount of value added by the preparedness program at alternative levels of funding for risk reduction (red bars) and the promotion of beneficial wildfire (green bars). Note that the amount of value added, including the benefits from wildfire, increases as budgets increase. STARFire can assess the potential value added from beneficial wildfire (green portion of the bars) and the value added from loss mitigation (red portion of the bars) by budget level.

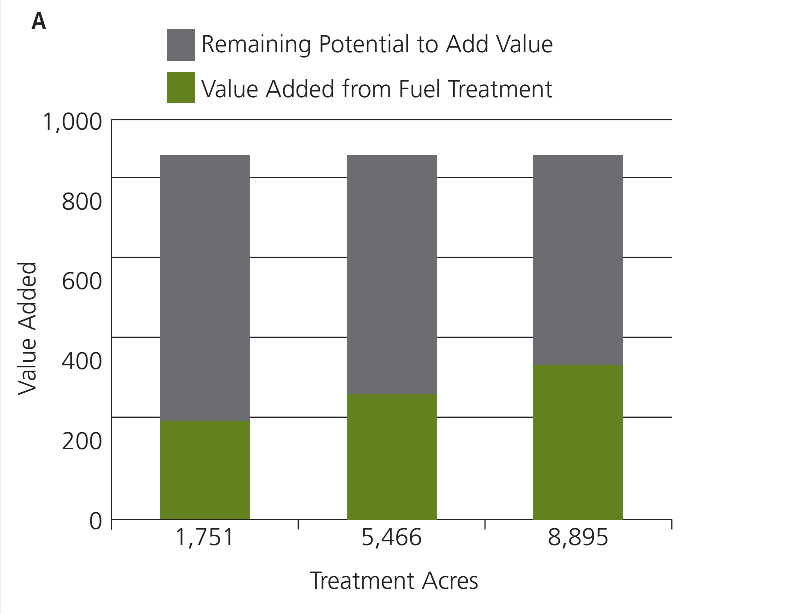
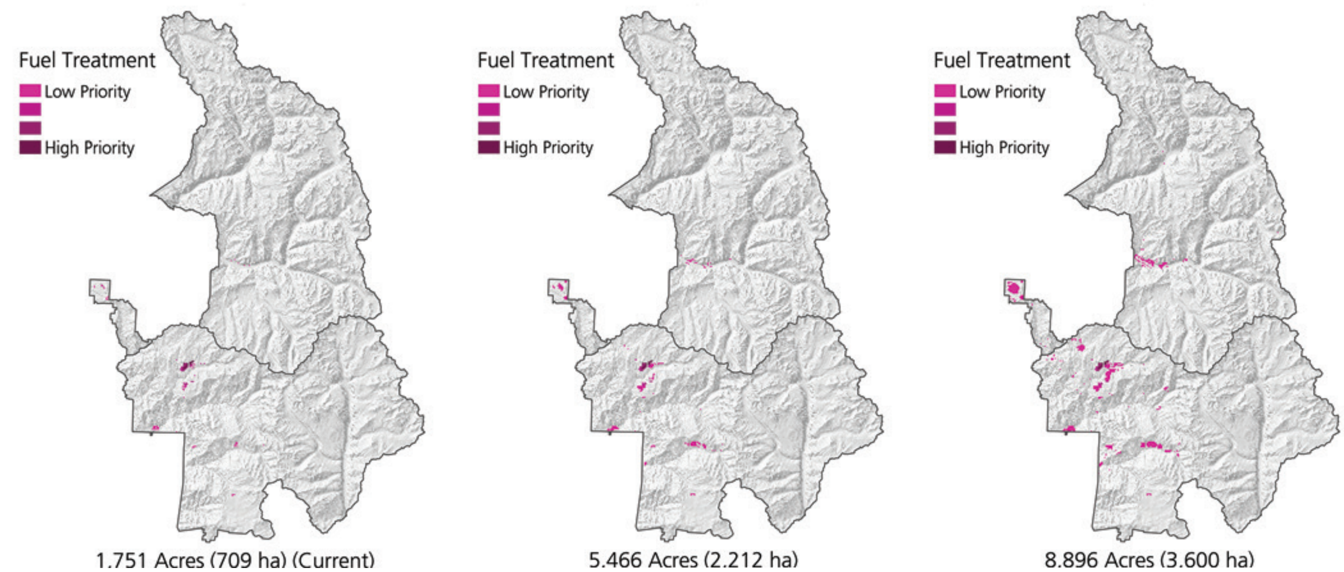


Figure 3. STARFire demonstrates the amount of value added from three different fuel treatment budgets in this example at Sequoia and Kings Canyon National Parks. Panel A (above) shows the value added from three different acreage budgets at the parks. (Data are shared online in a linked table.) Panel B (facing page, at top) shows the STARFire-recommended fuel treatments at three different acreage budgets at these parks.

Interprogram Analysis

Another novel feature of STARFire is its ability to integrate the fuel treatment and preparedness analyses to guide more efficient management and budgeting for the fire program. Fuel treatments for hazardous fuel reduction typically reduce fire intensity and spread rates of future wildfires (Stratton 2004). Reduced spread rates improve the ability of the firefighting operation to contain fires successfully in initial attack, and lower intensities often reduce expected losses across the full range of resources at risk. Fires contained in initial attack are typically much less costly than those that spread. This is a key linkage between the preparedness program and the fuels program, and STARFire can quantify and provide decision support for managing the trade-off of this interaction. For example, figure 5, panel A (page 40) shows an interpolated surface of the relationship of fuel treatment (y-axis) and preparedness (x-axis) funding levels. The height of the surface (z-axis) shows the amount of expected landscape value added by all combinations of the programs (Wei et al. 2016). The black line (expansion path) shows how increased funding would be allocated to the two programs. Starting at a zero budget, it balances the program funding alternatives to generate the greatest increase in value added without disrupting either program. This gives an intuitive interpretation of how funding allocations between the two programs affect value added to the landscape from the fire program. In panel B, the dotted line represents an equal balance of preparedness and fuel treatment funding and is used as a visual reference for equal funding between the two programs. The solid blue line was constructed from the expansion path in panel A. The white circle in panel A indicates the current mix of funding. Land managers can use STARFire’s interprogram analysis as a contextual guide on the allocation of funding between fuel treatment and preparedness programs. This example suggests that a relatively balanced allocation between fuel treatment and preparedness programs would yield optimal results for available funds.

B



NPS/SEQUOIA–KINGS CANYON NATIONAL PARK (3)

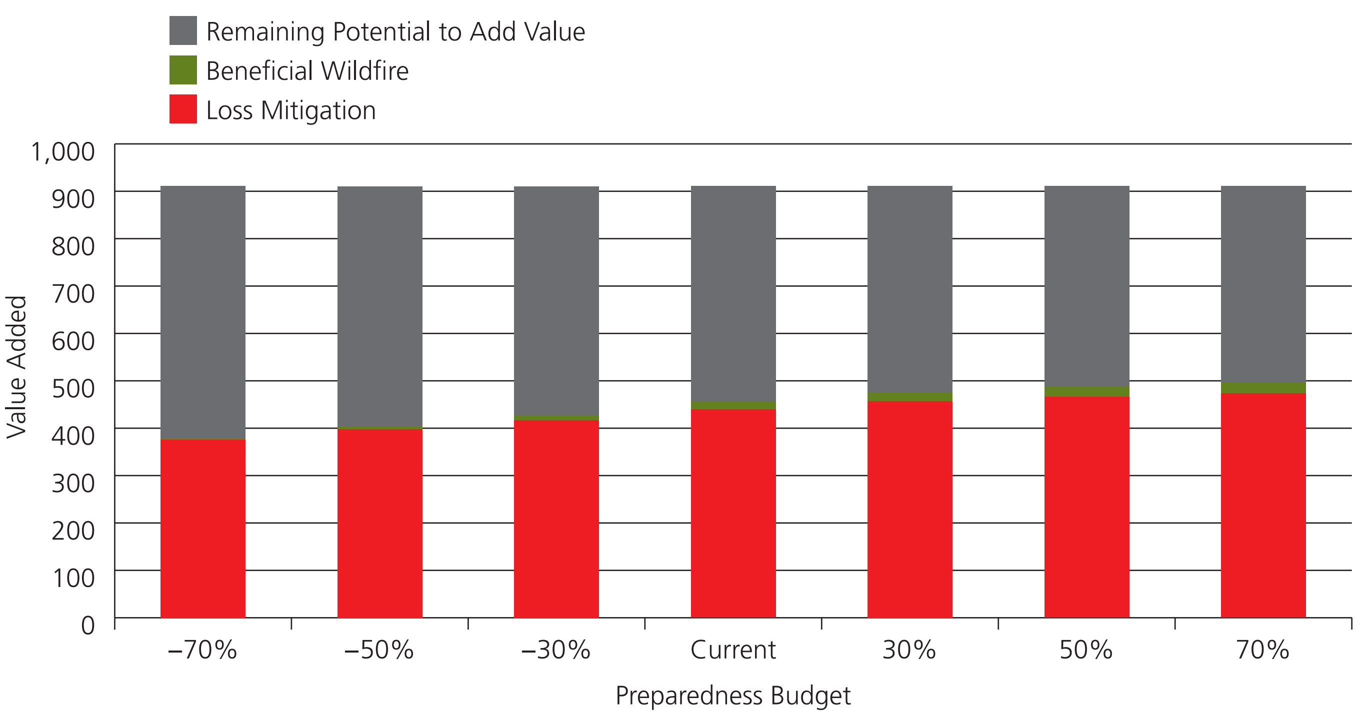


Figure 4. STARFire analyzes value added to the landscape by the preparedness program funded at alternative levels in this example at Sequoia and Kings Canyon National Parks. (Data are shared online in a linked table.)

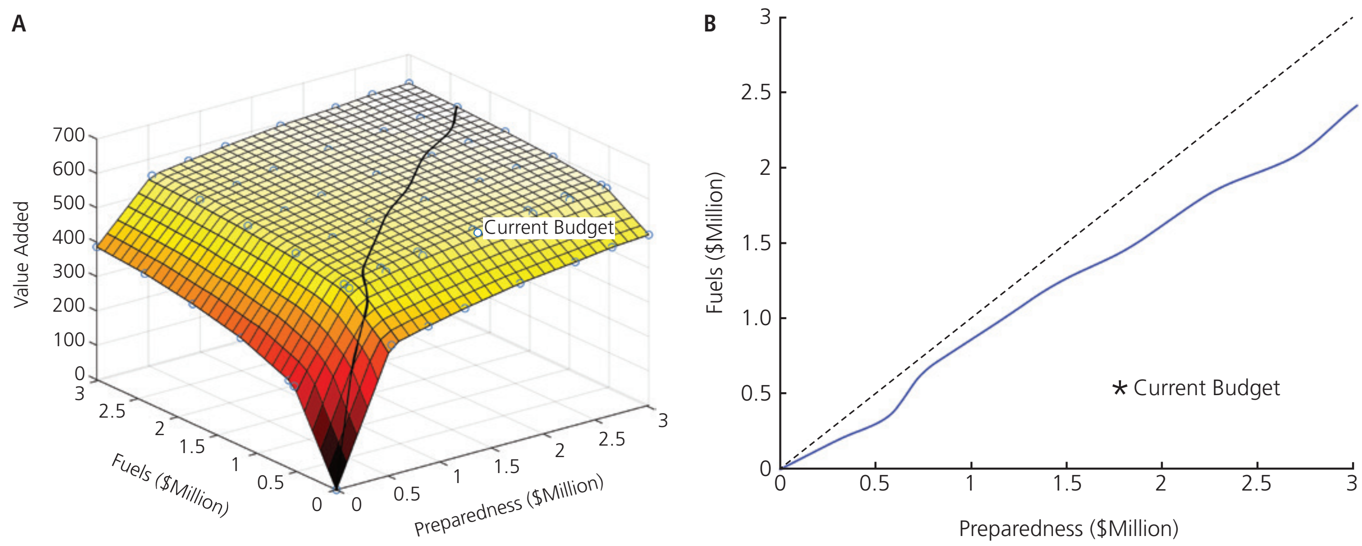


Figure 5. The STARFire-interpolated surface (panel A, above left) shows how much value can be added to the landscape by funding alternative levels of the fuels and preparedness programs. Users can visually identify how funding options for each program affect performance. The expansion path (black line) of funding between fuel treatment programs and preparedness programs is used to maximize the value added by a fire program at Sequoia and Kings Canyon National Parks. In panel B (right), the solid blue line represents the expansion path of funding between the fuels and preparedness programs. The black dotted line represents equal allocation of funding between the two programs. The black star indicates the current allocation of funding.

Conclusions

STARFire represents the first science-based spatial planning and budgeting system available to the National Park Service and other bureaus of the Department of the Interior. The system reflects the stringent design criteria outlined in the Cohesive Strategy (USDOI and USDA 2014), especially pertaining to the inclusion and promotion of resilient landscapes and the protection of highly valued resources, while incorporating the key elements highlighted by the USDOI Office of Policy Analysis. To address the policy analysis concerns, STARFire uses a foundational analysis and common performance metric that is tightly integrated across each program component from risk analysis to the interaction of the fuels and preparedness programs. As such, the system enables land management agencies to plan and budget their wildfire programs in accordance with national directives. It is scalable from the local planning unit to regions and to national program analysis (Wei et al. 2016). For example, it can be used at the unit level to inform appropriate response to wildfire, optimize fuel treatment locations, and demonstrate the impact of budget changes on fire programs. At the program level, it helps agencies allocate their budgets for optimal return on investment, provides metrics for supporting budgeting decisions and appropriation requests, and aligns national and regional budgets with the goals and objectives of local units.

While STARFire was originally developed as a risk management tool to be applied at the planning unit level, its core principles, common metric, and modular design enabled it to grow into a comprehensive planning and budgeting system at the strategic level. With its rapid growth, the system has been tested on approximately 20 of the nation's national parks. It has become part of the NPS national budgeting framework, where it is being evaluated for use at the regional level, including park groups in Alaska. Within the next three years, STARFire is planned to be completed in more than 50 locations that include all parks where wildland fire management actions occur. Because of its flexibility and scalability, it was also used to aid in the evaluation of fuel treatments on more than 15 million acres (6 million ha) of greater sage-grouse habitat in the northern Great Basin. It is currently being used to support fire management planning on BLM districts across the

STARFire represents the first science-based spatial planning and budgeting system available to the National Park Service.… [and] enables land management agencies to plan and budget their wildfire programs in accordance with national directives.

state of Idaho where the entire state will be processed singularly. These applications will provide crucial feedback as the system is developed for future implementations.

References

Rideout, D. B., J. B. Loomis, P. S. Ziesler, and Y. Wei. 2012. Comparing fire protection and improvement values at four major U.S. national parks and assessing the potential for generalized value categories. International Journal of Safety and Security Engineering 2(1):1–12.

Rideout, D. B., P. S. Ziesler, and N. Kernohan. 2014. Valuing fire planning alternatives in forest restoration: Using derived demand to integrate economics with ecological restoration. Journal of Environmental Management 141:190–200.

Rideout, D. B., P. S. Ziesler, R. Kling, J. B. Loomis, and S. J. Botti. 2008. Estimating rates of substitution for protecting values at risk for initial attack planning and budgeting. Forest Policy and Economics 10:205–219.

Rideout, D. B., Y. Wei, A. G. Kirsch, and N. K. Kernohan. 2016. Strategic planning and budgeting of wildland fire preparedness programs for risk management. International Journal of Safety and Security Engineering 6(2):246–253.

Stratton, R. D. 2004. Assessing the effectiveness of landscape fuel treatments on fire growth and behavior. Journal of Forestry 102:32–40.

US Department of the Interior and US Department of Agriculture (USDOI and USDA). 2014. The national strategy: Final phase in the development of the National Cohesive Wildland Fire Management Strategy. 93 pages. Accessed 28 July 2016 at https://www.forestsandrangelands.gov/strategy/documents/strategy/CSPhaseIIINationalStrategyApr2014.pdf.

USDOI Office of Policy Analysis. 2012. Wildland Fire Management Program benefit-cost analysis: A review of relevant literature. US Department of the Interior, Office of Policy Analysis, Washington, DC, USA. Accessed 1 April 2016 at http://www.doi.gov/ppa/upload/Wildland_fire_literature_review_060812FINAL.pdf.

US General Accounting Office (GAO). 2002. Wildland fire management: Improved planning will help agencies better identify fire-fighting preparedness needs. Report GAO-02-158. US General Accounting Office, Washington, DC, USA. 35 pages.

US Government Accountability Office (GAO). 2005. Wildland fire management: Forest Service and Interior need to specify steps and a schedule for identifying long-term options and their costs. Testimony GAO-05-353T. US Government Accountability Office, Washington, DC, USA. 15 pages.

———. 2009. Wildland fire management: Federal agencies have taken important steps forward, but additional, strategic action is needed to capitalize on those steps. Report GAO-09-877. US Government Accountability Office, Washington, DC, USA. 49 pages.

Wei, Y., D. B. Rideout, A. Kirsch, and N. Kernohan. 2016. Comparing alternative budget allocation models to support strategic wildland fire program analysis across US national parks. International Journal of Safety and Security Engineering 6(2):238–245.

Westerling, A. L., H. G. Hidalgo, D. R. Cayan, and T. W. Swetnam. 2006. Warming and earlier spring increase western US forest wildfire activity. Science 313:940–943.

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PS

Trail drainage features: Development and testing of an assessment tool

By Kaitlin Burroughs, Yu-Fai Leung, Roger L. Moore, and Gary B. Blank

Abstract
Sustainably designed and well-maintained trails are important, because they allow for the protection of adjacent natural and cultural resources by concentrating visitor use on linear paths, and they facilitate visitor enjoyment of these areas. Environmental factors related to water are common and can have negative impacts on trail conditions. Park managers often combat these issues by installing and maintaining trail drainage features (TDFs) as a means of diverting surface runoff from tread surfaces. As such, TDFs are intended to contribute directly to trail sustainability. This report presents the development and testing of a field tool that managers can use to assess and better understand the effectiveness of trail drainage features. For phase one, we created a TDF assessment tool based upon relevant literature and pilot tested it in a North Carolina segment of the Appalachian National Scenic Trail (AT). Phase two involved a reliability test that determined the degree of agreement in measurements between two different trail assessment crews. Results demonstrated that TDF measurement items had moderate to very high agreement ratings, indicating that the assessment tool can provide reliable information about trail drainage features to park managers. The assessment tool provides a compilation of important variables to consider when determining TDF effectiveness.

Key words
assessment tool, effectiveness, trail drainage feature, trail sustainability

TRAILS THAT ARE SUSTAINABLY DESIGNED AND WELL maintained allow visitors better access to natural areas and reduce their impacts on those resources by concentrating use on a limited number of linear paths (Hesselbarth et al. 2007). Increased understanding about what makes trails sustainable supports protected area and park managers who strive to integrate conservation and recreation goals.

The sustainability of trails as a recreation resource depends, to a large extent, on how effectively surface runoff can be controlled (Appalachian Mountain Club 2008; Grab and Kalibbala 2008; Hesselbarth et al. 2007; Marion and Wimpey 2017). Running water on and alongside trail treads leads to degradation problems such as muddiness, widening, multiple treading (additional trampled tracks alongside the original tread), root exposure, and soil erosion (Monz et al. 2010; Upland Pathwork Advisory Group 2004). If trail degradation becomes too advanced, rehabilitation can be prohibitively expensive with lasting impacts on surrounding resources and recreational experiences (Garland 1990). Trail degradation often leads to altered visitor behavior in negotiating degraded areas and can act as a catalyst for larger-scale resource damage, such as vegetation trampling, land erosion, water pollution, and wildlife displacement (Leung and Marion 1996; Olive and Marion 2009).

A common solution to water-induced trail degradation is to construct and maintain drainage features (Birchard and Proudman 1982; Grab and Kalibbala 2008; Hesselbarth et al. 2007; Marion and Wimpey 2017). A trail drainage feature or TDF is a purposeful arrangement or installation of any material (most commonly rock, wood, or soil) on or adjacent to the trail tread that aids in intercepting continuous surface runoff and diverting water from tread surfaces (fig. 1). Trail drainage features are commonly used by land management agencies such as the National Park Service, the US Forest Service, and state park systems. A variety of "best practice" approaches to constructing trail drainage features have been developed by various agencies and outdoor organizations (Appalachian Mountain Club 2008; Birchard and Proudman 1982; Hasselbarth et al. 2007). However, there is little evidence that this guidance is directly linked to empirical research, and little information exists on assessing, monitoring, and evaluating TDFs and their effectiveness. Thus data are limited for empirical examination of factors that contribute to the effectiveness of TDFs.

KAITLIN BURROUGHS, 2015 (2)

Figure 1. Rock (left) and wood waterbars (right) are common examples of trail drainage features.

This study aims to contribute to the long-term sustainability of trails through an improved TDF assessment tool that can generate

Table 1. Assessment measures and descriptions for trail drainage features

Category	Measurement	Description	Unit
General TDF Information	1. TDF Number	Identification number	N/A
	2. Date and Time	Date and time of assessment	N/A
	3. Trimble GPS Number	Spatial reference identification number	N/A
	4. Photo Up/Downslope	View of TDF looking uphill and downhill	N/A
TDF Characteristics	5. Material Type	Material used to construct TDF (rock, wood, soil, plastic, other)	N/A
	6. Construction Method	Building style (flushed, stacked over, stacked under, stacked alternating, tree log, treated log, rolling dip, knick, other)	N/A
	7. TDF Length	Length of TDF from end to end along the centerline	cm
	8. TDF Thickness	Average thickness of TDF material on the left, center, and right side or centerline of each individual rock, whichever is most appropriate	cm
	9. TDF to Tread Angle	Angle of TDF and trail tread taken on the downhill side hugging the inside of the landscape (opposite end of drainage/trench)	degrees
	10. Material Gaps	Categorical estimation of existing gaps in TDF structure (0–5 cm, 5.1–10 cm, or >10 cm)	cm
	11. Side Slope Connection	Whether or not TDF material is tied into the trail's surrounding inside landscape	N/A
	12. Structure Stability	Categorical estimation of TDF strength using a firm boot shove (strongly anchored, moderately anchored, weakly anchored)	N/A
Sediment Characteristics	13. TDF Height	Average depth of sediment/organic material measured 3 cm uphill from TDF feature and on the left side, center, and right side	cm
	14. Erosion Feature	The presence of erosion within 5 m of TDF uphill or downhill	N/A
	15. Trench Extension	Whether or not an existing channel dug into the soil exists on the outside side slope	N/A
	16. Trench Extension Depth	Depth of sediment/organic material in trench measured 30 cm away from TDF and from the top of the trench to the bottom	cm
Trail Characteristics	17. Trail Grade	Trail slope percentage measured from the TDF feature and 5 m upslope along existing trail	%
	18. Trail Direction	Trail direction measured from TDF feature and existing trail centerline	degrees
	19. Landform Grade	Landform slope percentage measured from the TDF feature and 4 m upslope along the fall line of existing landscape	%
	20. Landform Direction	Landform direction measured from TDF feature and fall line of existing landscape	degrees
	21. Canopy Cover	Percentage of canopy cover from the center of existing trail recorded 10 m upslope, 5 m upslope, and directly at TDF	%
Maintenance	22. Recent Maintenance	Evidence of recent TDF maintenance (trench cleaning, sediment clearing, upturned soil, fresh material, other)	N/A
Effectiveness	23. Effectiveness Rating	Categorical estimation of the overall TDF effectiveness (effective, partially effective, not effective)	N/A

timely and objective data supporting analysis and evaluation, thereby informing trail and TDF management decisions. The purpose of this report is to illustrate the TDF assessment tool, including its conception, development, and testing.

Methods

Phase one: Assessment tool

We reviewed construction and maintenance "best practice" methods used by land management agencies and associated trail-building organizations such as the US Forest Service, the National Park Service, the Conservation Corps Trail Crews, the Appalachian Trail Conservancy, the Pacific Crest Trail Association, and the International Mountain Bicycling Association. Characteristics of trail drainage features described as a priority in multiple handbooks were among those selected for review (Appalachian Mountain Club 2008; Birchard and Proudman 1982; Hesselbarth et al. 2007; Upland Path Advisory Group 2004). In addition, we consulted previous research on trail and other drainage features used on logging and unpaved backcountry roads to better understand the empirical data collected on similar drainage characteristics. Significant findings related to drainage attributes were among those selected for review (Garland 1990; Grab and Kalibbala 2008; Leung and Marion 1999). Last, we considered personal knowledge and experience gained from participating in and leading trail-building crews for three years in generating a list of important characteristics that should be assessed when determining overall effectiveness of trail drainage features.

Collectively, we selected 30 measurements for pilot testing in Wesser, North Carolina, in February 2015, on 10 different trail drainage features constructed along the Appalachian Trail. Measurements, definitions, and methods were refined as a result of the pilot. For example, we further distinguished the TDF construction measurement responses so as to provide more accurate identification of TDF construction methods (displayed in fig. 2). A TDF material type categorized as "rock" may describe a construction method of rocks assembled flush to each other, stacked on top of or underneath one another, arranged in an alternating pattern, or combined in a way that has no distinguishable pattern.

Phase two: Reliability test

We collected data on existing TDFs to determine the reliability of the measurements used in the trail drainage feature assessment as performed by different field staff. Two groups of two raters, or field assessment tool users, were recruited and trained separately on how to use the assessment tool. Each training session lasted 30 minutes, in which participants were given background information and walked through each measurement as defined, explained, and illustrated in two assessment handouts. An example of these procedures is shown in table 1 (previous page) and figure 4 (opposite page).

The first group of raters consisted of students with undergraduate environmental knowledge in addition to trail assessment experience. They performed the reliability test in Baxter State Park, Maine. The second group had advanced environmental knowledge (MS and PhD) and some trail assessment experience. They performed the reliability test in Umstead State Park, North Carolina (fig. 3). We chose the two locations for variety in trail drainage features and settings and to ensure consistency in application of the assessment across a diverse region where TDFs are common in managed natural areas.

Using the data collected in the field, we assessed the inter-rater reliability using Cohen's Kappa (K) and Intraclass Correlation Coefficient (ICC). Inter-rater reliability describes the degree of agreement among different raters and reflects the consistency among ratings. We selected two statistics according to the different types of data we collected. Some of the measurements generated categorical data (such as material type and construction method, indicated in table 2 by an asterisk); thus we applied Cohen's Kappa (K), which compares the observed accuracy among raters with expected accuracy and considers the possibility that raters give similar answers by random chance (Hallgren 2012). Other measurements generated numeric data (such as TDF length and TDF thickness, indicated in table 2 by the absence of an asterisk); therefore, we applied the Intraclass Correlation Coefficient (ICC, using a two-way random, absolute

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Figure 2. Rock waterbars are often constructed using different methods. Shown here are flush (left) and stacked under (right).

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Figure 3. Field assessors perform a reliability test at Umstead State Park, North Carolina.

Table 2. Inter-rater reliability results from tests performed at Baxter State Park, Maine, and Umstead State Park, North Carolina

Measurement	K/ICC	Measurement	K/ICC
TDF Characteristics		***Trail Characteristics***	
Material Type*	1	Trail Grade	0.52
Construction Method*	0.64	Trail Direction	0.96
TDF Length	0.85	Landform Grade	0.76
TDF Thickness	0.93	Landform Direction	0.96
TDF to Tread Angle	0.70	Canopy Cover (10 m)	0.66
Material Gaps**	0.62	Canopy Cover (5 m)	0.58
Side Slope Connection*	0.69	Canopy Cover (TDF)	0.42
Structural Stability**	1		
Sediment Characteristics		***Maintenance***	
TDF Height	0.95	Recent Maintenance**	0.78
Erosion Feature*	0.69		
Trench Extension*	1	Overall Effectiveness Rating	
Trench Depth	0.56	Effectiveness Rating**	0.54

Note: The absence of an asterisk (*) signifies Intraclass Correlation Coefficient (exact measurements), one asterisk indicates Cohen's Kappa (categorical measurements), and two asterisks denote the measurement was weighted using Cohen's Kappa.

The sustainability of trails as a recreation resource depends, to a large extent, on how effectively surface runoff can be controlled.

PHOTOS KAITLIN BURROUGHS, 2015 (4)

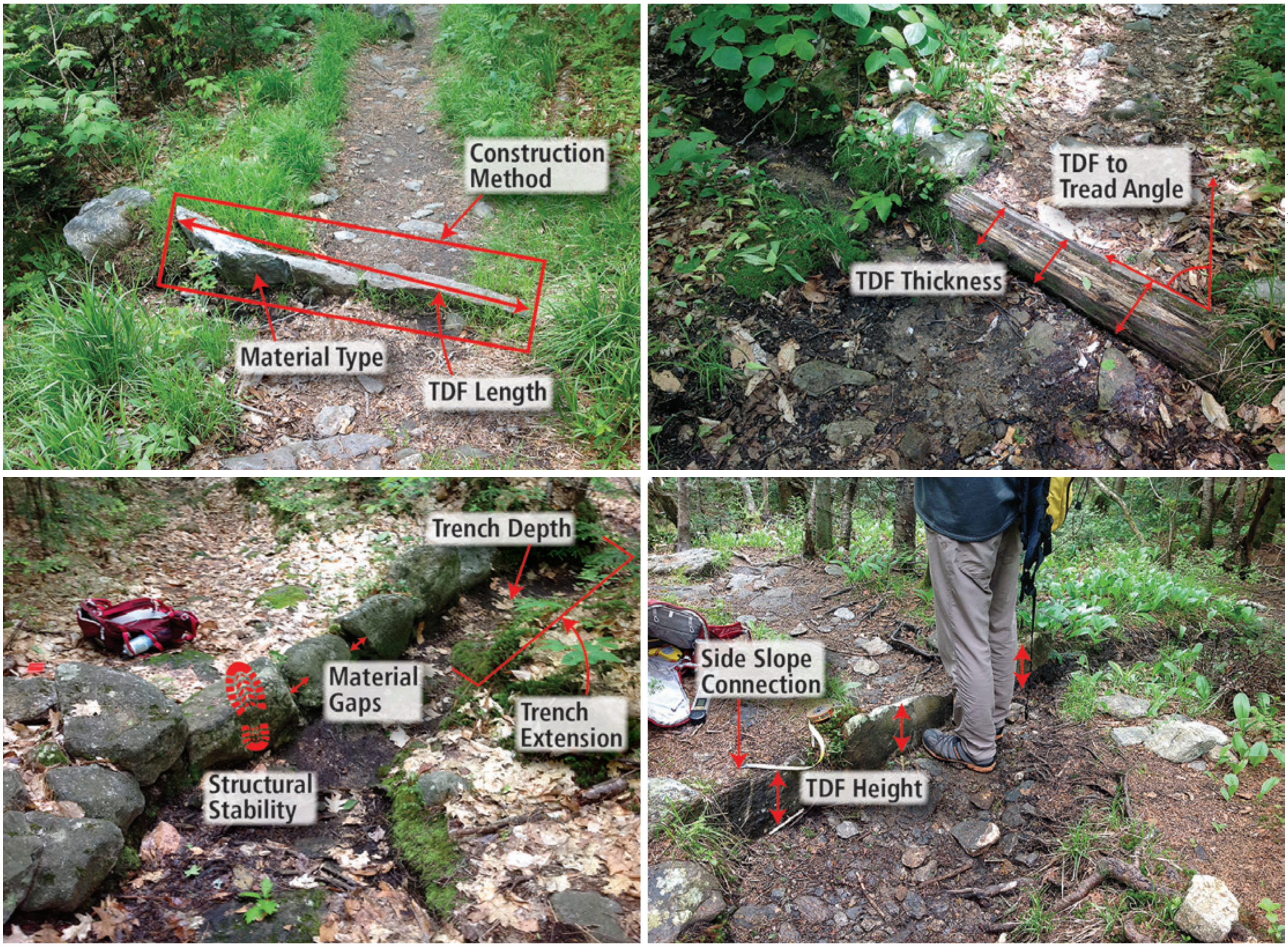

Figure 4. The photo diagram illustrates examples of measurements from the trail drainage feature assessment.

agreement), which compares the variability of different ratings of the same attribute to the total variation across all ratings and all attributes. It incorporates the magnitude of disagreement and assumes that attributes are composed of a true score and a measurement error (Hallgren 2012). High inter-rater reliability scores mean that different raters are more likely to record the same or very similar values for each measure. This consistency in measuring is important as it demonstrates a decrease in the amount of subjectivity a rater uses to provide a given score, and consistency in measurement is important when providing a tool that can be used across varying land management agencies in different regions of the world. Both statistical models were run using IBM SPSS Statistics 2015 software.

Results

Phase one: Assessment tool

A refined version of the TDF assessment tool from the pilot yielded 21 measurements (25 total questions), representing four distinct categories (fig. 5): (1) TDF characteristics, (2) sediment characteristics, (3) trail characteristics, and (4) maintenance. We added an "overall effectiveness rating" measure from Leung and Marion's 1999 study of Great Smoky Mountains National Park to build upon previous research on trail drainage features.

A description of each measurement category used in the assessment is shown in table 1. Those categorized as "TDF characteristics" measure physical attributes of and relate to the integrity of the trail drainage features. Measurements under "sediment characteristics" document trends in sediment deposition around the features and serve as indicators of whether or not water is effectively diverted from the trail. "Trail characteristics" capture trail and landform attributes that may influence how effectively water is drained from the trail. Finally, the "maintenance" measure identifies evidence of recent or obvious maintenance of the features.

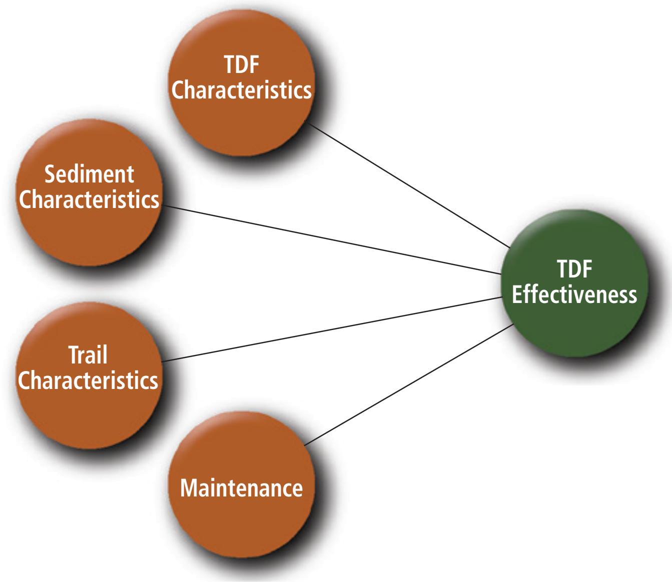

Figure 5. The training materials paired written instructions and illustrations for these measurement categories, which contribute to TDF effectiveness.

Phase two: Reliability test

Each measurement listed in table 1 was calculated for inter-rater reliability, shown in table 2, and resulted in moderate agreement (Cohen's K or ICC ≥ 0.41) or higher as interpreted using the six-category K scale displayed in table 3 (Zenk et al. 2007). Measurements among highest agreement were material type (1.0), TDF length (0.85) and thickness (0.93), structural stability (1.0), TDF height (0.95), and trail (0.96) and landform (0.96) direction. Measurements among moderate agreement (and the lowest recorded agreement in this study) were trench extension depth (0.56), trail grade (0.52), canopy cover (at TDF location) (0.42), and canopy cover (at 5 m) (0.58). The "overall effectiveness rating" applied by guidelines in Leung and Marion (1999) received a lower inter-rater reliability value of 0.54 when compared to three of the identified key variables of TDF length (0.85) (fig. 6), TDF thickness (0.93), and TDF to tread angle (0.70). It received a comparable inter-rater reliability value when compared to the last key measurement of trail grade (0.52).

Table 3. Inter-rater reliability interpretation

Kappa	Interpretation
< 0	Poor Agreement
0.0 – 0.20	Slight Agreement
0.21 – 0.40	Fair Agreement
0.41 – 0.60	Moderate Agreement
0.61 – 0.80	Substantial Agreement
0.81 – 1.00	Strong Agreement

Source: Zenk et al. 2007

Discussion

Measurements with high K and ICC scores such as material type likely occurred because trail drainage features are commonly built with only one type of material, and different material types are distinct (e.g., rock versus tree log). Consistent recording of material type is valuable as several "best practices" manuals describe soil-based TDFs as more effective over the long term compared to waterbars made of rocks and logs (Appalachian Mountain Club 2008; Hesselbarth et al. 2007). Additional measurements with higher consistency such as TDF thickness and diagonal tread length are valuable because past research has found thickness of drainage features to be an important indicator of TDF effectiveness (Grab and Kalibbala 2008).

Trail drainage feature height, also a high-performing inter-rater reliability measurement, may be a good indication of TDF effectiveness, given that an assessor is able to record precise measurements. Such precision may allow for a better understanding of the amount of sediment deposited from surface runoff in front of a trail drainage feature, further informing land managers how often it may need to be serviced or maintained.

KAITLIN BURROUGHS, 2015

Figure 6. An assessor measures TDF length along the Appalachian Trail in New Hampshire.

Measurements such as trench depth performed less favorably in terms of consistency. Trail drainage feature trenches vary in construction and often have uneven surfaces on either side. Grab and Kalibbala (2007) determined the importance of TDF trenches (referring to them as drainage furrows); however, features with poorly constructed trenches do not function well, consequently demonstrating the importance of trench characteristic measurements such as trench depth.

Also among the less favorably performing K and ICC scores (moderate agreement) were trail grade, canopy cover (TDF), and canopy cover (5 m). Although these measurements received moderate agreement, more accurate measurements may be obtained using GIS if geospatial data are available. For example, trail grade can be obtained with high-tech lidar data for a given area and can provide consistent measurements over entire landscapes, as described by Marion et al. (2011). The canopy cover measurements would also benefit from lidar data as more accurate readings can be taken along the entire trail system or surrounding landscape, enabling further analysis and modeling of rainfall drainage patterns as influenced by trail networks at a watershed or landscape scale. Trail grade measurements can and should still be taken in the field to check lidar data for accuracy. More precise instructions can be given for making the trail grade measurement, such as "Stand at the center of the TDF, just above the feature and not standing on top of the TDF material, and measure 5 m uphill with an accurate measuring device." Wind can be a significant factor when recording tree canopy, so wind strength should be monitored with an anemometer in order to record wind speed and direction.

There is little evidence that [traditional trail maintenance] guidance is directly linked to empirical research, and little information exists on assessing, monitoring, and evaluating TDFs and their effectiveness.

Finally, the singular "overall effectiveness" measure had the least consistency among raters. This parallels past discussion by Leung and Marion (1999) identifying the limitation of subjectivity in determining TDF effectiveness. By using the other 24 measurements, a more quantitative and objective assessment is possible in determining actual TDF effectiveness. Additionally, the assessment of one TDF can be recorded in an average of just six minutes after all initial training and practice TDFs are completed. Newly trained field staff will complete assessments in about 20 minutes for the first four to five features and then rapidly increase in speed as they become more familiar with the process, leading quickly to the six-minute TDF assessment speed.

Recommendations

We suggest training improvements be made for similar research in the future. First, approximate measurements associated with trail grade and canopy cover can be changed to exact measurements. For example, a tool such as a laser range finder can be used to determine exactly how far along the trail 5 meters is. Additionally, precise directions should be given to assessors describing where to stand to take such measurements as trail grade and canopy cover. Field training will continue to improve as assessors become familiar with multiple examples of trail drainage features and terminology. Finally, consistency in measurements will improve as individuals who already have a background in trail building and maintenance are recruited, because of their familiarity with terms and features.

We have several recommendations for improving the TDF assessment tool in the field. A side slope measurement will be helpful in determining what percentage of trail is sloping outward, aiding in better water drainage. Additionally, canopy cover, trail grades, and landscape grades may be recorded for features using categorical data when lidar data are unavailable. However, high-precision field measurements may not add value to the evaluation of trail drainage features and trail condition. For example, a trail grade of 5% can be variously measured as 4–7% depending on where and how far apart recorders stand, and what material the trail is made of. These differences decrease inter-rater reliability even though the fine level of detail recorded increases, and they do not add meaningful information to the evaluation. It is more important to record major differences in trail grade (e.g., 5% or 20%) as this has a dramatic effect on the flow of water across the trail.

The TDF trench measurement can be improved by tying a string to two stakes, laying out the string line perpendicular to and across the trench, and measuring trench depth from the center of the line down to the deepest spot. Finally, maintaining a log in which the age of trail drainage features is recorded and information about how often each is maintained is important in evaluating the effectiveness of the feature and greatly reduces subjectivity. Information such as construction and maintenance dates, type of maintenance, and presence of erosion can be recorded using the NPS Facility Management Software System or filed online by maintenance crews and volunteer groups.

Implications

Management

An assessment tool is indispensable in constructing and maintaining effective trail drainage features insofar as it uses the most relevant measurements in conjunction with information from research. Our assessment tool provides a way to inventory existing trail drainage features and their corresponding attributes. It highlights undesirable attributes that can lead to poor feature performance such as incorrect tread to TDF angle or trench depth, to which managers can respond by allocating additional time and resources. The tool also helps identify TDFs that should be removed if, for example, a majority of the measurements produced results that were undesirable. Finally, this tool helps land managers to justify the expense of money, time, and resources on trail management with objectively collected evidence.

Research

Future research should test this assessment tool with larger sample sizes. Also, it should evaluate the need for additional TDF measurements and measurement alterations in order to determine the reliability and value of incorporating this information into the existing assessment tool. As measurements are updated, added, and tested, this rapid assessment tool can be further developed by leveraging the best and most reliable measurements (Marion and Wimpey 2017). Additionally, training methods such as in the classroom, in the field, or a combination of the two, can be assessed to determine which is most effective at producing consistent and high inter-rater reliability measurement outcomes. The assessment tool can also be used to give each TDF a composite score, meaning one simple score to serve as an overall effectiveness measure allowing for efficient comparisons among trail drainage features.

Conclusion

This field assessment tool gives trail managers a quantitative and more objective tool to aid in determining the effectiveness of trail drainage features in parks and protected areas. It compiles a suite of important variables that can be used in assessments while highlighting those that are critical in determining TDF effectiveness. The assessment complements existing trail-building manuals such as the Appalachian Mountain Club's *Complete Guide to Trail Building and Maintenance* of 2008 and the US Forest Service's *Trail Construction and Maintenance Notebook* of 2007. The longer list of variables incorporated into the assessment tool is informed by these and other relevant literature and helps to differentiate levels of effectiveness among trail drainage features. Finally, identifying, locating, and fixing underperforming TDFs will improve overall trail quality and long-term sustainability, and contribute to surrounding environmental health and overall visitor enjoyment.

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References

Appalachian Mountain Club. 2008. AMC's complete guide to trail building and maintenance. Fourth edition. Appalachian Mountain Club, Boston, Massachusetts, USA.

Birchard, W., and R. Proudman. 1982. Appalachian Trail: Design, construction, and maintenance. Second edition. The Appalachian Trail Conference, Harpers Ferry, West Virginia, USA.

Garland, G. G. 1990. Technique for assessing erosion risk from mountain footpaths. Environmental Management 14(6):793–796.

Grab, S., and F. Kalibbala. 2008. "Anti-erosion" logs across paths in the southern Ukhahlamba-Drakensberg Transfrontier Park, South Africa: Cure or curse? Catena 73(1):134–145.

Hallgren, K. A. 2012. Computing inter-rater reliability for observational data: An overview and tutorial. Tutorials in Quantitative Methods for Psychology 8(1):23–34.

Hesselbarth, W., B. Vachowski, and M. A. Davies. 2007. Trail construction and maintenance notebook: 2007 edition. US Forest Service and Missoula Technology and Development Center, Missoula, Montana, USA.

Leung, Y-F., and J. L. Marion. 1996. Trail degradation as influenced by environmental factors: A state-of-knowledge review. Journal of Soil and Water Conservation 51(2):130–136.

———. 1999. Assessing trail conditions in protected areas: Application of problem-assessment method in Great Smoky Mountains National Park, USA. Environmental Conservation 26(4):270–279.

Marion, J. L., and J. F. Wimpey. 2017. Assessing the influence of sustainable trail design and maintenance on soil loss. Journal of Environmental Management 189:46–57.

Marion, J. L., J. F. Wimpey, and L. O. Park. 2011. The science of trail surveys: Recreation ecology provides new tools for managing wilderness trails. Park Science 28(3):60–65.

Monz, C. A., D. N. Cole, Y-F. Leung, and J. L. Marion. 2010. Sustaining visitor use in protected areas: Future opportunities in recreation ecology research based on the USA experience. Environmental Management 45(3):551–562.

Olive, N., and J. L. Marion. 2009. The influence of use-related environmental and managerial factors on soil loss from recreational trails. Journal of Environmental Management 90(3):1483–1493.

Upland Path Advisory Group. 2004. Upland pathwork: Construction standards for Scotland. Second edition. Scottish Natural Heritage, Battleby, Scotland, UK.

Zenk, S. N., A. J. Schulz, G. Mentz, J. S. House, C. C. Gravlee, P. Y. Miranda, P. Miller, and S. Kannan. 2007. Inter-rater and test-retest reliability: Methods and results for the neighborhood observational checklist. Health and Place 13(2):452–465.

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State of the Science

White-nose syndrome decontamination procedures for backcountry subterranean projects

By J. Judson Wynne

Abstract
White-nose syndrome (WNS), a disease caused by the fungal pathogen *Pseudogymnoascus destructans*, is responsible for the population decline of at least 10 subterranean hibernating bat species in eastern North America and has recently been confirmed in the northwestern United States. The US Fish and Wildlife Service (USFWS), in concert with other federal and state agencies and university personnel, has developed, and periodically updates, a WNS Decontamination Protocol (e.g., USFWS 2016) for working in the subterranean realm. The protocol is a combination of scientifically tested and untested steps that provide a foundational framework for protecting hibernating bats from inadvertent human-assisted transmission of WNS to uninfected hibernacula. However, it does not specifically address extended backcountry research needs. During four research trips to Grand Canyon–Parashant National Monument, Arizona, from 2011 through 2012, colleagues and I tested and refined backcountry WNS decontamination procedures. The procedures presented here are developed to complement the WNS Decontamination Protocol; provide a stepwise method for disinfecting equipment, clothing, and personnel; and proactively address WNS containment concerns in the backcountry.

Key words
bats, caves, mines, *Pseudogymnoascus destructans*

WHITE-NOSE SYNDROME (WNS) HAS RESULTED in the mortalities of more than five million bats (USFWS 2012a) in 33 states and five Canadian provinces (WDFW 2016). Bat species presently affected by this epizootic include the cave myotis (*Myotis velifer*), Townsend's big-eared bat (*Corynorhinus townsendii*), tricolored bat (*Perimyotis subflavus*), big brown bat (*Eptesicus fuscus*), little brown bat (*Myotis lucifugus*), eastern small-footed bat (*Myotis leibii*), the federally listed (by the US Fish and Wildlife Service; USFWS) as threatened northern long-eared bat (*Myotis septentrionalis*), the federally listed as endangered Indiana bat (*Myotis sodalis*), the federally listed as endangered gray bat (*Myotis grisescens*) (Meteyer et al. 2009; Turner et al. 2011; USFWS 2014; USFWS 2015b), and the federally listed as threatened northern long-eared bat (*Myotis septentrionalis*; USFWS 2015b). In Canada, the Canadian Cooperative Wildlife Health Centre emergency-listed the tricolored (*Perimyotis subflavus*), little brown (*Myotis lucifugus*), and northern long-eared (*Myotis septentrionalis*) bats as endangered due to population declines associated with WNS (CCWHC 2014).

White-nose syndrome is caused by the cold-adapted fungus *Pseudogymnoascus destructans* (Minnis et al. 2013). When *P. destructans* is fully expressed, it presents as a white fungus that attacks the epithelial layer and digests live skin cells of the rostral muzzle (furless area around the nose), ears, wing membrane, forearms, and uropatagium (tail membrane between the thighs) of hibernating bats (Meteyer et al. 2009; Blehert et al. 2009; Gargas et al. 2009; Cryan et al. 2010; Foley et al. 2011; fig. 1C and D). Because numerous dematophytes (pathogenic fungi) occur on bats, histology is required to confirm the presence of WNS (Meteyer et al. 2009). However, long-wave ultraviolet (UV) light (wavelength 366–385 nm) may now be used to detect WNS on hibernating bats in the field. Bats with expressed effects of *P. destructans* present with a distinct orange-yellow fluorescence in the affected areas under UV light (Turner et al. 2014).

Spread of the pathogen

Since it was first documented in Howe Cave, New York, in 2007, WNS has spread from upstate New York northwestward through southern Ontario, Canada, northeastward to Nova Scotia, southward to Missouri and Arkansas, and westward through northern Texas (USFWS 2015a; TPWD 2017). Last year WNS was detected in King County, Washington, resulting in a 1,300-mile (2,092 km) leap from its previous westernmost locality (WDFW 2016). Figure 2 shows the current extent, including 2017 range expansion into Minnesota, Nebraska, and Texas. Updated maps of the spread are maintained at www.whitenosesyndrome.org.

The primary vector believed responsible for the westward expansion of WNS is bat-to-bat transmission (e.g., Frick et al. 2010; Lorch et al. 2011; Puechmaille et al. 2011; Turner et al. 2011). Turner et al. (2011) suggest transmission likely occurs during fall swarming and interhibernacula movements of infected bats. Therefore, to manage for and develop mitigation strategies against WNS on a landscape scale, we will need to understand movements between fall swarming and winter hibernacula roosts as well as roost switching during the hibernation period.

Evidence suggests white-nose syndrome (and the causative agent, *P. destructans*) was introduced from Eurasia to North America by humans. WNS has been identified in 13 bat species from cave hibernac-

A AND B: COURTESY OF J. JUDSON WYNNE, NORTHERN ARIZONA UNIVERSITY COURTESY OF PETE PATTAVINA COURTESY OF MARVIN MORIARTY

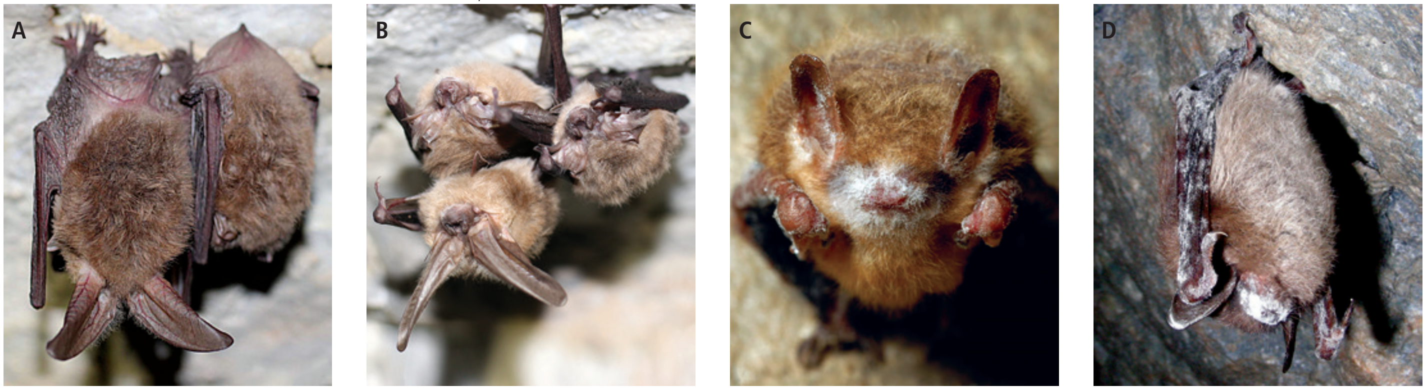
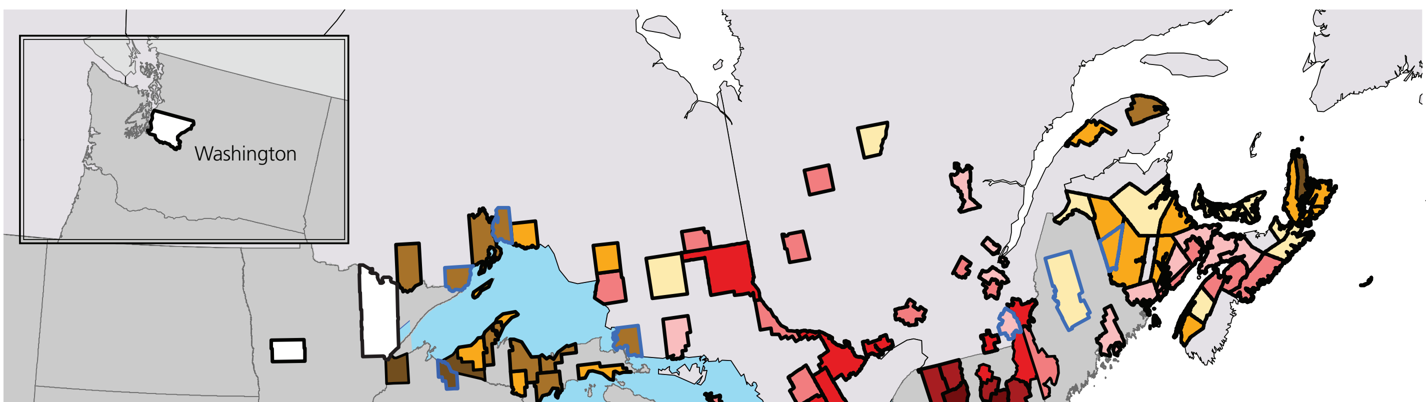


Figure 1. (A and B) Two clusters of healthy hibernating Townsend's big-eared bats at Grand Canyon–Parashant National Monument, Arizona. Examples of (C) a tricolored bat in a cave at Cloudland State Park, Georgia, 2013, and (D) a little brown bat at the Greeley Mine, Vermont, 2009, with fully expressed white-nose syndrome.



SOURCE: LINDSEY HEFFERNAN, PENNSYLVANIA GAME COMMISSION; UPDATED AND ADAPTED BY NPS

Figure 2. Known distribution of white-nose syndrome in the United States and Canada by county and district as of March 2017. On 31 March 2016, WNS was confirmed in King County, Washington, resulting in a 1,300-mile (2,092 km) leap from its previous westernmost locality (map inset, top left). Locations of counties in Texas and Minnesota are approximate. (Counties/municipalities are listed by name, year, and state/province in a table available online.)

ula in several European countries (Wibbelt et al. 2010; Puechmaille et al. 2011; Zukal et al. 2014) and 6 bat species in eastern China (Hoyt et al. 2016) with no reported mass mortalities. Humans were the most likely vector for the introduction of *P. destructans* from Europe (Frick et al. 2010; Blehert et al. 2011; Foley et al. 2011) or temperate regions of Asia to the northeastern United States. The New York Department of Environmental Conservation, Wildlife Pathology Unit, detected a fungal conidia (asexually reproducing spore) with a morphology similar to *P. destructans* on caving gear tested immediately after exiting a WNS confirmed site (Okoniewski et al. 2010).

In addition to the initial introduction of *P. destructans* to North America, humans likely contribute to the dispersal of this epizootic pathogen. Early on, Wolf and Wolf (1947) identified humans as a vector for pathogenic fungi. On Hawai‘i, Baker (1966) identified at least 65 different species of fungi from the shoes of travelers (both being worn and within luggage) arriving from outside debarkation points. Of these, 15 species were unknown to Hawai‘i. The most recent range expansion of WNS to Washington State, involving a 1,300-mile (2,092 km) distance between the closest known WNS affected area and the detection site, cannot be explained by natural bat movements. It probably represents a human-assisted range expansion event. WNS was likely introduced to Washington on contaminated clothing or caving equipment originating from eastern North America, Europe, or northern Asia.

Disease containment

Given that direct management of bat-to-bat transmission is not possible, scientists and land managers have focused on developing and implementing procedures to reduce the potential for human-caused dispersal of this pathogen to uninfected areas. Since winter 2008, a multiagency team led by the USFWS has provided a protocol for WNS decontamination (e.g., USFWS 2016) for regions where the disease is confirmed, suspected, or unconfirmed. This protocol provides guidelines for laundering clothing for 10 minutes or immersing in 131° F (55° C) water for 20 minutes, and recommends decontamination of other washable gear and equipment following the manufacturer's cleaning guidelines. It also requires all equipment be used in a site-specific manner (e.g., no equipment from the WNS confirmed or suspected area may be used in an unaffected area; USFWS 2016).

In the WNS affected areas (presently eastern North America and one locality in the Pacific Northwest), either underground research on most state and federal lands has been restricted or compliance with the current WNS Decontamination Protocol is required. For example, Indiana bat winter survey protocols limit researchers to inventorying hibernacula every other year (Hicks et al. 2009). On US Forest Service lands in Arkansas, a five-year moratorium was recently passed on the three national forests to protect bat populations (USDAFS 2014). In general, the National Park Service (NPS) requested that cave resource management plans for all park units include provisions to reduce the threat of human-assisted transmission of WNS; these provisions may involve closure of some caves. Where the risk of spreading *P. destructans* into or out of parks by visitors can be minimized (e.g., through screening, decontamination, and the permitting process), most NPS-managed caves remain open (NPS 2010).

While the most recent WNS Decontamination Protocol (USFWS 2016) has explicit language regarding decontamination procedures, implementation remains at the discretion of the regulatory and resource management agencies under which land management jurisdiction resides. These entities may choose to develop addenda and supplemental documentation to accompany the most recent WNS Decontamination Protocol. Thus, regulatory and resource managers have the flexibility to incorporate additional requirements or exemptions based upon the perceived threat level of WNS in a given region, local conditions, logistical constraints with implementation, and the best available scientific information.

Need for backcountry decontamination methods

In backcountry settings, cave researchers and resource managers must plan for a variety of environmental concerns associated with proper disposal of WNS decontaminated water-chemical mixtures, as well as logistical constraints on both chemical and water use and transportation. Dumping chemical products, such as quaternary ammonium compounds, may have negative environmental impacts. These activities are often illegal on state and federally administered lands in the United States (e.g., NPS 2006). Preparing solutions for gear submersion requires a significant amount of water, and packing large amounts of water is often difficult to impossible in remote backcountry settings. The decontamination protocol (USFWS 2016) is typically implemented upon return from the field—in most cases, on a daily basis. Many backcountry trips are up to two weeks in duration, and it is not possible to wash clothing daily. Moreover, it is difficult to submerse equipment in water-chemical mixtures on a regular basis while in the field. Doing so is logistically challenging when a large number of sites are visited during a specific research trip, a large number of field personnel are participating in the field, and when field personnel pack all equipment into and out of remote areas.

Procedure development and refinement

Using the earlier 2011 (USFWS 2011a, b, c) and later the 2012 decontamination protocols (USFWS 2012b), NPS resource managers, research technicians, and I applied these techniques to the backcountry to devise methods for effectively decontaminating gear in areas where logistics were challenging and resources limited. Ten different field personnel tested and refined these techniques during four research trips (February, June, and September 2011 and February 2012) at Grand Canyon–Parashant National Monument, northwestern Arizona—an area where WNS does not occur. We applied incrementally improved versions of these procedures during the four different research trips, which totaled 100 individual applications in the field (table 1). Discussions were held at the end of each field day and during a post-expedition debriefing whereby problem areas with applying these procedures were captured and improvements were made accordingly. Additionally, we compared DuPont™ brand Tyvek® and ProShield® model disposable coveralls specifically for durability in constricted passageways over long hours of use underground.

Table 1. Number of research trips with related information for testing and refining backcountry white-nose syndrome decontamination procedures

Trip Date	Personnel Involved[1]	Procedures Applied[2]	Total[3]
March 2011	3	11	33
June 2011	7	5	35
September 2011	5	4	20
March 2012	4	3	12
Total	12[1]	23	100

Note: The procedures were tested and developed at Grand Canyon–Parashant National Monument, Arizona.

[1] Several of the same team members participated on multiple trips; therefore, the total number provided is for the number of individuals who participated in this work.

[2] The number of times each team applied the procedures.

[3] The total number of times procedures were applied per trip, calculated by the number of personnel times the number of procedures used in the field.

Results

Through rigorous field testing, we developed a set of stepwise procedures for disinfecting field equipment and provide recommendations for washing and cleaning exposed parts of the body, as well as disinfecting and storing gear after daily field operations. We present this information as four appendixes combining checklists and protocols in a format that can easily be printed and laminated for field use. Appendix I lists required supplies, equipment, and explanations. Appendix II recommends fieldwork preparations. Appendix III describes procedures prior to entry and after exiting a study site (i.e., cave or mine), while Appendix IV provides procedures for full decontamination (i.e., prior to moving from one study site to another). The appendixes follow on pages 57–62.

To prevent the potential for contamination of clean gear that would be used to facilitate our return to the vehicles and camp (e.g., hiking boots, backpacks, and satellite phones), we employed a three-containment-zone approach (Appendix II, Section 3). The three containment areas are the (1) **clean zone**, an area to stage non-cave-related gear (e.g., backpacks, extra water bottles, satellite phone, and other equipment), and to change into clean coveralls, boots, and other equipment once the person has left the intermediate zone; (2) **decontamination zone,** the location for staging disinfecting equipment and supplies, and using them to clean exposed parts of the body, stripping off and isolating coveralls, and changing into clean clothing; and (3) **intermediate zone**, the area for staging clean boots and a clean change of clothes (for the hike back to vehicles/camp) isolated in a ziplock bag, as well as cleaned gear that can be moved into the clean zone once decontamination procedures are completed. When used correctly, this approach should enable workers to stage and isolate contaminated gear and maintain clean equipment in different areas at a safe distance apart.

When the performance of Tyvek® and ProShield® coveralls was compared, we found both suit types sustained breaches by abrading and tearing when navigating constricted passageways. Although breaches in suits were repaired as detected using duct tape, this resulted in the introduction of pieces of coverall fabric into the cave environment. Thus, the use of both suits resulted in physical "litter" and a chemical contamination concern for the subterranean environment. During all field trials, team members attempted to collect and remove all coverall debris as encountered.

We also encountered problems when using inexpensive duct tape. Short-term placement (<5 minutes) in direct sunlight on 81°F (27°C) clear days resulted in the adhesive melting and the tape becoming useless until it cooled. We did not experience any problems with short-term placement of Gorilla® duct tape in direct sunlight.

The 2012 WNS Decontamination Protocol suggests covering electronic equipment with plastic wrap such as clear plastic bags (USFWS 2012b). We attempted to cover our digital single-lens camera in plastic wrap; however, the plastic wrap made it difficult to use the buttons and view the LCD display. Additionally, without the use of duct tape (which further restricts one's ability to use the camera), the plastic wrap does not adhere to the camera. Though it was not tested, clear packaging tape used with plastic wrap may help. For photographing hibernating bats during our February 2012 trip, we chose to use the camera without any barrier, wiping it down with isopropyl alcohol (70%) wipes after use and placing it out of the camera box so that it was completely dry before being stored. The 2016 WNS Decontamination Protocol recommends site-specific use for this type of equipment (USFWS 2016). Given that WNS has not been identified in northwestern Arizona, our approach was compliant with the new recommendations.

Discussion

The backcountry techniques proposed here were developed to complement the most recent WNS Decontamination Protocol

(USFWS 2016). This addendum provides stepwise procedures and eliminates much of the guesswork for first-time users decontaminating clothing and equipment. Although they were developed in response to backcountry subterranean research needs in the southwestern United States, these methods are applicable for all backcountry research projects.

These procedures are dynamic, and should be reviewed and modified as disinfectants and disinfection techniques are improved, or when additional information prompts further revision. One method for improving these techniques may be through working with professionals outside the disciplines of microbiology and wildlife science such as hazardous materials professionals and military personnel. Both have long histories of dealing with biological threats and developing techniques to isolate pathogens from human populations. Through such a collaboration, we may be able to further advance our ability to more effectively decontaminate equipment and personnel and thus better protect bat populations.

To reduce the likelihood of human-to-hibernacula transmission of WNS, caves should not be entered unless either a research question or administrative issue warrants such entry. If so, we recommend adhering to the most recent WNS Decontamination Protocol (e.g., USFWS 2016) and following the guidelines, addenda, and other supplemental documentation issued by state and federal regulatory and resource management agencies that have jurisdiction over the lands where the work will take place.

While the backcountry procedures presented in the four appendixes provide a stepwise approach for decontaminating equipment and personnel (in compliance with the WNS Decontamination Protocol), there are limitations. For many cave research projects, workers must use expensive, often irreplaceable electronic equipment (e.g., meteorological instruments, laser distance finders, and hammer drills). We recommend users of this type of equipment explore methods to best create a buffer between the equipment and the cave environment. The WNS Decontamination Protocol suggests site-specific dedication of equipment (USFWS 2016). Though expensive, this certainly eliminates the need to apply decontamination protocols for most gear and thus may be the best approach.

When used in constricted passageways, both brands of coveralls (Tyvek® and ProShield®) that we tested were subject to breaches, tears, and the resultant introduction of fabric into the cave environment. Thus, both suit types are of limited use within caves requiring belly crawling or walking through constricted passageways. We should further acknowledge that neither suit type is designed for the rigors of the cave environment.

In caves with constricted passageways, we do not recommend using either type of disposable coverall. Instead, we recommend the use of reusable ballistic nylon coveralls (which are designed for use in caves), following USFWS (2016) site-specific designation procedures. However, in backcountry settings it may be challenging to portage multiple pairs of nylon coveralls, and this approach would require the same decontamination procedures applied to other caving equipment when moving between study sites (USFWS 2016).

Regarding vertical climbing equipment, experiments have been conducted to test the strength of only Sterling® climbing ropes and one-inch tubular webbing; Barton (2009) was able to demonstrate that after numerous WNS decontamination treatments, the strength of this equipment was not affected. There are more than a dozen manufacturers that make rope and perhaps twice as many companies that manufacture climbing harnesses, webbing, and other such equipment. Conducting experiments similar to Barton (2009) on all ropes, webbing, harnesses, and other gear made by different companies has not been attempted. General care and cleaning of ropes (e.g., Cox and Fulsaas 2003) and harnesses (e.g., Black Diamond Journal 2010) involves machine washing on the gentle cycle or hand washing in a bathtub using mild soap with no harsh chemicals.

The US Fish and Wildlife Service (2016) recommends either that rope and webbing be dedicated to a single cave or the cave should not be entered; ropes and harnesses should be cleaned following the manufacturer's specifications after use at each study site. We suggest using ropes nearing retirement or those designated for site-specific applications (USFWS 2016); subsequently, these ropes may be retired after use or used site-specifically. In areas where WNS is neither confirmed nor suspected, it may be possible to use ropes, webbing, harnesses, and other vertical gear and rope rigging equipment with soft components at different sites after cleaning this equipment following the manufacturer's recommendations. However, the manner in which vertical equipment is used and the frequency of cleaning will be at the discretion of the jurisdictional regulatory or resource management agency (and according to the manufacturer's recommendations).

Management implications

The backcountry WNS decontamination procedures described here follow the current decontamination protocol (USFWS 2016), as well as previous versions of the protocol (USFWS 2011a, b, c; 2012b). The approach presented here is the first to outline a stepwise procedure for implementing WNS decontamination strategies in the backcountry. Although these procedures were developed for areas outside the WNS confirmed and suspected areas (i.e., the western United States), they are applicable in confirmed or suspected areas as well.

As time progresses and we learn more about the natural history characteristics and habitat requirements of *P. destructans*, we will be able to use this information to further improve decontamination procedures. Additionally, as more information becomes available regarding the fall and winter movements of bat species that hibernate in caves and mines, we will continue to improve our abilities to manage bats and their roost sites under a WNS paradigm.

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Disclaimer

While these procedures were improved through communication with employees of several state and federal agencies, this article does not necessarily reflect the positions or viewpoints of any of these state governments or of the United States government on this important issue.

Literature cited

Baker, G. E. 1966. Inadvertent distribution of fungi. Canadian Journal of Microbiology 12:109–112.

Barton, H. A. 2009. Safety of Sterling rope following white nose syndrome decontamination protocol. Unpublished report submitted to National Speleological Society. http://www.caves.org/WNS/Sterling%20Results.pdf.

Black Diamond Journal. 2010. QC Lab: Strength of a worn belay loop and when to retire a harness. http://www.blackdiamondequipment.com/en-us/journal/climb-qclab/qclab/qc-lab-strength-of-worn-belay-loops/.

Blehert, D. S., A. C. Hicks, M. Behr, C. U. Meteyer, B. Berlowski-Zier, E. L. Buckles, J. T. H. Coleman, S. R. Darling, A. Gargas, R. Niver, J. C. Okoniewski, R. J. Rudd, and W. B. Stone. 2009. Bat white-nose syndrome: An emerging fungal pathogen? Science 323:227.

Blehert, D. S., J. M. Lorch, A. E. Ballmann, P. M. Cryan, and C. U. Meteyer. 2011. Bat white-nose syndrome in North America. Microbe 6:267–273.

CCWHC (Canadian Cooperative Wildlife Health Centre). 2014. Little brown myotis, northern myotis and tri-colored bat. CCWHC, Minister of Environment Canada. 4 pages. http://www.registrelep-sararegistry.gc.ca/virtual_sara/files/gen_info/fs%5Fchauvesouris%5Fbats%5Fgen%2Dv03%5F0215%5Fe%2Epdf.

Cox, S. M., and K. Fulsaas. 2003. Mountaineering: The freedom of the hills. Seventh edition. The Mountaineers Books, Seattle, Washington, USA.

Cryan, P. M., C. U. Meteyer, J. G. Boyles, and D. S. Blehert. 2010. Wing pathology of white-nose syndrome in bats suggests life-threatening disruption of physiology. BMC Biology 8:135. http://www.biomedcentral.com/1741-7007/8/135.

Foley, J., D. Clifford, K. Castle, P. Cryan, and R. S. Ostfield. 2011. Investigating and managing the rapid emergence of white-nose syndrome, a novel, fatal, infectious disease of hibernating bats. Conservation Biology 25:223–231.

Frick, W. F., J. F. Pollock, A. C. Hicks, K. E. Langwig, D. S. Reynolds, G. G. Turner, C. M. Butchkoski, and T. H. Kunz. 2010. An emerging disease causes regional population collapse of a common North American bat species. Science 329:679–682.

Gargas, A., M. T. Trest, M. Christensen, T. J. Volk, and D. S. Blehert. 2009. *Geomyces destructans* sp. nov. associated with white-nose syndrome. Myotoxin 108:147–154.

Hicks, A., C. Herzog, A. Ballmann, and A. King. 2009. Protocol for 2008–2009 hibernacula surveys of cave bats, Indiana bat protocol. US Fish and Wildlife Service unpublished report, Bloomington, Indiana, USA. 45 pages.

Hoyt, J. R., K. Sun, K. L. Parise, G. Lu, K. E. Langwig, T. Jiang, S. Yang, F. W. Frick, A. M. Kilpatrick, J. T. Foster, and J. Feng. 2016. Widespread bat white-nose syndrome fungus in northeastern China [Letter]. Emerging Infectious Disease. doi:10.3201/eid2201.151314.

Lorch, J. M., C. U. Meteyer, M. J. Behr, J. G. Boyles, P. M. Cryan, A. C. Hicks, A. E. Ballmann, J. T. H. Coleman, D. N. Redell, D. M. Reeder, and D. S. Blehert. 2011. Experimental infection of bats with *Geomyces destructans* causes white-nose syndrome. Nature 480(7377):376–378. doi:10.1038/nature10590.

Meteyer, C. U., E. L. Buckles, D. S. Blehert, A. C. Hicks, D. E. Green, V. Shearn-Bochsler, N. J. Thomas, A. Gargas, and M. J. Behr. 2009. Histopathologic criteria to confirm white-nose syndrome in bats. Journal of Veterinary Diagnostic Investigations 21:411–414.

Minnis, A. M., and D. L. Lindner. 2013. Phylogenetic evaluation of Geomyces and allies reveals no close relatives of *Pseudogymnoascus destructans*, comb. nov., in bat hibernacula of eastern North America. Fungal Biology 117:638–649.

NPS (National Park Service). 2006. Management Policies 2006. US Department of the Interior, National Park Service. 180 pages. http://www.nps.gov/policy/mp2006.pdf.

———. 2010. Memorandum (N16:2300) to regional directors: Revised guidance on white-nose syndrome in bats and impacts on cave use. National Park Service, Washington, DC. 2 pages.

Okoniewski, J. C., J. Haines, A. C. Hicks, K. E. Langwig, R. I. von Linden, and C. A. Dobony. 2010. Detection of the conidia of *Geomyces destructans* in northeast hibernacula, at maternity colonies, and on gear—Some findings based on microscopy and culture. (May) 2010. White-nose Syndrome Symposium, Pittsburgh, Pennsylvania, USA.

Puechmaille, S. J., G. Wibbelt, V. Korn, H. Fuller, F. Forget, K. Mühldorfer, A. Kurth, W. Bogdanowicz, C. Borel, T. Bosch, T. Cherezy, M. Drebet, T. Görföl, A. J. Haarsma, F. Herhaus, G. Hallart, M. Hammer, C. Jungmann, Y. Le Bris, L. Lutsar, M. Masing, B. Mulkens, K. Passior, M. Starrach, A. Wojtaszewski, U. Zöphel, and E. C. Teeling. 2011. Pan-European distribution of white-nose syndrome fungus (*Geomyces destructans*) not associated with mass mortality. PLoS One 6 (e19167). doi:10.1371/journal.pone.0019167.

TPWD (Texas Parks and Wildlife Department). 2017. Fungus that causes white-nose syndrome in bats detected in Texas. News release. 23 March. Texas Parks and Widllife Department. http://tpwd.texas.gov/newsmedia/releases/?req=20170323c.

Turner, G. G., C. U. Meteyer, H. Barton, J. F. Gumbs, D. M. Reeder, B. Overton, H. Bandouchova, T. Bartonicka, N. Martínková, J. Pikula, J. Zukal, and D. S. Blehert. 2014. Nonlethal screening of bat-wing skin with the use of ultraviolet fluorescence to detect lesions indicative of white-nose syndrome. Journal of Wildlife Diseases 50:566–573.

Turner, G. G., D. M. Reeder, and J. T. H. Coleman. 2011. A five-year assessment of mortality and geographic spread of white-nose syndrome in North American bats and a look to the future. Bat Research News 52:13–27.

USDAFS (USDA Forest Service). 2014. Cave closure order extended for five years; forest managers hopeful a cure can be found for deadly bat disease. Press release. Ouachita, Ozark, and St. Francis National Forests, Hot Springs, Arkansas, USA. 2 pages.

USFWS (US Fish and Wildlife Service). 2011a. White-nose syndrome decontamination protocol, Version 01.25.2011. US Fish and Wildlife Service. http://www.fws.gov/whitenosesyndrome/pdf/WNSDecon_Cavers_v012511.pdf.

———. 2011b. Supporting decontamination documentation for cavers (WNS decontamination supplement 1 of 2), Version 01.25.2011. US Fish and Wildlife Service. http://www.fws.gov/whitenosesyndrome/pdf/WNSDecon_Cavers_v012511.pdf.

———. 2011c. Supporting decontamination documentation for researchers (WNS decontamination supplement 2 of 2), Version 01.25.2011. US Fish and Wildlife Service. http://www.fws.gov/whitenosesyndrome/pdf/WNSDecon_Researchers_v012511.pdf.

———. 2012a. North American bat death toll exceeds 5.5 million from white-nose syndrome. News release. 17 January. US Fish and Wildlife Service. 2 pages. http://www.batcon.org/pdfs/USFWS_WNS_Mortality_2012_NR_FINAL.pdf.

———. 2012b. White-nose syndrome decontamination protocol, Version 03.15.2012. US Fish and Wildlife Service. 3 pages.

———. 2014. White-nose syndrome: The devastating disease of hibernating bats in North America, June. 2 pages. https://www.whitenosesyndrome.org/sites/default/files/resource/white-nose_fact_sheet_6-2014_1.pdf.

———. 2015a. Fungus that causes bat disease detected in Nebraska. News release. 12 November. 1 page. https://www.whitenosesyndrome.org/sites/default/files/files/wns_fungus_ne_news_release_final.pdf.

———. 2015b. US Fish and Wildlife Service protects northern long-eared bat as threatened under Endangered Species Act. News release. 1 April. 4 pages. https://www.whitenosesyndrome.org/sites/default/files/files/4.1.15_nleb_news_release_final_version.pdf.

———. 2016. National White-Nose Syndrome Decontamination Protocol, Version 04.12.2016. https://www.whitenosesyndrome.org/sites/default/files/files/national_wns_decon_protocol_04.12.2016.pdf.

WDFW (Washington Department of Fish and Wildlife). 2016. Bat with white-nose syndrome confirmed in Washington State. News release. 31 March. Washington Department of Fish and Wildlife. 2 pages. http://wdfw.wa.gov/news/mar3116b/.

Wibbelt, G., A. Kurth, D. Hellmann, M. Weishaar, A. Barlow, M. Veith, J. Prüger, T. Görföl, L. Grosche, F. Bontadina, U. Zöphel, H.-P. Seidl, P. M. Cryan, and D. S. Blehert. 2010. White-nose syndrome fungus (*Geomyces destructans*) in bats, Europe. Emerging Infectious Diseases 16:1237–1242.

Wolf, F. A., and F. T. Wolf. 1947. The fungi, Volume II. John Wiley and Sons, New York, New York, USA.

Zukal, J., H. Bandouchova, T. Bartonicka, H. Berkova, V. Brack, J. Brichta, M. Dolinay, K. S. Jaron, V. Kovacova, M. Kovarik, N. Martínková, K. Ondracek, Z. Rehak, G. G. Turner, and J. Pikula. 2014. White-nose syndrome fungus: A generalist pathogen of hibernating bats. PLOS ONE 9.5(e97224). doi:10.1371/journal.pone.0097224.

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Editor's Note: The following four appendixes, by J. Judson Wynne, are intended as a "field-friendly" supplement to the preceding article, "White-nose syndrome decontamination procedures for backcountry subterranean projects," also by Wynne. They can be removed from the publication, laminated, and used in the field.

Appendix I. Required equipment and explanations on use

NO GEAR used in caves within a WNS confirmed or suspected area (i.e., state) may be used in areas where the disease has not been confirmed or suspected (USFWS 2016).

1. Required equipment

The amount of disinfecting supplies required depends upon team size, number of days in the field, and number of sites visited. Generally, the supply list provided below will accommodate a six-person team for one week. Isopropyl alcohol (70%) wipes are a more benign decontaminant than the other disinfectants listed in the decontamination protocol. Thus, it would be more appropriate for backcountry work. We used Lysol® disinfectant wipes during protocol development. Further, if caves are characterized by walkable passage, then one pair of disposable coveralls per person per day will be sufficient. If not, at least two pairs of ballistic nylon coveralls per person should be considered.

A. Supply checklist for procedures prior to entry and after exiting a cave or mine

- Disposable coveralls or ballistic nylon coveralls (1 pair per person, per study site)
- Duct tape (2 large rolls)
- 70% isopropyl alcohol (70%) wipes (2 canisters; 44-count)
- Large (10–15 gallons) heavy-duty plastic garbage bags (40-count box)
- Plastic zip ties (25-count)
- Heavy-duty resealable ziplock freezer bags (2 boxes [10-count] each of quart and gallon sizes)
- Properly laundered bandanas or rags (number depends on number of sites visited)
- Biodegradable/all-natural hand sanitizer (2 bottles; 12 oz. container)
- Compressed air (two 10-ounce cans)
- Trauma shears (2 pairs)
- Small nylon scrub brush (1 per person)
- Nitrile gloves, powder-free (2 boxes; 100 count; at least 2 pairs per person, per day, per study site required)
- Permanent black markers (1 box; 12-count)

B. Full decontamination supply checklist

- Tyvek® or ProShield® coveralls (1 pair)
- Tyvek® or ProShield® slip-on shoe covers (1 pair)
- Disinfectant cleaner (1 gallon; refer to decontamination protocol; USFWS 2016)
- 5-gallon buckets (number of buckets required depends on number of full decontaminations required; minimum is 2 buckets per full decontamination with the rinse bucket being reused)
- 2 scrub brushes, nylon-bristled
- Plastic zip ties (25-count)
- 2 pairs rubber cleaning gloves
- Biodegradable soap (16 fluid oz.)
- Biodegradable wipes (2 boxes; 30-count)

C. Personal gear checklist (WNS-related)

- Clothing (1 set of clothing per site; at least 1 set for transit between study site and camp/vehicles)
- Knee and elbow pads (at least 2 pairs)
- Caving gloves (synthetic leather/nylon; at least 2 pairs)
- 1 pair PVC boots or hiking boots (number of pairs of hiking boots required will be determined based on number of sites visited and time required for boots to completely dry following decontamination)
- 1 PVC caving backpack
- 2 pairs gaiters (only if hiking boots are used)
- Dry bags (recommended)

2. Equipment explanations and disinfecting recommendations

We provide explanations on select items listed in checklists *A* through *C*. We also provide recommendations for disinfecting personal and project equipment not discussed in these checklists. The instructions provided in the most recent version of the WNS Decontamination Protocol (e.g., USFWS 2016) must be used for decontaminating all personal gear, equipment, and clothing.

Tyvek®, ProShield®, or ballistic nylon coveralls and duct tape

Coveralls should be large enough to fit over underclothing and knee/elbow pads. Use of coveralls will further limit contact of underclothing and knee/elbow pads with the cave environment. In caves with walkable passage, Tyvek® or ProShield® coveralls are appropriate. Coveralls may be purchased with elastic cuffs on wrists, or duct tape can be used to secure the sleeves close to the wrists. Duct tape is used to affix the pant legs of the coveralls to boots or gaiters. In caves with constricted passageways requiring belly crawling or moving through narrow passageways, ballistic nylon coveralls are preferred. Upon completing work at a study site, coveralls are isolated and properly stored in a heavy-duty plastic garbage bag or gallon-sized, resealable ziplock bag.

Quaternary ammonium compounds

We used Lysol® IC™ Quaternary Disinfectant Cleaner. However, the WNS Decontamination Protocol (e.g., USFWS 2016) provides several alternatives that have been confirmed to kill *P. destructans* conidia.

Nitrile gloves

Applying and removing duct tape while wearing nitrile gloves ultimately results in torn gloves. If gloves are torn during decontamination procedures, immediately wash hands and put on a new pair of gloves.

Trauma shears

For cutting duct tape from wrist cuffs and around pant legs to detach disposable coveralls from boots/gaiters.

Reusing decontaminated equipment among different study sites
For equipment that requires decontamination by submersion in one of the known disinfectants/applications (e.g., gloves, knee/elbow pads, hiking boots, and gaiters), the number of extra pairs required will depend upon the number of different study sites visited in rapid succession and the amount of time needed for recently decontaminated equipment to completely dry before reuse. For most xeric regions in the southwestern United States, one extra pair of each item (gloves, knee/elbow pads, hiking boots, and gaiters) will probably be sufficient; the second pair may be worn at the next study site while the recently decontaminated pair is drying. In more mesic regions (e.g., the Pacific Northwest), drying time may require two or more days. Workers will need to determine if (1) the equipment will dry adequately following decontamination so it may be reused while in the field, or (2) a pair of each item is required per study site.

Clothing
One set of clothing per person per study site is required. These sets of clothing will be designated for underground use only. Upon completion of each site, clothing is isolated in a gallon-sized, resealable ziplock bag and is properly decontaminated in the field or once field personnel have returned to their respective homes. Additionally, a "clean" set of clothing, which never comes into contact with dirty caving equipment or the cave environment, is required for use in transit between the study site and vehicle/camp.

Gloves
At least two pairs of synthetic leather/nylon gloves per person are recommended. Rubber or nitrile gloves easily tear when abraded on rock surfaces. Synthetic leather/nylon gloves are more durable and are invaluable to work safely underground.

Knee and elbow pads
At least two sets of pads per person are recommended.

PVC boots or other footwear/gaiters
One pair of Wellington or knee-length-style PVC boots per team member is recommended. These boots are easy to clean and dry quickly. However, these boots often do not fit as well as hiking boots; as a result, it may be difficult to safely navigate cave passages and scramble over boulders and rocks. Consequently, some workers may choose to use hiking boots and gaiters rather than PVC boots.

Cave packs
One PVC cave pack per person is recommended. It is easy to clean and dries quickly.

Helmet
One helmet, two light sources on the helmet, and at least one additional light source within the caving bag per person are recommended. Before entering each study site, helmets will be decontaminated with isopropyl alcohol (70%) wipes. The use of porous headlamp straps can be eliminated by mounting the primary light source directly on the helmet.

Miscellaneous gear
When possible, additional gear should be stored in sealed ziplock bags or PVC dry bags within cave packs and accessed as needed. This includes food, urine bottles, solid human waste disposal bags, medical supplies, and tool kits. Any items used underground are properly cleaned, isolated, or disposed of as appropriate. Water should be stored in containers (hard plastic bottles or stainless steel containers) that can be easily disinfected. Water bladders are not recommended because they are difficult to disinfect.

Electronic sampling equipment
We recommend disinfecting electronic equipment between study sites using (1) compressed air to carefully clean the equipment and (2) isopropyl alcohol (70%) wipes to wipe down those areas lacking movable parts, buttons, or screens. Isopropyl alcohol wipes are one of the cleaning agents recommended by the WNS Decontamination Protocol (USFWS 2016). Compressed air may help remove fungal spores/conidia from keypads and other components. Care should be taken when wiping down electronic equipment with alcohol wipes because some surfaces may be damaged.

Headlamps and batteries
Headlamps are disinfected by (1) removing the elastic head straps and submersing them in solution following steps identified in the WNS Decontamination Protocol (USFWS 2016), and (2) wiping down the electronic parts using isopropyl alcohol (70%) wipes. Backup headlamps and batteries should be stored in sealed individual ziplock bags, kept in cave packs, and accessed as needed.

Vertical caving equipment
All technical caving equipment must be designated for site-specific, regional use within a WNS confirmed, suspected, or unaffected area (USFWS 2016). When moving between study sites within one of those designated areas, all equipment should be cleaned following the manufacturer's specifications (USFWS 2016).

Exposed skin
We recommend wiping all exposed body parts with all-natural/biodegradable wipes or soapy water following decontamination procedures. This is done not as part of the decontamination protocol per se, but rather to reduce accidental chemical exposure to any areas of skin. For example, accidental exposure may occur after handling decontamination equipment, recently decontaminated equipment, or personal gear. Users of isopropyl alcohol wipes should follow the Centers for Disease Control and Prevention's occupational health guidelines (CDC 1978).

NOTE: Once all equipment and personal gear are disinfected, we recommend using a clean bandana dampened with water or all-natural/biodegradable wipes to remove chemical residues from surfaces. This will reduce chemical exposure of field personnel.

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Appendix II. Fieldwork preparations

NO GEAR used in caves within a WNS confirmed or suspected area (i.e., state) may be used for subterranean research in those states where the disease has not been confirmed or suspected (USFWS 2016).

1. Packing decontamination supplies to and from study sites

Options for portaging decontamination supplies: There are two general approaches that may be undertaken for mobilizing decontamination equipment at a study site. (1) For study sites within 1 mile of vehicles/camp, workers may choose to portage multiple containers and required equipment itemized in Appendix I directly to the study site. Decontamination equipment and disinfectant containers used during decontamination procedures must be cleaned with isopropyl alcohol (70%) wipes (USFWS 2016) before these materials are integrated with other equipment and packed out. (2) Regarding single study sites requiring a many-mile hike to access a particular backcountry site, it may be easier for each person on the backcountry team to have a personal decontamination kit with all of the necessary items to follow the WNS Decontamination Protocol (USFWS 2016) in the field; they will also be responsible for packing their own personal supplies into and out of the remote study site. Personal decontamination kits should contain the following: 16 isopropyl alcohol (70%) wipes, eight all natural/biodegradable wipes, personal hand sanitizer, two pairs of nitrile gloves, two garbage bags, and two zip ties. Supplies must be multiplied appropriately if more than one site is to be visited in a given day. Two pairs of trauma shears are adequate for a six-person team and may be carried to and from the site by a designated person.

2. Personal equipment

Personal equipment should be assembled as follows: (1) One pair of disposable or ballistic nylon coveralls per person per day. For visiting multiple study sites in a given day, the number of coveralls will increase accordingly. (2) Cache of personal duct tape per person to be used to tape down wrist cuffs, secure boots/gaiters to coveralls, and repair disposable coveralls as necessary. (3) Various-sized disposable ziplock freezer bags (e.g., sandwich, quart, and gallon sizes). The number of bags per size depends upon the equipment required for a specific research task and the needs of each team member. We recommend double bagging all equipment.

3. Establishing staging areas at the study site

Three staging areas near the study site entrance should be established and designated as “clean,” “decontamination,” and “intermediate” zones. All zones should be at least 20 m (66 ft) apart, and clean and intermediate zones must be located upwind from the decontamination zone. (1) The **clean zone** is used to stage non-cave-related gear (e.g., backpacks, extra water bottles, satellite phone, and other equipment), and to change into clean coveralls, boots, and other equipment. (2) The **decontamination zone** is where chemical disinfectants, isopropyl alcohol and all-natural/biodegradable wipes, hand sanitizer, trauma shears, garbage bags, zip ties, and related supplies are staged. It is also the location for disinfecting equipment, cleaning exposed parts of the body, stripping off and isolating coveralls, and changing into clean clothing. If logistics permit, a hand and body washing station may be established where personnel may clean themselves prior to returning to the clean zone. (3) The **intermediate zone** must be established in an area that team members do not have to walk through to reach the clean zone. This area is used to stage clean boots and a clean change of clothes (isolated in a ziplock bag for the hike back to vehicles/camp). This zone is also used for staging recently cleaned gear to be moved into the clean zone once decontamination procedures are completed. Refer to the following protocols for clarification on zones and their functions.

4. Establishing an area for full decontamination/disinfecting of equipment prior to changing study sites

Designate a decontamination area at least 20 m (66 ft) downwind from vehicles and camp. All decontamination and containment supplies, and personal isolation bags (i.e., gear to be disinfected) should be placed within this area. Full decontamination of equipment (e.g., caving bags, PVC or hiking boots and gaiters, knee/elbow pads, gloves, and any other gear that requires submersion in a chemical mixture) between individual study sites should be determined at the discretion of the jurisdictional regulatory or resource management agency.

5. General recommendations and notes

- Proper disposal of camp refuse: Clearly label and segregate garbage bags designated for “contaminated” items from daily camp/project garbage.

- Proper storage of duct tape: Do not place inexpensive duct tape in direct sunlight during warm spring and summer months or store in hot areas (e.g., enclosed vehicles). Depending on the type of duct tape used, the glue adhesive may melt. Gorilla® duct tape works well when exposed to direct sunlight and heat.

- After exiting a study site, decontaminate equipment (helmets, water bottles, urine bottles, metal clipboards, cave survey equipment, and the exterior ziplock and dry bags containing gear) using a three-step procedure. (1) Physically remove dirt and mud from boots, coveralls, and caving and other equipment using nylon brushes. (2) Carefully clean surfaces with isopropyl alcohol (70%) wipes. (3) Remove chemical residue by wiping down all surfaces with all-natural/biodegradable wipes or a clean, damp bandana. This should be done prior to removing gloves.

- Team members should work together and watch each other to ensure appropriate decontamination protocols are applied between study sites. We recommend using the "buddy system" when possible. With team members watching one another, this will reduce the likelihood of overlooking gear, equipment, and clothing that require disinfecting. When working in caves characterized by narrow passages or sections requiring belly crawls, "buddies" are responsible for periodically inspecting each other's coveralls for breaches and work together during decontamination to make sure all steps are being followed and decontamination proceeds correctly.

- If personnel are portaging equipment into and out of a remote area, quart- and gallon-sized ziplock bags may be used to store used coveralls, nitrile gloves, disinfecting wipes, and other gear. Garbage bags are required to store PVC backpacks and boots. These items should then be placed within a larger backpack for hiking to and from remote study sites. However, compartmentalizing smaller items and equipment in smaller resealable ziplock bags may make packing equipment into a backpack much easier.

- For large multiperson projects, individuals should label their personal isolation bag containing their cave bag, boots, and other equipment by writing their name on a strip of tape adhered to their bag.

- When personnel spend multiple days at the same study site, it may be easier to stage most of the personal and WNS disinfection equipment in the appropriate zones—provided that the site is secure and the risk of theft is low.

- When staging caving equipment at a study site overnight, properly secure all equipment to prevent entry of insects and rodents. Be certain to remove any food items from gear that will be left overnight.

- Staff with regulatory or resource management agencies may require cave/mine personnel to bathe upon completion of operations at each study site prior to returning to their vehicles/camp (e.g., P. Ormsbee, 2011, personal communication).

- Print all field forms on weather-/waterproof paper for easier decontamination upon return to the office.

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Appendix III. Procedures prior to entering and after exiting a cave or mine

This approach discusses preparations for daily decontamination activities, including procedures prior to and after exiting a study site.

1. Prior to entering a cave or mine

Multiday or single visits to a study site: (1) Upon arrival at a study site, stage non-caving gear (e.g., backpacks, hats, and trekking poles) in the clean zone. (2) Put on caving clothes and knee/elbow pads, then clean coveralls. (3) If coveralls lack elastic wrist cuffs, use duct tape to secure wrist cuffs to prevent the coverall arms from sliding up and exposing skin or underclothing.[1] (4) Put on boots. (5) Tape pant legs of coveralls to each boot/gaiter.[2] (6) For additional protection against a disposable coverall breach, place duct tape on elbows and knees (and seat, if necessary). (7) Stage clean clothing and hiking boots in the intermediate zone and place disinfecting equipment in the decontamination zone.

Return to same study site for multiple days at a cave/mine: (1) Stage non-caving equipment in the clean zone. (2) Proceed to the decontamination zone to obtain cave clothing, knee/elbow pads, boots, and related gear.[3] (3) Carefully remove clean clothing and place it in a clean, resealable ziplock bag. (4) Remove cave clothing from the sealed ziplock bag. (5) Follow steps 2 through 7 above ("Multiday or single visits to a study site").

2. Procedures after exiting a cave or mine

(1) After exiting the study site, proceed directly to the decontamination zone. (2) Put on nitrile gloves. (3) Isolate field forms and notes.[4] (4) Brush off boots with nylon brush and disinfect coveralls and boots using isopropyl alcohol (70%) wipes. (5) Remove all necessary equipment from caving bag and place caving bag in the personal isolation bag (i.e., a garbage bag).[5] (6) Disinfect all personal equipment (e.g., helmet, water bottles, urine bottles, dry bags containing vertical gear and the exterior of ziplock bags used for equipment and isolating field forms) and group gear (e.g., metal clipboards, cave survey equipment, and electronics) using the most appropriate decontamination procedures (e.g., the three-step procedure for all equipment except vertical gear[6]). Disinfect vertical gear in accordance with the most recent WNS Decontamination Protocol (e.g., USFWS 2016). (7) Clean gloved hands.[6] (8) Move disinfected equipment to the intermediate zone and retrieve clean clothing and hiking boots. (9) Return to the decontamination zone and use trauma shears to cut the duct tape wrapped around wrist cuffs and PVC boots/gaiters. (10) Remove PVC boots/hiking boots and then coveralls by turning the suit inside out. (11) Step into the inside of the coveralls. If there are no ruptures, the inside of your coveralls should not be "contaminated." Therefore, you can safely stand on them, keeping your socks clean, until they are isolated in the subsequent steps. (12) Place PVC boots/hiking boots and knee/elbow pads in the personal isolation bag along with the previously isolated caving bag. (13) Remove clothing worn under the coveralls, place in a resealable ziplock bag, and deposit in the personal isolation bag. (14) Clean gloved hands and personal isolation bag.[6] (15) Wipe down the inside of the bag up to where it is tied or zip-tied.[7] (16) Wipe personal isolation bag with isopropyl alcohol wipes followed by all-natural/biodegradable wipes. (17) Using all-natural/biodegradable wipes, clean exposed areas of skin (e.g., face, neck, and arms) and areas exposed to isopropyl alcohol during decontamination procedures.[7] (18) Change into clean clothes. (19) Step out of coveralls when changing into clean boots. (20) With gloved hands, carefully place used coveralls into the appropriate isolation bag (e.g., personal or group) for either laundering/decontamination or disposal. (21) Remove nitrile gloves using standard medical glove removal procedures.[8] (22) Place used nitrile gloves into the appropriate isolation bag. (23) Clean hands. (24) Tie or zip-tie the group and personal isolation bags.[9] (25) Retrieve disinfected equipment from the intermediate zone and proceed to the clean zone.

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1 In some cases it may be possible to tape down glove cuffs to the coverall cuffs. However, from our experience, it is necessary to remove gloves to use survey and electronic equipment. Additionally, when working several hours at a given study site, this may also be impractical for toileting.

2 Before taping, be sure to slide pant leg cuff up boot approximately 5 cm (2 in) to permit knee-bending mobility. If using hiking boots and gaiters, tape the top of the gaiter to the coveralls and the bottom of the gaiter to the boot.

3 All equipment will have been staged at the study site on the previous day. Change from clean clothing into cave clothing and coveralls in the decontamination zone.

4 Access to data collected daily is important, so that it can be evaluated and logged each evening. Place each page in its own resealable ziplock bag. Do not place multiple pages in one bag, because it cannot be opened at camp without risk of contamination.

5 If operations at the study site are complete, dump contents of the caving bag onto the ground and place the caving bag in a garbage bag. If returning to the study site the next day, remove equipment from the caving bag that needs to be maintained for the next day (e.g., water bottles for replenishing, batteries for recharging, urine bottles for cleaning). In either case, follow the most recent WNS Decontamination Protocol (e.g., USFWS 2012).

6 Decontaminate using isopropyl alcohol (70%) wipes. For water bottles, rinse the exterior with clean water prior to reuse.

7 If logistics permit, biodegradable soap and water should be used to wash hands and body. P. Ormsbee (2011, personal communication) used this approach in Washington State. By vigorously washing hands and exposed parts of the body with soap and water, you can potentially remove *P. destructans* hyphae and spores/conidia mechanically. If this is not possible, use antibacterial hand sanitizer and antibacterial wipes in an attempt to mechanically remove the hyphae and conidia from skin.

8 Pinch glove of one hand carefully on the inside of the wrist and remove it by turning it inside out, then remove the other glove using the clean interior of the glove previously removed.

9 The last person to complete the procedures after exiting a cave or mine is responsible for closing the group isolation bag. Follow same procedures as for closing personal isolation bags.

Appendix IV. Procedures for full decontamination

Another option is to designate one person to be responsible for disinfecting all personal equipment, as follows.

1. Put on a clean pair of disposable or ballistic nylon coveralls, shoe covers, and rubber cleaning gloves.
2. Prepare chemical decontamination mixture (see USFWS 2016) in 5-gallon bucket[1] and clean water for rinsing (in another 5-gallon bucket).
3. Dump all equipment out of personal isolation garbage bags and place all empty personal isolation bags in a clean garbage bag.
4. Use a nylon brush to remove any dirt and mud from boots, caving bags, knee/elbow pads, gloves, and other equipment (USFWS 2016).
5. Decontaminate gear following the most recent WNS Decontamination Protocol (e.g., USFWS 2016). Submerge recently disinfected gear in rinse water following decontamination treatment.
6. Once all gear is disinfected, nylon brushes and any other equipment used in the decontamination process are decontaminated following step 5.
7. Remove rubber gloves and put on a pair of nitrile gloves.
8. Decontaminate rubber gloves.[2]
9. Carefully roll up pant legs of coveralls so they do not touch shoe covers.
10. Remove shoe covers and place in a garbage bag (same bag used to dispose of personal isolation bags).
11. Remove shoes (the ones worn underneath the shoe covers) and place on ground in front of you.
12. Remove coveralls by peeling them off and turning the suit inside out.
13. Put on shoes.
14. Place coveralls in garbage bag.
15. Wipe exterior of garbage bag. Wipe inside of bag to area below where zip tie will be secured.
16. Remove nitrile gloves following standard medical procedure.[3]
17. Place nitrile gloves in garbage bag.
18. Close and seal the garbage bag with a zip tie.
19. Double bag the garbage bags containing contaminated or presumed contaminated gear/garbage and zip tie shut.
20. Wash hands with all-natural/biodegradable wipes or soap and water.

1 One mixture of decontamination solution is prepared in a 5-gallon bucket and used on a per study site basis. Used solution remains in the bucket, covered with a tightly fastened lid, and is then placed in a garbage bag and zip-tied. The bucket is stored securely in the vehicle to prevent it from tipping and spilling while driving on rough roads. All chemical-water mixtures are properly disposed of following the manufacturer's recommendations at the nearest suitable facilities exist.

2 Decontaminate using isopropyl alcohol (70%) wipes.

3 Pinch glove of one hand carefully on the inside of the wrist and remove it by turning it inside out, then remove the other glove using the clean interior of the glove previously removed.

Literature cited

CDC (Centers for Disease Control and Prevention). 1978. Occupational health guidelines for isopropyl alcohol. http://www.cdc.gov/niosh/docs/81-123/pdfs/0359.pdf.

Ormsbee, P. 2011. Personal communication: E-mail to J. Judson Wynne, 16 November. USDA Forest Service Region 6, Portland, Oregon, USA.

USFWS (US Fish and Wildlife Service). 2016. National white-nose syndrome decontamination protocol, Version 04.12.2016. https://www.whitenosesyndrome.org/sites/default/files/files/national_wns_decon_protocol_04.12.2016.pdf.

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Sea-level rise and inundation scenarios for national parks in South Florida

By Joseph Park, Erik Stabenau, and Kevin Kotun

Abstract
National parks in South Florida are intimately connected to the sea. As sea levels rise, coastal regions of these parks experience both physical and ecological changes. Based on a state-of-the-art sea-level rise projection we propose two sea-level rise trajectories for South Florida, a low projection for general planning purposes and a high projection for risk assessment of sensitive ecological or physical systems. Sea-level rise projections only consider long time horizons; on shorter time scales the growth of recurrent coastal inundation events and storm surges have immediate ecological and physical impacts and we provide quantitative assessments of these processes.

Key words
inundation, sea-level rise, South Florida

THE NATIONAL PARK SERVICE (NPS) IS TASKED WITH the unimpaired preservation of the natural and cultural resources of the National Park System for the enjoyment, education, and inspiration of current and future generations. This mission and perspective positions the National Park Service as a leader in the recognition of and adaptation to changes in Earth's climate. It is now unequivocal that the climate is warming, and since the 1950s many of the observed changes are unprecedented over decades to millennia. The atmosphere and oceans have warmed, snow and ice have diminished, sea level has risen, and concentrations of greenhouse gases have increased (Steffan et al. 2015; IPCC 2013).

One of the most robust indicators of climate change is rising sea level driven by thermal expansion of ocean water and addition of land-based ice-melt to oceans. Sea-level rise is not evenly distributed around the globe, and the response of a regional coastline is highly dependent on local natural and human settings (Cazenave and Le Cozannet 2014). Nowhere is this more evident than in the national parks and national preserve located at the southern end of the Florida peninsula—Dry Tortugas, Biscayne, and Everglades National Parks and Big Cypress National Preserve—where low elevations and exceedingly flat topography provide an ideal setting for encroachment of the sea.

The physical and ecological impacts of sea-level rise on these parks will be pronounced, and in some cases, such as the distribution of mangrove forests, change has already been observed (Krauss et al. 2011). The natural ecological capacity for adaptation and resilience to these changes will be enhanced through the timely implementation of the Comprehensive Everglades Restoration Plan (CERP), simultaneously protecting the regional water supply for both natural and urban needs (NRC 2014).

Given these current and anticipated changes, it is prudent to define expectations for sea-level rise and the associated physical responses over the coming decades. This article is intended to inform the current state of science regarding these expectations.

Sea-level rise

The Intergovernmental Panel on Climate Change (IPCC) is composed of leading scientists from around the world whose mission is to review and assess the most recent scientific, technical, and socioeconomic information relevant to the understanding of climate change. Its most recent assessment, published in 2013, is the Fifth Assessment Report (AR5), which includes projections of global sea-level rise based on different representation concentration pathway (RCP) scenarios reflecting possible scenarios for future concentrations of greenhouse gases. RCP 8.5 is the highest emission and warming scenario under which greenhouse gas concentrations continue to rise throughout the 21st century, while RCP 6 and RCP 4.5 expect substantial emission declines to begin near 2080 and 2040, respectively.

The IPCC sea-level rise scenarios are comprehensive, but do not include contributions from a potential collapse of Antarctic ice sheets. However, recent evidence suggests that such a collapse may be under way (Holland et al. 2015; Wouters et al. 2015). In addition, the IPCC projections do not account for local processes such as land uplift or subsidence and ocean currents, and do not provide precise estimates of the probabilities associated with specific sea-level rise scenarios, which are a crucial decision support metric in the development and assessment of risk.

A contemporary estimate of local effects and comprehensive probabilities for the RCP scenarios is provided by Kopp et al. (2014). This work is based on a synthesis of tide gauge data, global climate models, and expert elicitation, and includes consideration of the Greenland ice sheet, West and East Antarctic ice sheets, glaciers, thermal expansion, regional ocean dynamic effects, land water storage, and long-term, local, nonclimatic factors such as glacial isostatic adjustment, sediment compaction, and tectonics. Following a review of scientific literature, we have adopted the work of Kopp et al. (2014) as the basis for sea-level rise scenarios at the four South Florida national parks.

Datums and mean sea level

A tidal datum provides a geodetic link between ocean water level and a land-based elevation reference such as the North American Vertical Datum of 1988 (NAVD88). The National Tidal Datum Epoch (NTDE) in the United States is a 19-year period over which tidal datums specific to each tide gauge are determined. The current NTDE for the United States is 1983–2001 and sea-level rise projections are referenced to the midpoint of this period (1992), consistent with procedures for sea-level rise design determined by the U.S. Army Corps of Engineers (USACE) and the National Oceanic and Atmospheric Administration's (NOAA) National Climate Assessment (USACE 2014). Common tidal datums include mean sea level (MSL), mean high-higher water (MHHW), and mean low-lower water (MLLW) as defined by NOAA (Center for Operational Oceanographic Products and Services 2013). As sea level rises, tidal datum elevations also rise, and a new tidal datum is established every 20 to 25 years to account for sea-level change and vertical adjustment of the local landmass (Center for Operational Oceanographic Products and Services 2000).

Kopp et al. (2014) use a local mean sea-level reference starting in the year 2000 instead of the NTDE MSL datum centered on 1992. To convert these projections to NTDE we estimate mean sea-level rise over the 1992 to 2000 period at Vaca Key with a nonlinear trend analysis and add the resulting value of 1.4 cm (0.6 in) to their projections. All projected water levels are then converted to NAVD88 by subtraction of the 25.3 cm (10.0 in) NAVD88 to NTDE MSL offset at the Vaca Key tide station.

Projection

Examination of local sea-level rise projections around South Florida finds small differences among Naples, Virginia Key, Vaca Key, and Key West, which are geographically closest to Big Cypress National Preserve, Biscayne National Park, Everglades National Park, and Dry Tortugas National Park, respectively. We chose the Vaca Key station sea-level data as representative of all four natural areas since it best reflects local oceanographic processes that influence coastal sea levels around South Florida.

Regarding selection of greenhouse gas emission scenarios, we employ RCP 8.5, also known as the "business-as-usual" scenario in which greenhouse gas emissions continue to rise. Although significant rhetoric is aimed at global emissions reduction, emissions continue to escalate and presently there is no clear socioeconomic driver to depart from a carbon-based energy infrastructure. More specifically, recent assessments of global energy production and population conclude that the RCP 4.5 emission scenario is unobtainable, and there is significant uncertainty as to whether the RCP 6.0 scenario can be realized (Jones and Warner 2016).

Each emission scenario and geographic location will have a spectrum of projections that span the possible ranges of sea-level rise, and this range is expressed as a probability of occurrence. A probability is commonly understood as the chance or likelihood of an event happening out of a large pool of possible events, and in this case the probability refers to occurrence of a specific sea-level rise curve out of the many possible curves under a particular climate scenario. Many different curves are possible for each scenario since there are uncertainties in the observable data (e.g., ice sheets and thermal expansion) as well as limitations in the models from which the projections are derived. The median projection (50th percentile) is in the middle of the projections (one-half of the projections are lower, one-half are higher) and can be considered a likely scenario given the current state of knowledge. A high percentile projection such as the 99th percentile is one with only a 1% chance that sea levels would exceed it, and is considered a worst-case scenario.

Since this projection is intended to inform authorities of sea-level rise for adaptation and planning purposes, and in light of the significant uncertainties inherent in generation of the projections and future dynamics of the climate, it is prudent to consider the upper percentile range of projections. In evaluating these factors we select the RCP 8.5 median (50th percentile) as the lower boundary of the projection, and the 99th percentile as the upper boundary. We are therefore conservatively biasing the projections to lie between a lower bound of likely sea-level rise and a high projection representing an upper limit to be considered in risk assessments for highly vulnerable, costly, or risk-averse applications. We emphasize that the high projection is deemed to have only a 1% chance of occurrence under current climate conditions, but in the event of Antarctic ice sheet collapse, its projected sea-level rise is consistent with estimates that include Antarctic ice melt contribution (DeConto and Pollard 2016).

The sea-level rise projection for South Florida referenced to the NAVD88 datum for the RCP 8.5 emission scenario and occurrence probabilities of 50% and 99% is shown in figure 1, and is tabulated in tables 1A and 1B (pages 65–66). These projections have been offset to match currently observed mean sea level in Florida Bay over the period 2008–2015 shown in figure 2 and tabulated in appendix 1 (available online with this article at http://www.nps.gov/subjects/ParkScience/ParkScience33-1Winter2016-2017.htm). These projections do not include tides

Table 1A. Sea-level rise projection: NAVD88 (cm)

Year	Low	High	Year	Low	High	Year	Low	High	Year	Low	High
2015	–14.8	–14.8	2045	6.8	18	2075	35.8	76.6	2105	68.3	159.9
2016	–14.2	–13.8	2046	7.7	19.6	2076	36.9	79	2106	69.5	162.7
2017	–13.6	–12.8	2047	8.6	21.1	2077	38	81.5	2107	70.8	165.4
2018	–12.9	–11.8	2048	9.6	22.8	2078	39.2	84	2108	72	168.3
2019	–12.3	–10.8	2049	10.5	24.4	2079	40.3	86.5	2109	73.2	171.2
2020	–11.6	–9.8	2050	11.4	26.2	2080	41.4	89.2	2110	74.4	174.2
2021	–10.9	–8.9	2051	12.3	27.9	2081	42.6	91.8	2111	75.6	177.2
2022	–10.2	–7.9	2052	13.2	29.7	2082	43.7	94.5	2112	76.7	180.3
2023	–9.5	–6.9	2053	14.1	31.6	2083	44.8	97.2	2113	77.9	183.5
2024	–8.8	–5.9	2054	15	33.5	2084	45.9	100	2114	79	186.8
2025	–8.1	–4.9	2055	15.9	35.4	2085	47.1	102.8	2115	80.1	190.1
2026	–7.4	–3.9	2056	16.8	37.3	2086	48.2	105.6	2116	81.2	193.4
2027	–6.7	–2.9	2057	17.7	39.3	2087	49.3	108.5	2117	82.2	196.8
2028	–6	–1.9	2058	18.6	41.2	2088	50.3	111.3	2118	83.3	200.2
2029	–5.3	–0.9	2059	19.5	43.2	2089	51.4	114.2	2119	84.4	203.7
2030	–4.6	0.2	2060	20.4	45.2	2090	52.4	117.2	2120	85.4	207.2
2031	–3.9	1.2	2061	21.4	47.1	2091	53.4	120.1			
2032	–3.2	2.2	2062	22.3	49	2092	54.4	123			
2033	–2.6	3.2	2063	23.3	51	2093	55.4	125.9			
2034	–1.9	4.3	2064	24.3	52.9	2094	56.3	128.9			
2035	–1.2	5.3	2065	25.3	54.9	2095	57.3	131.8			
2036	–0.5	6.4	2066	26.3	56.9	2096	58.3	134.7			
2037	0.2	7.6	2067	27.3	58.9	2097	59.3	137.6			
2038	0.9	8.7	2068	28.3	60.9	2098	60.3	140.5			
2039	1.6	9.9	2069	29.4	63	2099	61.3	143.3			
2040	2.4	11.2	2070	30.4	65.2	2100	62.4	146.2			
2041	3.2	12.4	2071	31.5	67.3	2101	63.5	148.9			
2042	4.1	13.8	2072	32.6	69.6	2102	64.7	151.7			
2043	5	15.1	2073	33.6	71.8	2103	65.9	154.4			
2044	5.9	16.6	2074	34.7	74.2	2104	67.1	157.1			

Notes: Sea-level rise in centimeters NAVD88 from Kopp et al. (2014) at Vaca Key, Florida. Values between decades (e.g., 2010, 2020) have been interpolated with a third-order polynomial fit. Low is the 50th percentile of the RCP 8.5 projection, high the 99th percentile. An offset of 1.4 cm (0.6 in) has been added to account for sea-level rise from 1992 to 2000 to convert the Kopp projections starting in 2000 to the NTDE MSL datum of 1992. The NAVD88 datum is 25.3 cm (10.0 in) above the NTDE MSL so that 25.3 cm has been subtracted to convert NTDE MSL to NAVD88. The projections have been offset to match observed mean sea level over the period 2008–2015 in Florida Bay of –14.8 cm (–5.8 in) NAVD88 (see appendix 1, online).

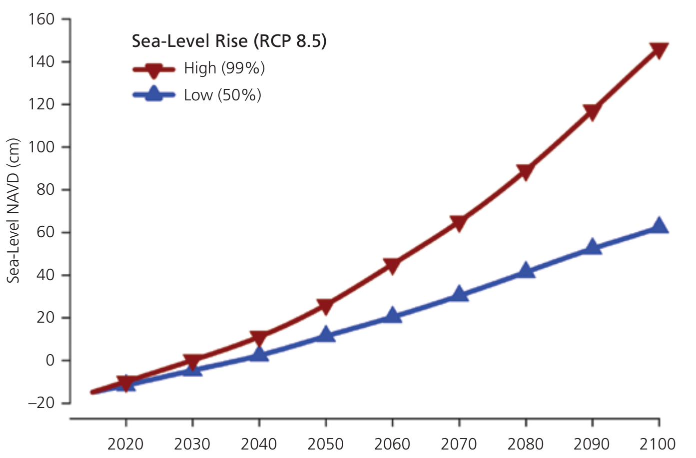

Figure 1. South Florida sea-level rise projection in centimeters NAVD for the RCP 8.5 greenhouse gas emission scenario. Low projection in blue is the median (50th percentile), high projection in red (99th percentile). Tides and storm surges are not included in this projection. Values are tabulated in tables 1A and 1B.

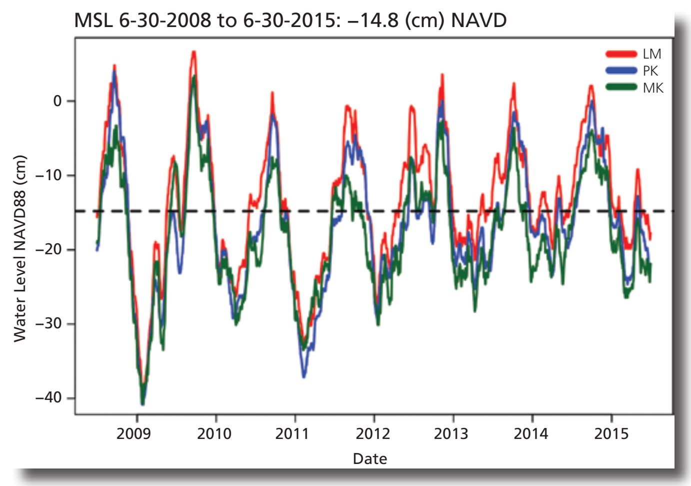

Figure 2. Thirty-day moving averages of daily mean sea level at Murray Key (MK), Peterson Key (PK), and Little Madeira Bay (LM) in Florida Bay. The dashed line is the mean of all three data sets.

Table 1B. Sea level rise projection: NAVD88 (ft)

Year	Low	High	Year	Low	High	Year	Low	High	Year	Low	High
2015	−0.49	−0.49	2045	0.22	0.59	2075	1.17	2.51	2105	2.24	5.25
2016	−0.47	−0.45	2046	0.25	0.64	2076	1.21	2.59	2106	2.28	5.34
2017	−0.45	−0.42	2047	0.28	0.69	2077	1.25	2.67	2107	2.32	5.43
2018	−0.42	−0.39	2048	0.31	0.75	2078	1.29	2.76	2108	2.36	5.52
2019	−0.40	−0.35	2049	0.34	0.80	2079	1.32	2.84	2109	2.40	5.62
2020	−0.38	−0.32	2050	0.37	0.86	2080	1.36	2.93	2110	2.44	5.72
2021	−0.36	−0.29	2051	0.40	0.92	2081	1.40	3.01	2111	2.48	5.81
2022	−0.33	−0.26	2052	0.43	0.97	2082	1.43	3.10	2112	2.52	5.92
2023	−0.31	−0.23	2053	0.46	1.04	2083	1.47	3.19	2113	2.56	6.02
2024	−0.29	−0.19	2054	0.49	1.10	2084	1.51	3.28	2114	2.59	6.13
2025	−0.27	−0.16	2055	0.52	1.16	2085	1.55	3.37	2115	2.63	6.24
2026	−0.24	−0.13	2056	0.55	1.22	2086	1.58	3.46	2116	2.66	6.35
2027	−0.22	−0.10	2057	0.58	1.29	2087	1.62	3.56	2117	2.70	6.46
2028	−0.20	−0.06	2058	0.61	1.35	2088	1.65	3.65	2118	2.73	6.57
2029	−0.17	−0.03	2059	0.64	1.42	2089	1.69	3.75	2119	2.77	6.68
2030	−0.15	0.01	2060	0.67	1.48	2090	1.72	3.85	2120	2.80	6.80
2031	−0.13	0.04	2061	0.70	1.55	2091	1.75	3.94			
2032	−0.10	0.07	2062	0.73	1.61	2092	1.78	4.04			
2033	−0.09	0.10	2063	0.76	1.67	2093	1.82	4.13			
2034	−0.06	0.14	2064	0.80	1.74	2094	1.85	4.23			
2035	−0.04	0.17	2065	0.83	1.80	2095	1.88	4.32			
2036	−0.02	0.21	2066	0.86	1.87	2096	1.91	4.42			
2037	0.01	0.25	2067	0.90	1.93	2097	1.95	4.51			
2038	0.03	0.29	2068	0.93	2.00	2098	1.98	4.61			
2039	0.05	0.32	2069	0.96	2.07	2099	2.01	4.70			
2040	0.08	0.37	2070	1.00	2.14	2100	2.05	4.80			
2041	0.10	0.41	2071	1.03	2.21	2101	2.08	4.89			
2042	0.13	0.45	2072	1.07	2.28	2102	2.12	4.98			
2043	0.16	0.50	2073	1.10	2.36	2103	2.16	5.07			
2044	0.19	0.54	2074	1.14	2.43	2104	2.20	5.15			

Notes: Sea-level rise in feet NAVD88 from Kopp et al. (2014) at Vaca Key, Florida. Values between decades (e.g., 2010, 2020) have been interpolated with a third-order polynomial fit. Low is the 50th percentile of the RCP 8.5 projection, high the 99th percentile. An offset of 0.55 inch (1.40 cm) has been added to account for sea-level rise from 1992 to 2000 to convert the Kopp projections starting in 2000 to the NTDE MSL datum of 1992. The NAVD88 datum is 0.83 feet (0.25 m) above the NTDE MSL so that 0.83 feet has been subtracted to convert NTDE MSL to NAVD88. The projections have been offset to match observed mean sea level over the period 2008–2015 in Florida Bay of −0.49 feet (−0.15 m) NAVD88 (see appendix 1, online).

or storm surges. Water levels will be both higher and lower than mean sea level depending on the tidal, weather, and storm conditions.

Hypsographic maps

The impact of sea-level rise on a landscape is largely controlled by topography. In southwestern Florida, Everglades National Park contains a broad, flat, freshwater slough (Shark River Slough) that connects to the coastal ocean by rivers along the west coast, and by small passes through a slightly elevated marl ridge on the southern coast. Directly south of this coastal ridge is Florida Bay, a basin formed approximately 4,000 years ago as rising sea level flooded the region. In southeastern Florida, Biscayne National Park contains a mangrove fringe bordered by canals and developed properties, and islands within the park are typically less than 2 m (6.6 ft) above sea level. Not far away are the low-lying islands of Dry Tortugas National Park, located about 113 km (70 mi) west of Key West. Each of these areas will be affected by sea-level rise in different ways as shown in figures 3 and 4 (pages 67–68), which are water-level elevation maps based on the sea-level rise projections through 2100 overlaid on a digital elevation model of the region (Fennema et al. 2013). These projections do not include tides or storm surge and are available online at http://nps.maps.arcgis.com (Alarcón 2016).

NPS/EVERGLADES NATIONAL PARK (2)

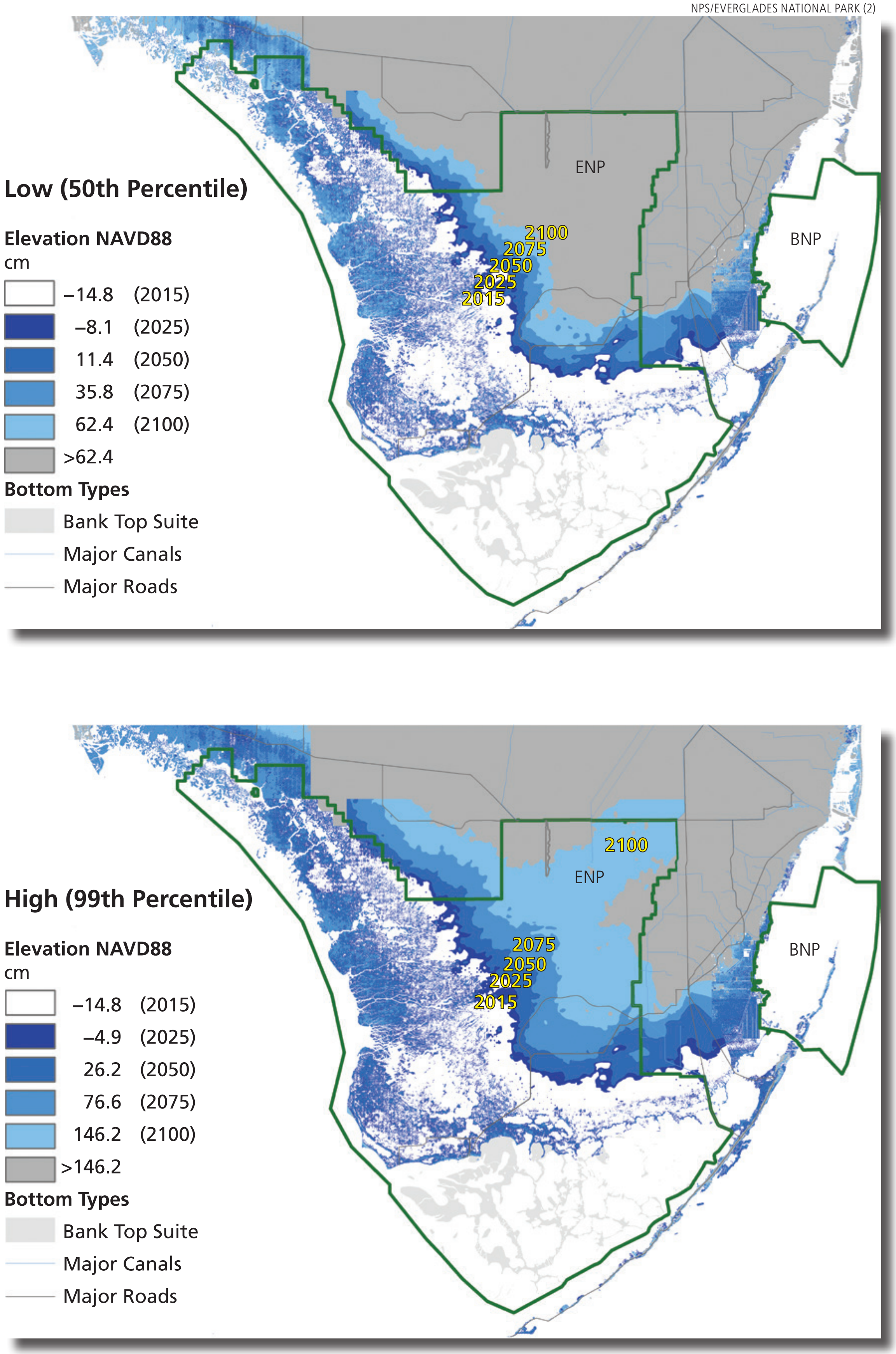

Figure 3. Mean sea-level elevation maps for South Florida including Everglades and Biscayne National Parks for the median (50th, top) and high (99th percentile, bottom) RCP 8.5 projections using current topography and NAVD-referenced digital elevation data. Tides and storm surges are not included in this projection.

An important aspect of sea-level rise is that it significantly shortens the expected recurrence intervals of storm surge.

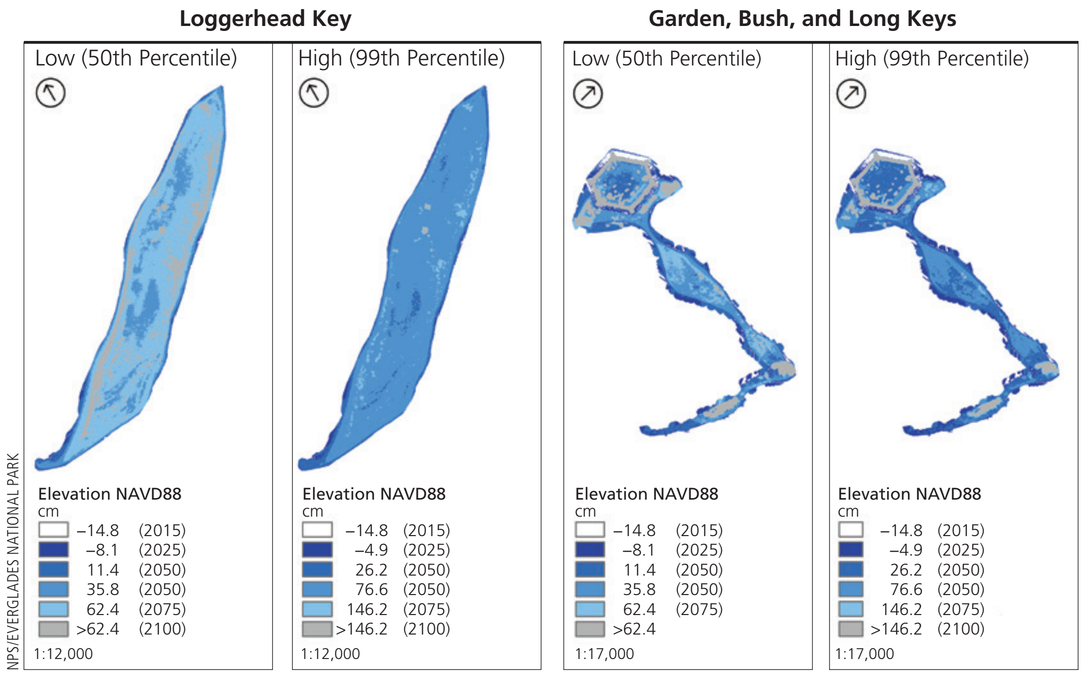

Figure 4. Mean sea-level elevation maps for Dry Tortugas National Park showing conditions at Loggerhead, Garden, Bush, and Long Keys for the median (50th) and high (99th percentile) RCP 8.5 projections using current topography and NAVD. Tides and storm surges are not included in this projection.

As previously noted, the projections are adjusted to match mean sea level in Florida Bay over the period 2008–2015 (−14.8 cm NAVD88), which is represented in the maps with a white color level. This could be misleading since it indicates that southern Everglades National Park is currently at mean sea level and possibly inundated with seawater. However, these regions are freshwater marsh and freshwater to salt-tolerant transition zones. It is important to realize there is a dynamic equilibrium between freshwater flowing from the Everglades and the sea, and with sufficient freshwater elevation the seawater is effectively kept at bay. Another important factor is the buttonwood and mangrove ridge defining the boundary between Florida Bay and freshwater marsh that serves as a hydraulic barrier allowing the freshwater to maintain elevations above mean sea level, thus limiting saltwater intrusion. This ridge will eventually be permanently inundated, allowing seawater to flow freely inland, but even then as Florida Bay expands, freshwater flowing downstream will serve to mitigate the extent of saltwater intrusion. As a result, mean sea-level elevations on the maps may not correspond to a marine environment. For example, figure 5 compares the current and projected sea-level elevations at the 50th percentile with an aerial photograph of the region near the Ingraham Highway in Everglades National Park. Although the current mean sea-level elevation dominates the lower portion of the region, this is not a marine environment but a transition zone between mangroves and freshwater marsh.

Influences of sea-level rise

Over the next 10 years, represented by the 2025 estimates, dramatic change in sea level is not anticipated. The expected sea-level rise is 7 cm (3 in) for the low scenario and 10 cm (4 in) for the high projection. These changes will result in more frequent tidal inundation along coastal regions; however, the buttonwood ridge located along the north shore of Florida Bay will remain above sea level. This modest increase is not likely to have an impact on the terrestrial portions of Dry Tortugas or Biscayne National Parks; however, the increased sea level will likely reduce freshwater flow from the Biscayne Bay coastal wetlands into Biscayne National Park.

By 2050 sea level is expected to increase between 26 and 41 cm (10 to 16 in). The effect on Shark Slough is similar for both projections with an increase in perennially inundated areas. It is difficult to project ecological impacts here since the amount of freshwater exerts important influence over the ecological response. Taylor Slough appears to experience significant impact under both scenarios with increasing pressure from sea level advancing up the slough perhaps as far as the Old Ingraham Highway. The eastern panhandle of the park is more heavily impacted by the high estimate than the low estimate simply because the high estimate exceeds the land surface elevation in this area and begins to overtop the buttonwood ridge.

NPS/EVERGLADES NATIONAL PARK (2)

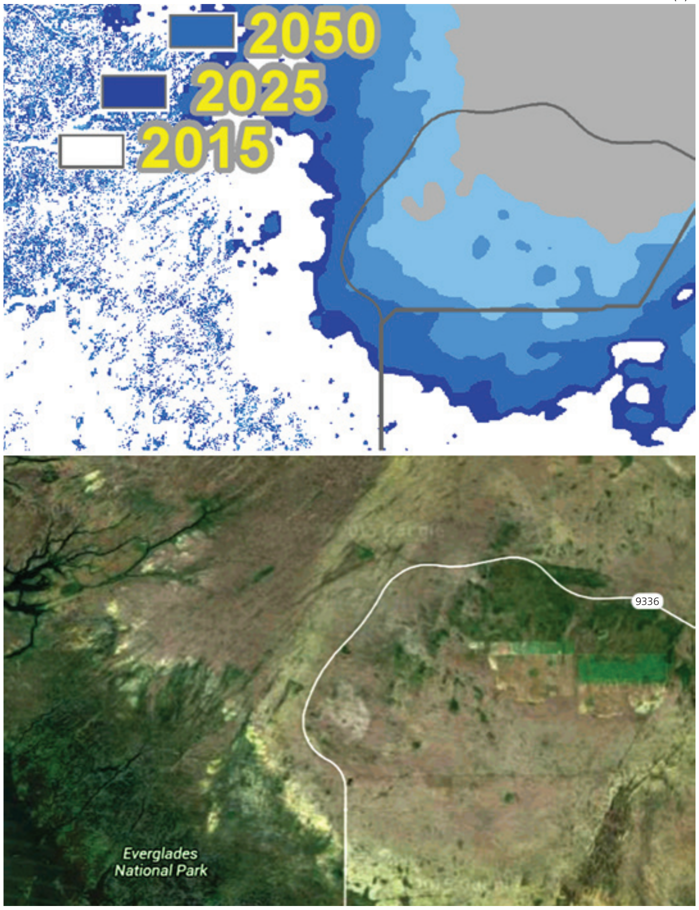

Figure 5. Comparison of sea-level elevations applied to digital elevation data (top) with an aerial photograph of the corresponding mangrove and marsh transition zone.

By 2075 sea-level elevations are expected to increase by 51 and 91 cm (20 and 36 in) for the low and high projections, respectively. Assuming that the buttonwood ridge does not increase in elevation from accretion or deposition, it appears that sometime between 2050 and 2075 much of the buttonwood ridge will be permanently inundated. This could signal an important tipping point in the ecological response of freshwater marshes since freshwater basins delineated by the ridge will no longer be viable. It appears likely that these impacts will extend to the Ingraham Highway.

By 2100 the projected sea-level rise is 77 cm (30 in) for the low projection and 161 cm (63 in) for the high scenario. It is likely that widespread ecological changes will be evident around the coastal Everglades as Florida Bay expands. In the case of the low-lying islands of Biscayne and Dry Tortugas National Parks, many of these can be expected to become submerged.

One important caveat is that these inundation projections do not account for land elevation changes, either positive or negative, as may be observed as water level and salinity change over time. It is

NPS/EVERGLADES NATIONAL PARK

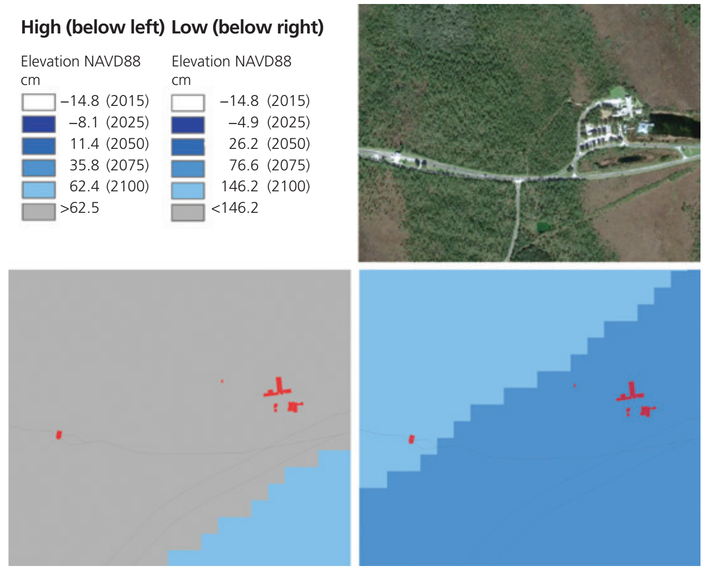

Figure 6. Projected mean sea-level elevations at Ernest F. Coe Visitor Center, Everglades National Park, and the main park entrance. Under the low sea-level rise scenario these buildings will not be perennially inundated out to 2100 (lower left). In the high projection (lower right), land surrounding the visitor center can be expected to be tidally inundated by 2075, while the park entrance will experience tidal inundation by 2100.

well understood that increased freshwater flow, as expected with Everglades restoration efforts, will help to protect against freshwater peat collapse by maintaining soil elevation and reducing the extent of saltwater intrusion (NRC 2014).

Park infrastructure

In addition to natural system ecological changes as sea level rises, visitor facilities and park infrastructure will also accrue impacts. For example, figure 6 presents application of the two sea-level rise scenarios to the Everglades National Park main entrance and Ernest F. Coe Visitor Center. These are comparisons of projected mean sea level with the best available land elevations surrounding the infrastructure and do not represent the actual finished floor elevations of the structures, which are likely higher than the surrounding land elevation. It is also important to note that mean sea level in Florida Bay fluctuates by approximately 30–40 cm in a yearly oceanographic cycle, as well as monthly and daily cycles from tides, so that effects of tidal inundation will be observed before the projected dates when mean sea level reaches a specific land elevation.

While some Everglades infrastructure such as the Ernest F. Coe Visitor Center, main park entrance, and Daniel Beard and Robertson Centers are projected to be unaffected by the low sea-level rise scenario out to 2100, all of these locations would be tidally inundated under the high sea-level rise projection at horizons from 2075 to 2100. Everglades central receiving, the Royal Palm Visitor

Center, and the Nike missile silos are expected to be at mean sea level by 2100 under the low projection and by 2075 under the high scenario. Conditions at Flamingo are mixed, with the low projection forecasting the housing and visitor center to remain above mean sea level out to 2100, but with the boat basin, maintenance yard, and water plant reaching mean sea level by 2100. Under the high projection the housing area is at mean sea level by 2100, the visitor center will be partially inundated by 2050, and the maintenance yard and water plant will be tidally inundated by 2075.

At Dry Tortugas National Park the projections indicate that as early as 2075 or as late as 2100 Loggerhead Key will be tidally submerged. At Fort Jefferson the north coal docks and campground remain above mean sea level to 2100 while areas around the ferry dock and the isthmus to Bush and Long Keys are expected to be at mean sea level by 2075 under the low sea-level rise projection. Under the high projection much of the north coal dock and campground will be at mean sea level by 2075, as will much of the land between the ferry dock and moat, although a portion of this will be at sea level by 2050. The isthmus to Bush Key will be at mean sea level by 2050.

Florida Current

These mean sea-level estimates represent the contemporary state of the art in local sea-level rise projection. However, knowledge of all processes and feedbacks driving sea levels is limited, and the models on which these projections are based are necessarily incomplete. The models do not have the spatial resolution required to resolve significant fine-scale oceanographic processes such as variability in the Florida Current. The Florida Current is one of the strongest and most climatically important ocean currents and forms the headwater of the Gulfstream (Gyory et al. 1992). As the Florida Current fluctuates in intensity, sea levels along the Atlantic coast of Florida respond by falling when the current increases, and rising when current decreases (Montgomery 1938).

The Gulfstream and Florida Current are components of the Atlantic meridional overturning circulation (AMOC), a component of the global ocean conveyor belt. Climate models agree that as the ocean warms and fresh meltwater is added, there will be a decline in the strength of the AMOC (Rahmstorf et al. 2015). If the Florida Current decreases in strength, then sea levels will rise along the Florida east coast and in Florida Bay, which is the southernmost extent of Everglades National Park. The extent of this change is difficult to forecast, but recent evidence suggests that a 10% decline in transport has contributed 60% of the roughly 7 cm (2.8 in) increase in sea level at Vaca Key over the last decade (Park and Sweet 2015). It is therefore plausible that a drastic slowdown of the AMOC and Florida Current could contribute an additional 10–15 cm (3.9–5.9 in) of sea-level rise to South Florida over this

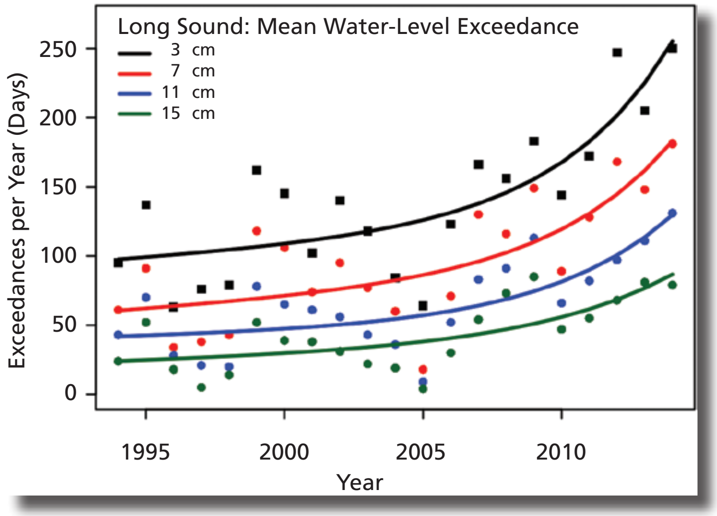

Figure 7. Daily water-level exceedances above the 1993–2011 mean water level in Long Sound of Florida Bay, Everglades National Park.

century. This potential is not reflected in the sea-level rise projections, but should be acknowledged by authorities and planners who use them.

Inundation and nuisance (recurrent) flooding

Sea-level rise is slow and difficult to discern when compared to the dynamic impacts of changing seasons and storms. Though a drastic change in sea level requires centuries or millennia, pronounced changes in the frequency and heights of coastal inundation along low-lying coastlines can occur in decades, and such changes are now evident around the United States over the last few decades as sea levels rise (Sweet and Park 2014). For example, the number of daily water-level exceedances per year above the 1993–2011 mean water level in Long Sound of Florida Bay within Everglades National Park is shown in figure 7. The curves show best-fit models based on general linear and geometric growth, suggesting that in the last decade the frequency of low-level inundations has transitioned from a slow, steady increase to one of escalating occurrences. These changes are a consequence of sea-level rise transitioning high water-level exceedances from low-chance events to common events, and this change is accelerating.

Infrequent high-impact flooding (storm surge)

Although sea-level rise and the associated increases in recurrent flooding are important physical stresses on South Florida natural areas, it is the infrequent but high-impact storm surge events that drastically change the landscape over the course of a few hours. For example, Hurricane Wilma in 2005 had a profound impact on the ecology of the Cape Sable region of Everglades National Park (Smith et al. 2009; Whelan et al. 2009), producing extensive damage at the Flamingo Visitor Center and permanently closing the Flamingo Lodge and Buttonwood Cafe.

Table 2. Hurricane storm surge inundation observations around Florida Bay from the SurgeDat database

Storm	Year	Longitude	Latitude	Surge (m)	Datum	Location
Katrina	2005	−81.0369	25.1294	1.22		Extreme SW Florida
Inez	1966	−80.5297	24.9976	1.10	Above Normal	Plantation Key
Alma	1966	−80.5135	25.0110	0.30	Above Normal	Tavernier
Gordon	1994	−80.5139	25.0108	1.22	Above Sea Level	Upper Florida Keys
Betsy	1965	−80.5148	25.0096	2.35	Mean Low Water	Tavernier
Donna	1960	−80.6353	24.9133	4.11		Upper Matecumbe Key
Andrew	1992	−80.9120	25.1431	1.50		Flamingo
Rita	2005	−80.7200	24.8605	1.22	NGVD 29	Middle and Upper Keys
Unnamed	1929	−80.3885	25.1848	2.68	Mean Sea Level	Key Largo
Wilma	2005	−81.0352	25.3523	2.50		Shark River 3
Gladys	1968	−80.5135	25.0110	0.15	Above Normal	Tavernier
David	1979	−80.6263	24.9231	0.61	Above Normal	Islamorada
Labor Day	1935	−80.7375	24.8516	5.49		Lower Matecumbe, Ferry Slip, Camp 3

Notes: Storm surge heights from these events are fit to a water-level exceedance and recurrence interval model to predict expected storm surge heights near Florida Bay with results shown in figure 8 and listed in table 3.

Storm surge is highly dependent on the severity and path of the storm, as well as the local bathymetric and topographic features of the coast, and since it occurs infrequently it is difficult to develop robust predictions of these rare events. A popular approach is to fit an extreme-value probability distribution to the highest water levels observed at a water-level monitoring gauge. However, gauges have short periods of record, typically a few decades at most, and they fail or are destroyed during extreme storms such that peak water levels are not recorded. A predictive storm surge database, SurgeDat, was developed in part to address this shortcoming by providing a statistical combination of data from multiple events in an area of interest (Needham et al. 2013). SurgeDat records storm surge water levels from all available sources, often from post-event high-water marks where gauge data are not available. SurgeDat then applies a statistical regression to estimate storm surge recurrence intervals. A recurrence interval is the length of time over which one can expect a storm surge to meet or exceed a specific inundation level. A familiar example is the 100-year flood level, which is really a 100-year recurrence interval at the specified flood level. In other words, in any one year there is a 1/100 or 1% chance that the flood level will be matched or exceeded. An excellent discussion of this can be found at the following US Geological Survey webpage: http://water.usgs.gov/edu/100yearflood.html.

Relevant to South Florida, a subset of SurgeDat was selected within a 40 km (25 mi) radius of 25.2° N, 80.7° as listed in table 2. Based on these events, the SurgeDat projection for storm surge recurrence intervals shown in figure 8 (page 72) and table 3 suggests that a 180 cm (6 ft) surge event can be expected every 20 years. This same level of sea-level rise is not expected to occur until at least 2100.

Table 3. Storm surge height recurrence intervals

Interval (year)	Surge (cm)	Interval (year)	Surge (cm)
10	45	56	388
12	82	58	395
14	112	60	402
16	139	62	408
18	162	64	415
20	183	66	421
22	202	68	427
24	219	70	433
26	235	72	438
28	250	74	444
30	264	76	449
32	277	78	454
34	289	80	459
36	300	82	464
38	311	84	469
40	321	86	473
42	331	88	478
44	340	90	482
46	349	92	487
48	357	94	491
50	365	96	495
52	373	98	499
54	381	100	503

Note: Recurrence interval projection in years shown in figure 8 from the hurricane data in table 2. The interval is the expected number of years one would wait for the associated hurricane storm surge to occur at least once. Note that this projection does not take into account future sea-level rise.

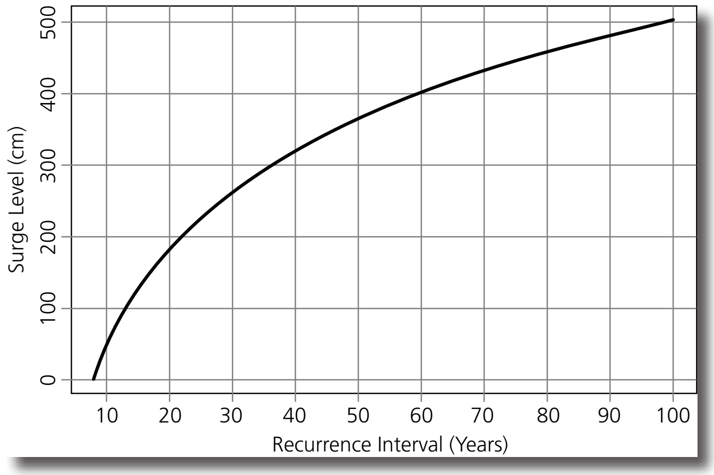

Figure 8. Storm surge recurrence intervals from the SurgeDat database and return periods predictor for a 25-mile radius centered on 25.2° N, 80.7° W.

We are … conservatively biasing the projections to lie between a lower bound of likely sea-level rise and a high projection representing an upper limit to be considered in risk assessments for highly vulnerable, costly, or risk-averse applications.

The recurrence interval projection is by necessity based on a sparse data set, and caution should be used in its interpretation. As projection intervals become longer, it is more likely that the observed data are inadequate to robustly represent all possibilities. Also, these projections do not incorporate changes from sea-level rise, or from a changing climate, which can alter the strength and frequency of storms. An important aspect of sea-level rise is that it significantly shortens the expected recurrence intervals of storm surge. For example, under a median sea-level rise projection at Key West, Park et al. (2011) find that a 1-in-50-year storm surge based on historical data in 2010 can be expected to occur once every five years by 2060.

Conclusion

Sea-level rise is one of the most robust indicators of climate change and a warming planet. The national parks of South Florida are intimately tied to the ocean, and are already experiencing physical and ecological changes in response to sea-level rise. Based on a review of the available science, we have developed a projection to inform park interests on sea-level rise and inundation, trends in the frequency of nuisance flooding, and recurrence intervals of storm surge. The sea-level rise projections are based on the RCP 8.5 emissions scenario published by the ICPP AR5, as this scenario is deemed the most likely given the current inability of the global industrial complex to realistically pursue emission reductions. Two estimates are provided that bracket the expected range of sea-level rise. The low projection is the 50th percentile (median) forecast, while the high projection is intended for worst-case planning and corresponds to the 99th percentile with only a 1% chance of occurring. However, these projections do not incorporate contributions from a collapse of Antarctic ice sheets, changes in the Florida Current, or inundation due to tides or storms. Although the high projection is deemed to have only a 1% chance of occurrence under current conditions, a collapse of the Antarctic ice sheets could render it more plausible. Regardless of the specific sea-level rise projection, Everglades restoration with increased freshwater flow into the Everglades will serve to mitigate the impacts of sea-level rise over the next century.

Management actions in natural coastal systems will necessarily be location and project specific. An appropriate planning horizon is a crucial component of managerial design since benefits observed today may be offset by changing conditions within the planned lifespan of the project. Updates to the climate projections presented here are almost certain to occur and adaptive management practices should be incorporated when considering project alternatives, and, when appropriate, preference given to solutions that are flexible and can be adjusted as our understanding of current and expected impacts changes. These practices should be institutionalized as part of the ongoing monitoring and assessment process, incorporated into our education and outreach efforts, and used to best manage the influence of climate change on park resources.

Acknowledgments

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References

Alarcón, C. 2016. Sea level rise projections for South Florida, 50th and 99th percentiles. 99th percentile: http://nps.maps.arcgis.com/home/webmap/viewer.html?layers=b61db3e154104ea486528c031390066c; 50th percentile: http://nps.maps.arcgis.com/home/webmap/viewer.html?layers=87e87e094680431eab085a18adb36836.

Cazenave, A., and G. Le Cozannet. 2014. Sea level rise and its coastal impacts. Earth's Future 2(2):15–34. doi:10.1002/2013EF000188.

Center for Operational Oceanographic Products and Services. 2000. Tidal datums and their applications. Special Publication NOS CO-OPS 1. National Oceanic and Atmospheric Administration, National Ocean Service Center for Operational Oceanographic Products and Services, Silver Spring, Maryland, USA. http://tidesandcurrents.noaa.gov/publications/tidal_datums_and_their_applications.pdf.

———. 2013. Tidal datums. National Oceanic and Atmospheric Administration, National Ocean Service Center for Operational Oceanographic Products and Services, Silver Spring, Maryland, USA. http://tidesandcurrents.noaa.gov/datum_options.html.

DeConto, R. M., and D. Pollard. 2016. Contribution of Antarctica to past and future sea-level rise. Nature 531(7596):591–597. doi:10.1038/nature17145.

Fennema, R., L. Pearlstine, and J. Parsons. 2013. EVER Elevation (version 1): A multi-sourced digital elevation model for Everglades National Park. Report. South Florida Natural Resources Center, Everglades National Park, Homestead, Florida, USA.

Gyory, J., E. Rowe, A. Mariano, and E. Ryan. 1992. The Florida Current. Gulf of Mexico Research Initiative, Consortium for Advanced Research on Transport of Hydrocarbon in the Environment, and Rosenstiel School of Marine and Atmospheric Science; University of Miami, Florida, USA. http://oceancurrents.rsmas.miami.edu/atlantic/florida.html.

Holland, P. R., A. Brisbourne, H. F. J. Corr, D. McGrath, K. Purdon, J. Paden, H. A. Fricker, F. S. Paolo, and A. H. Fleming. 2015. Oceanic and atmospheric forcing of Larsen C Ice-Shelf thinning. The Cryosphere 9:1005–1024. doi:10.5194/tc-9-1005-2015.

Intergovernmental Panel on Climate Change (IPCC). 2013. Climate change 2013: The physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. T. F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P. M. Midgley, editors. Cambridge University Press, Cambridge, UK, and New York, USA.

Jones, G. A., and K. J. Warner. 2016. The 21st century population-energy-climate nexus. Energy Policy 93:206–212. doi:10.1016/j.enpol.2016.02.044.

Kopp, R. W., R. M. Horton, C. M. Little, J. X. Mitrovica, M. Oppenheimer, D. J. Rasmussen, B. H. Strauss, and C. Tebaldi. 2014. Probabilistic 21st and 22nd century sea-level projections at a global network of tide gauge sites. Earth's Future 2(8):383–406. doi:10.1002/2014EF000239.

Krauss, K. W., A. S. From, T. W. Doyle, T. J. Doyle, and M. J. Barry. 2011. Sea-level rise and landscape change influence mangrove encroachment onto marsh in the Ten Thousand Island region of Florida, USA. Journal of Coastal Conservation 15(4):629–638. doi:10.1007/s11852-011-0153-4.

Montgomery, R. B. 1938. Fluctuations in monthly sea level on eastern U.S. coast as related to dynamics of western north Atlantic Ocean. Journal of Marine Research 1:165–185.

National Research Council (NRC). 2014. Progress toward restoring the Everglades: The fifth biennial review—2014. Committee on Independent Scientific Review of Everglades Restoration Progress, Water Science and Technology Board, Board on Environmental Studies and Toxicology; Division on Earth and Life Studies; National Research Council, Washington, DC, USA. doi:10.17226/18809.

Needham, H. F., B. D. Keim, D. Sathiaraj, and M. Shafer. 2013. A global database of tropical storm surges. EOS Transactions American Geophysical Union. 94(24):213–214. doi:10.1002/2013EO240001.

Park, J., J. Obeysekera, M. Irizarry, J. Barnes, P. Trimble, and W. Park-Said. 2011. Storm surge projections and implications for water management in South Florida. Climatic Change 107(1) (Special Issue: Sea level rise in Florida: An emerging ecological and social crisis):109–128. doi:10.1007/s10584-011-0079-8.

Park, J., and W. Sweet. 2015. Accelerated sea level rise and Florida Current transport. Ocean Science 11:607–615. doi:10.5194/os-11-607-2015.

Rahmstorf, S., J. E. Box, G. Feulner, M. E. Mann, A. Robinson, S. Rutherford, and E. J. Schaffernicht. 2015. Exceptional twentieth-century slowdown in Atlantic Ocean overturning circulation. Nature Climate Change 5:475–480. doi:10.1038/nclimate2554.

Smith, T. J., G. H. Anderson, K. Balentine, G. Tiling, G. A. Ward, and K. R. T. Whelan. 2009. Cumulative impacts of hurricanes on Florida mangrove ecosystems: Sediment deposition, storm surges, and vegetation. Wetlands 29(1):24–34. doi:10.1672/08-40.1.

Steffen, W., W. Broadgate, L. Deutsch, O. Gaffney, and C. Ludwig. 2015. The trajectory of the Anthropocene: The Great Acceleration. The Anthropocene Review 2(1):81–98. doi:10.1177/2053019614564785.

Sweet, W. V., and J. Park. 2014. From the extreme to the mean: Acceleration and tipping points of coastal inundation from sea level rise. Earth's Future 2(12):579–600. doi:10.1002/2014EF000272.

US Army Corps of Engineers (USACE). 2014. Procedures to evaluate sea level change: Impacts, responses, and adaptation. U.S. Army Corps of Engineers, Washington, DC, USA. Technical Letter No. 1100-2-1, 30 June 2014. http://www.publications.usace.army.mil/Portals/76/Publications/EngineerTechnicalLetters/ETL_1100-2-1.pdf.

Whelan, K. R. T., T. J. Smith III, G. H. Anderson, and M. L. Ouellette. 2009. Hurricane Wilma's impact on overall soil elevation and zones within the soil profile in a mangrove forest. Wetlands 29(1):16–23. doi:10.1672/08-125.1.

Wouters, B., A. Martin-Español, V. Helm, T. Flament, J. M. van Wessem, S. R. M. Ligtenberg, M. R. van den Broeke, and J. L. Bamber. 2015. Dynamic thinning of glaciers on the Southern Antarctic Peninsula. Science 348(6237):899–903. doi:10.1126/science.aaa5727.

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PS

In Focus

Grand Canyon's corridor trail system: Linking the past, present, and future

By Elyssa Shalla

NPS/MICHAEL QUINN

Abstract

Grand Canyon National Park is in the final stages of a multiyear process to revise the park's 1988 backcountry management plan. This article provides an overview of the early use, development, and management of the park's corridor trail system, as a means for understanding some of the current recreational trends that challenge park managers.

Key words

corridor, cultural history, Grand Canyon National Park, recreation

Figure 1. View of the upper Bright Angel Trail from Hermit Road on the South Rim of Grand Canyon.

THE CORRIDOR TRAIL SYSTEM OF GRAND Canyon National Park (Arizona) is one of the most popular and heavily visited backcountry destinations in the National Park System today (fig. 1, pages 74–75, and fig. 2) (USDI 2012). This backcountry area has a complex cultural history spanning thousands of years, serving as a homeland and transportation, utility, and recreation corridor for inhabitants, park managers, and visitors alike. Over the past several decades visitation to the park and recreational use of the corridor trail system have grown tremendously. Grand Canyon National Park is in the process of updating its backcountry management plan to address issues of visitor access, visitor experience, resource management, and resource protection in the corridor. As the first revision of this plan since 1988, it is coordinated with several management studies and program reviews. Public scoping for the revised plan began in spring 2011, and the park is now reviewing comments on the recently released draft environmental impact statement. A final decision is expected in the next year. This article outlines the history of the corridor trail system and is intended to “set the stage” for the three companion articles that follow, each of which highlights a related management program or study: visitor experience research on trail capacities, the canyoneering monitoring program, and the preventive search-and-rescue program.

Background

Grand Canyon National Park’s corridor primarily consists of the Bright Angel, South Kaibab, and North Kaibab trails (fig. 2). Descending at least 4,000 ft (1,219 m), each trail plunges off of forested rims and then switchbacks its way down into the lower Sonoran Desert life zone (see fig. 1). These 30.5 miles (49 km) of trail function as the main arteries for inner canyon travel and are linked at the heart of the canyon by two suspension bridges and the Colorado River Trail. A cultural and historic landscape distinct from the more than 1.1 million acres (445,000 ha) of proposed wilderness that surround it (fig. 3, page 78), the corridor reflects how human use and recreation have evolved in the park’s backcountry over time.

Early use of the Bright Angel Fault

Native uses

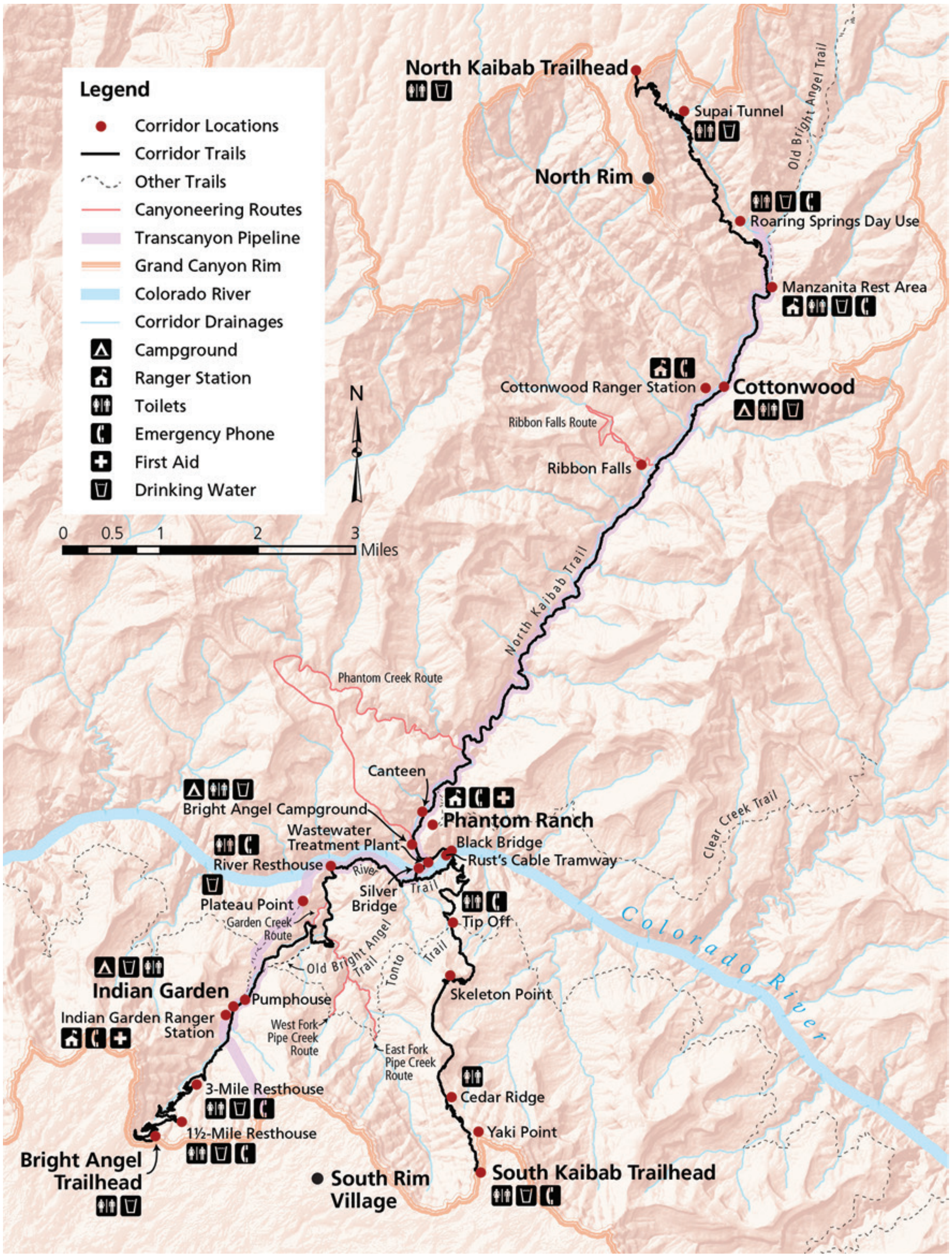
Grand Canyon has lured people to venture into its depths for thousands of years. Bisecting the canyon and contorting its most formidable geologic layers into penetrable terrain, the Bright Angel Fault has served as a natural means of access to the inner canyon since prehistoric times. At numerous sites along the fault, archaeologists have documented structures and artifacts created by Archaic, ancestral Puebloan, Cohonina, and protohistoric American Indians (Milner 2005). The availability of water and warmer temperatures likely inspired early travel and human occupation of the area.

Mining

At the turn of the 20th century, prospectors (and their mules) came in search of mineral wealth (Berkowitz and Thybony 2004). From 1890 to 1891, Pete Berry, along with brothers Niles and Ralph Cameron, widened what is now the Bright Angel Trail as far down as Indian Garden in hopes of exploiting nearby mineral deposits. However, it did not take them long to realize that “the real riches lay in tourism and not in ore” (Berkowitz and Thybony 2004). Much to the ire of the Santa Fe Railroad, whose tracks had reached the South Rim in 1901, Ralph Cameron filed mining claims at strategic points along the trail. He also charged a $1 toll for use of the trail (fig. 4, page 79) and profited from overnight guests at his newly established Indian Garden Camp (Berkowitz and Thybony 2004).

Tourism

Also hoping to profit from the burgeoning popularity of inner canyon tourism was E. D. Woolley, a Utah businessman. In 1903, Woolley established the Grand Canyon Transportation Company with his son-in-law, David Rust, a local schoolteacher (Swanson 2007). Rust would go on to develop a trail on the north side of Bright Angel Fault that had originated with Francois Matthes of the US Geological Survey. This trail, the predecessor to the modern North Kaibab Trail, led to a camp that Rust also developed, situated near the mouth



NPS/GRAND CANYON NATIONAL PARK GIS

Figure 2. The popular corridor trail system at Grand Canyon National Park connects the North and South Rims by way of the North and South Kaibab Trails and the Bright Angel Trail over a total distance of 30.5 miles (49 km).

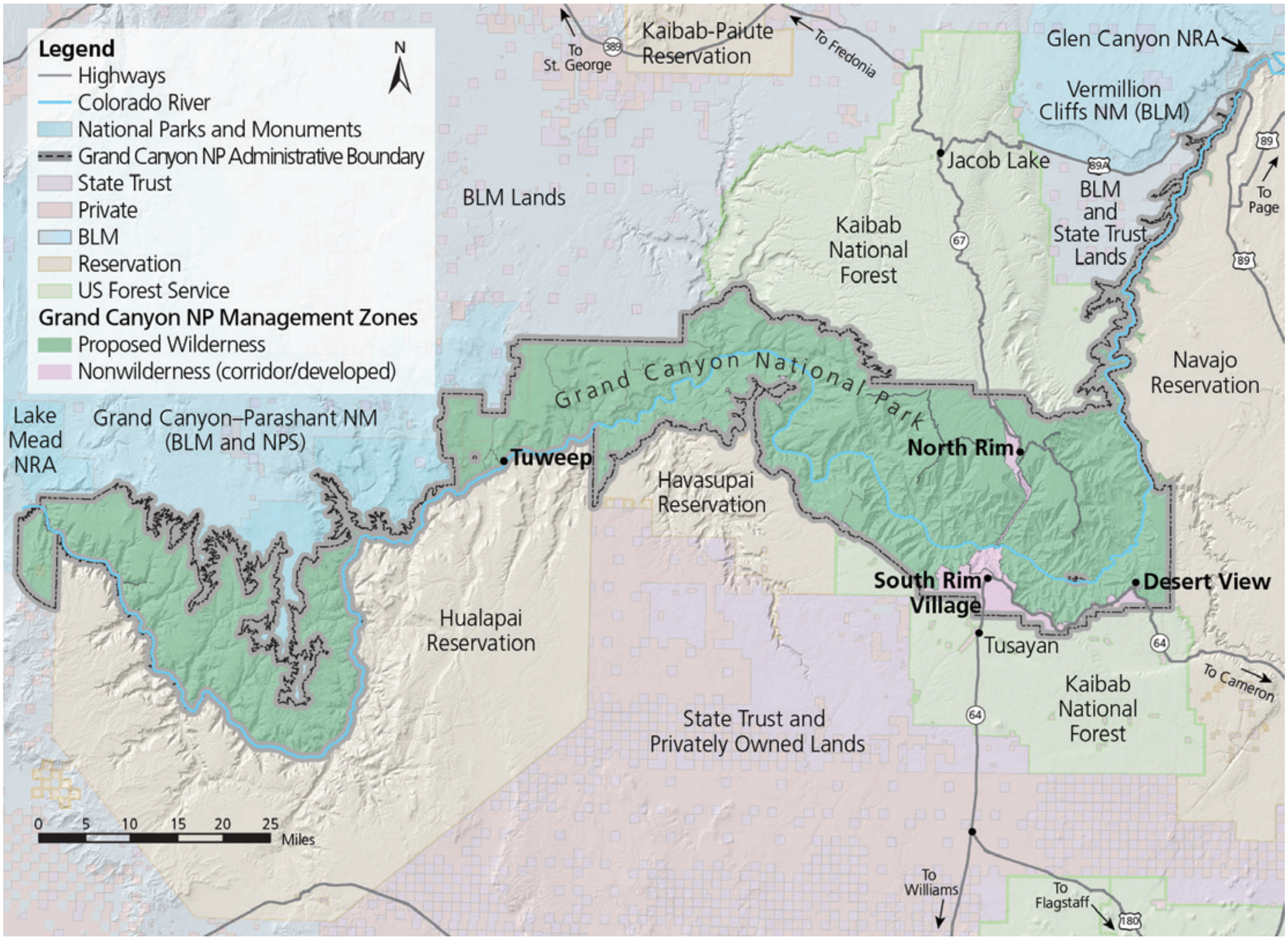


Figure 3. Multiple jurisdictions and various land uses surround the national park in the Grand Canyon region. Within the national park the corridor trail system is a designated cultural and historic landscape among the more than 1.1 million acres (445,000 ha) of proposed wilderness.

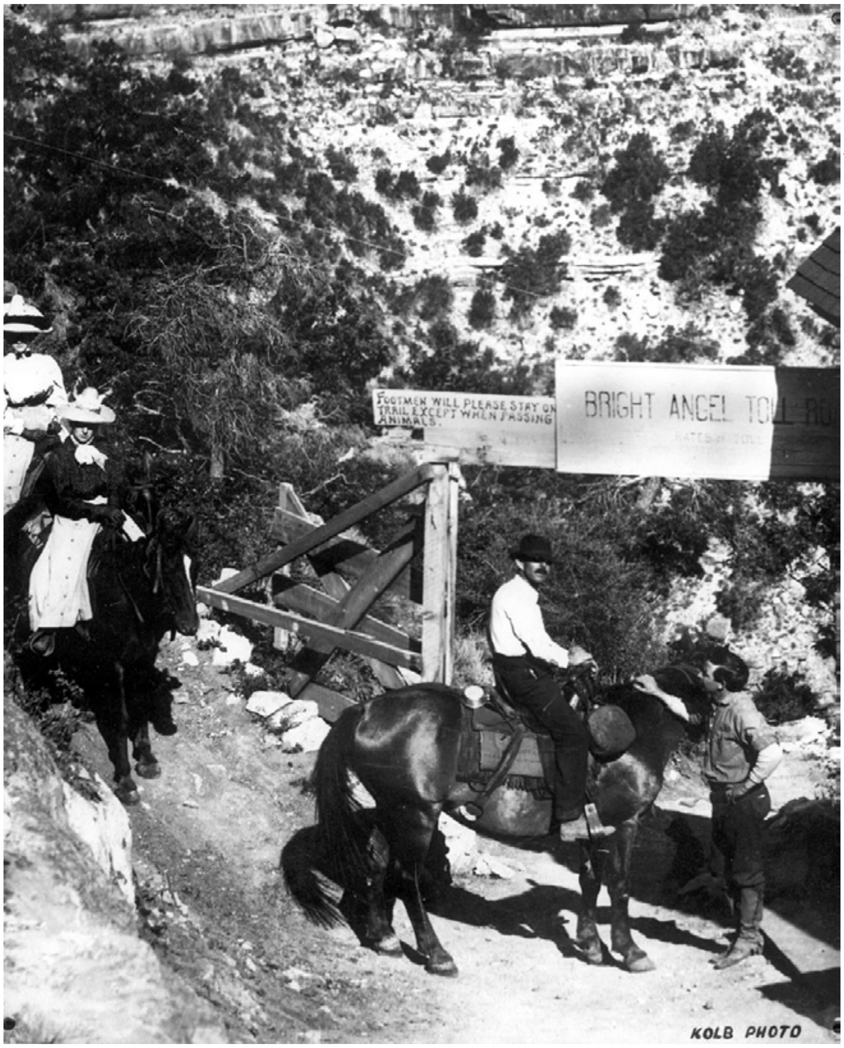
of Bright Angel Creek (Berkowitz and Thybony 2005). By 1907, outfitting services were offered from Kanab, Utah, to Rust's Camp, and Rust had erected a cable tramway over the Colorado River (fig. 5), linking trails on both sides of Bright Angel Fault (Anderson 2000). At this time, the majority of visitors to Grand Canyon's backcountry were visiting these remote locales via guided mule trips.

Developing the corridor trail system

South Kaibab Trail and Phantom Ranch

Coconino County took control of the Bright Angel Trail in 1912 when Cameron's legal right to operate the trail as a toll road expired (USDI 2006). The National Park Service (NPS) assumed management of lands adjacent to the Bright Angel Trail as a national park in 1919. The Park Service made improvements to the area around this time, including the construction of a swinging wooden suspension bridge that would mitigate safety concerns with Rust's old cable tramway (USDI 2012). However, sustained legal struggles between the county and the National Park Service over control of the Bright Angel Trail soon led to the construction of the South Kaibab Trail.

In 1924, two crews began constructing this trail between the west side of Yaki Point and the Colorado River. Completed in 1925, the South Kaibab Trail provided visitors with spectacular views and toll-free access to Phantom Ranch (fig. 6), a resort at the bottom of the canyon operated by the Fred Harvey company, a park concessioner, and the Santa Fe Railroad (Anderson 2000).



KOLB BROTHERS PHOTO, GRAND CANYON NATIONAL PARK MUSEUM COLLECTION

Figure 4. Riders pay a toll at Cameron's Bright Angel Trailhead, around 1910.

KOLB BROTHERS PHOTO, GRAND CANYON NATIONAL PARK MUSEUM COLLECTION

Figure 5. Visitors enjoy the convenience of David Rust's aerial tramway crossing the Colorado River, around 1908.

NPS/GRAND CANYON NATIONAL PARK MUSEUM COLLECTION

Figure 6. Three visitors sit outside the original lodge at Phantom Ranch, around 1925.

Situated near the site of Rust's Camp, and designed to resemble a rustic ranch in the desert, Phantom Ranch, designed by Santa Fe Railroad architect Mary Elizabeth Jane Colter, quickly became a popular hideaway for stylish celebrities of the era (Thybony 2001). The resort expanded, and by 1930, it consisted of many cabins, tents, a recreation hall, a bathhouse, and a canteen. The rapidly increasing visitation led to construction of the park's first corridor sewage system in 1936 (USDI 2012).

The North Rim

Improving recreational access to Phantom Ranch from the North Rim was a priority for the National Park Service from 1926 to 1928. During this time, the Park Service constructed the North Kaibab Trail. This new trail followed Rust's trail at its lower elevations but deviated from it nearer the top, passing through Roaring Springs Canyon and directly linking to the North Rim Entrance Road, currently known as Highway 67. In the lower trail segment, 94 crossings of Bright Angel Creek were reduced to a mere seven with the construction of steel and concrete bridges spanning the creek (Anderson 2000). Upon completion of this work, the North Kaibab Trail was connected to the South Kaibab Trail with a new, rigid, steel suspension bridge called the Black Bridge (fig. 7, next page).

Bright Angel Trail

Black Bridge was nearing completion in 1928 when Coconino County ceded the Bright Angel Trail to the National Park Service. Park administrators, confronted with the prospect of maintaining two rim-to-river trails on the south side of the canyon, considered abandoning the Bright

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Figure 7. Early corridor trail users benefited from the 1921 swinging bridge (lower of the two) and the 1928 Kaibab suspension bridge over the Colorado River in 1928. The Kaibab suspension bridge, also known as "Black Bridge," is still used today by hikers and for all mule crossings.

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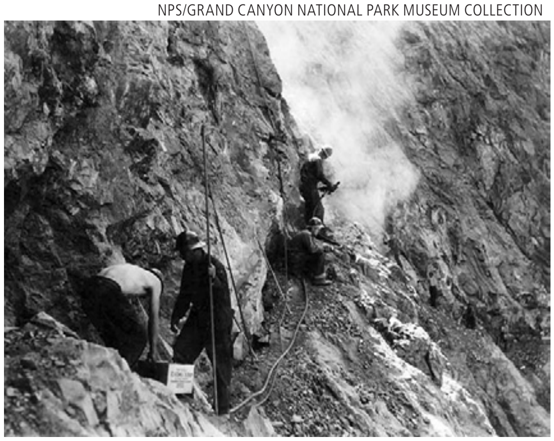

Figure 8. Workers with Civilian Conservation Corps Company 818 construct the River Trail, around 1935.

Angel Trail altogether, but ultimately recognized its value as an additional path to the river. The trail also provided access to perennial Garden Creek, the source of water for the first pipeline to the South Rim (Anderson 2000). Over the next decade, the National Park Service reconstructed and realigned the entire length of the Bright Angel Trail and created a new trail linking it to the South Kaibab Trail. This 1.5-mile (2.4 km) link, now known as the Colorado River Trail, was built by Civilian Conservation Corps Company 818—with the assistance of approximately 40,000 pounds (18,144 kg) of explosive powder (fig. 8) (Purvis 2002). At the close of the 1930s, the corridor trail system was complete. The system's infrastructure would see few major changes in the decades to come, but its dusty tread would soon capture more than just mule tracks.

Crowds in the corridor

Hiking and backpacking

Mule rides remained the primary form of recreation below the canyon's rims until the end of World War II, when "young men, conditioned to long walks with heavy packs," began embarking upon day hikes and overnight stays in the canyon (Anderson 2000). By 1946, registers at the South Kaibab and Bright Angel trailheads indicated that the number of hikers equaled or surpassed the nearly 10,000 annual mule riders descending into the canyon. As a result, the corridor soon became so congested that in 1947, mule parties departing Phantom Ranch were sent up the South Kaibab Trail in order to avoid the throngs of hikers on the more popular Bright Angel Trail (Anderson 2000).

Increased recreational use in the corridor reflected an overall boom in visitation that was occurring on the rim (fig. 9). With visitation to the park rising from 665,000 in 1950 to 1,168,000 in 1960, the pipeline from Indian Garden to the South Rim struggled to meet the demand for water (Anderson 2000). By the early 1960s, a critical water shortage developed, and construction began on a transcanyon pipeline that would supply water to the South Rim developed area from Roaring Springs, located nearly 5 miles (8 km) down the North Kaibab Trail. As it neared completion in 1966, a major flood destroyed the transcanyon pipeline. Reconstruction began the following year and by 1970, Roaring Springs water was being pumped to storage tanks on both rims (Hughes 1978). The transcanyon pipeline was the most significant addition to corridor infrastructure since the 1930s. It provided treated water to recreational visitors at various locations along the North Kaibab and Bright Angel Trails, and also resulted in the construction of another suspension bridge about one-half mile (0.8 km) downstream from Black Bridge. The new Silver Bridge, built to suspend the pipeline over the Colorado River, would also benefit an increasing demographic of hikers and backpackers. Mule traffic remained on Black Bridge, however, because

At the close of the 1930s, the corridor trail system was complete. The system's infrastructure would see few major changes in the decades to come, but its dusty tread would soon capture more than just mule tracks.

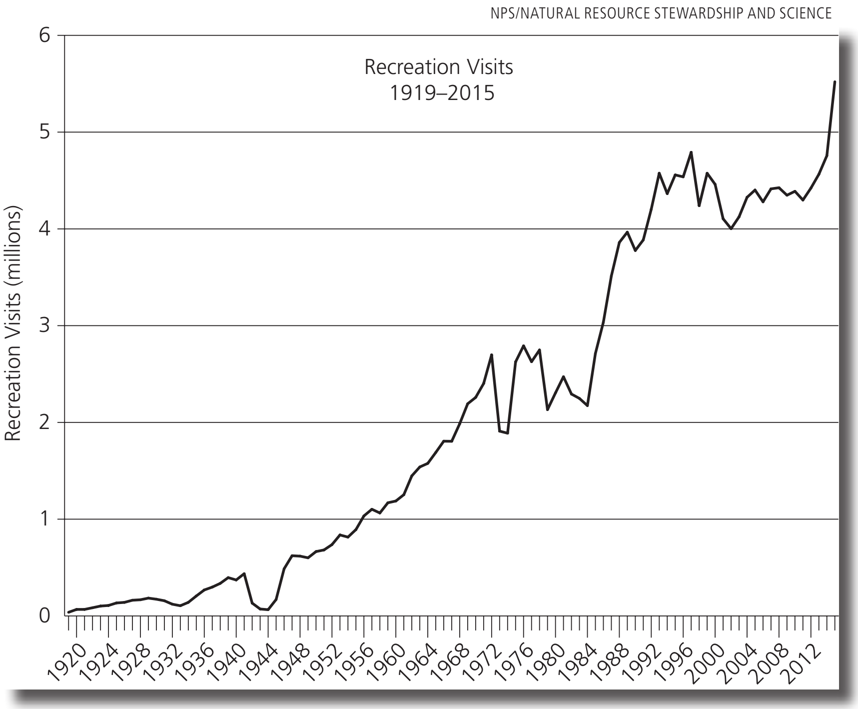

Figure 9. Annual recreation visitation at Grand Canyon National Park, 1919–2015 (NPS 2016). (The data are available in a linked file online.)

it was a more stable walking surface for pack animals.

By the 1970s, backpacking had exploded at Grand Canyon and established trails and campgrounds were overcrowded. According to Hughes (1978), "On some summer nights at Phantom Ranch, 800 to 1,000 campers occupied a campground that could comfortably accommodate 75 at most." The increase in recreational use was so dramatic that in 1974 a backcountry office, a reservation system, and the park's first backcountry management plan were created (Anderson 2000).

The rise of adventure and endurance sports

Backpacking remains popular in the corridor (fig. 10, next page), but in recent years, the number of people participating in activities such as canyoneering, trail running, and endurance hiking at Grand Canyon has increased from a mere handful of individuals into distinct user groups. For canyoneers, slot canyons and waterfalls located near the corridor provide opportunities to hike, climb, rappel, and swim (Martin 2011). Canyoneers use the corridor to access nearby routes such as Pipe Creek, Garden Creek, Phantom Creek, and Ribbon Falls. For endurance athletes, the corridor is a venue to execute laps, test one's stamina, and race against a stopwatch. Groups surpassing 300 people strain the water spigots, toilets, emergency telephones, and backcountry rangers along the route.

As occurred during the previous periods of recreational growth, corridor infrastructure is again struggling to meet the demands of emerging recreational uses with mass appeal. The transcanyon pipeline has exceeded its 30- to 40-year life expectancy and is prone to multiple breaks annually (Lowe 2013). Jerome Chavez, Grand Canyon National Park's Phantom Ranch sewage treatment plant operator, stated in an e-mail message dated 4 February 2014, "The treatment plant exceeds its daily capacity by 10:00 am on Saturdays during spring and autumn." Although rim-to-rim running and canyoneering both have their roots in the 1960s, it is in the 2010s that the National Park Service is grappling with how to best accommodate the number of people participating in these activities (Strout 2013).

NPS/MICHAEL QUINN

Figure 10. A backpacking party passes the Cottonwood Campground restrooms on the North Kaibab Trail. Cottonwood is a small campground located 6.8 miles (11 km) below the North Rim.

Conclusion

Park managers are in the final stages of a multiyear process to revise the park's 1988 backcountry management plan. Through this process, park managers are striving to understand how all of the corridor's recreational activities influence and affect the experience of different user groups, as well as the natural and cultural resources protected there (Strout 2013). Special-use permits have been tested for endurance sports over the past couple of years, adaptive management techniques are being adopted to handle emerging uses such as canyoneering, and modifications to staffing levels are being implemented to mitigate the strain of current recreational trends on emergency services personnel. The following three articles examine how the increased popularity of endurance sports has impacted visitor experience, how a canyoneering monitoring program has documented impacts to technical routes within the corridor, and how the implementation of a preventive search-and-rescue program has increased visitor safety.

Although rim-to-rim running and canyoneering both have their roots in the 1960s, it is in the 2010s that the National Park Service is grappling with how to best accommodate the number of people participating in these activities.

References

Anderson, M. F. 2000. Polishing the jewel: An administrative history of Grand Canyon National Park. Grand Canyon Association, Grand Canyon, Arizona, USA.

Berkowitz, A., and S. Thybony. 2004. Grand Canyon Bright Angel Trail guide. Grand Canyon Association, Grand Canyon, Arizona, USA.

———. 2005. Grand Canyon North Kaibab Trail guide. Grand Canyon Association, Grand Canyon, Arizona, USA.

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

Lowe, J. 2013. Pipeline vital to Grand Canyon near a "catastrophic failure." KPHO-TV CBS 5, Phoenix, Arizona, USA. Accessed 17 July 2016 from http://www.cbs5az.com/story/24235864/pipeline-vital-to-grand-canyon-near-a-catastrophic-failure.

Martin, T. 2011. Grand canyoneering: Exploring the rugged gorges and secret slots of the Grand Canyon. Todd's Desert Hiking Guide, Phoenix, Arizona, USA.

Milner, J. 2005. Indian Garden, Grand Canyon National Park. Cultural Landscape Report. John Milner Associates, Charlottesville, Virginia, USA. Available at https://www.nps.gov/parkhistory/online_books/grca/indiangarden_clr.pdf.

NPS (National Park Service). 2016. Grand Canyon National Park annual park recreation visitation (1904 to last calendar year). National Park Service Visitor Use Statistics website, Natural Resource Stewardship and Science, Fort Collins, Colorado, USA. Accessed 24 March 2016 from https://irma.nps.gov/Stats/Reports/Park/GRCA.

Purvis, L. L. 2002. Civilian Conservation Corps Company 818: Building the Colorado River Trail. Pages 81–85 *in* M. F. Anderson, editor. A gathering of Grand Canyon historians: Ideas, arguments, and first-person accounts. Grand Canyon Association, Grand Canyon, Arizona, USA.

Strout, E. 2013. National treasures: More runners are hitting the trails at national parks, for better or worse. Running Times 410:32–33.

Swanson, F. H. 2007. Dave Rust: A life in the canyons. University of Utah Press, Salt Lake City, Utah, USA.

Thybony, S. 2001. Phantom Ranch, Grand Canyon National Park. Grand Canyon Association, Grand Canyon, Arizona, USA.

USDI (US Department of the Interior). 2006. National Register of Historic Places registration form, Bright Angel Trail. Manuscript on file, Grand Canyon National Park Trail Archives, Grand Canyon, Arizona, USA.

———. 2012. National Park Service Cultural Landscape Inventory: Cross Canyon Corridor Historic District. National Park Service, Grand Canyon National Park, Arizona, USA.

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Understanding extended day use of corridor trails

By Peter Pettengill

Abstract
Studies conducted over nearly 40 years illustrate that solitude is important to visitors in the backcountry of Grand Canyon National Park. However, with the increasing popularity of endurance day hiking and trail running, opportunities for visitors to experience solitude along the park's classic rim-to-rim trails are becoming scarcer. This study used a questionnaire to assess visitor perceptions of what travel conditions along the trails *should be* and compared them with what conditions *actually are* as estimated by automated traffic counters, systematic staff observations, and hikers' perceptions of the number of encounters with others. Results from the normative and objective approaches demonstrate how often visitors may be experiencing unacceptable conditions. The survey also measured visitor perceptions of various management interventions that could be considered to increase opportunities for solitude.

Key words
day hiking, Grand Canyon National Park, trail running, visitor experience, visitor use management, visitor use planning

THE GROWING USE OF BACKCOUNTRY trails at Grand Canyon National Park, Arizona, is a concern among trail users and managers alike (fig. 1). Observations by NPS staff and public comments on the park's 2011 scoping process for the park's backcountry management plan revision reveal this trend. Increasing use of corridor trails has led to user conflict, increased litter, abandoned gear, improper disposal of human waste, crowding at restrooms and attraction sites, an overburdened wastewater treatment plant, vehicle congestion and crowding at trailheads, and general concerns over trail courtesy among visitors. Furthermore, park rangers have reported increases in unprepared and injured rim-to-rim hikers and runners resulting in additional search-and-rescue responses. Increases in use levels and commensurate impacts are exacerbated by publicity through social and other popular media outlets. Hiking and running rim to rim, particularly, has been reported on by a number of popular magazines and numerous Facebook sites, which promote the traverse as a day trip.

Grand Canyon's 1988 Backcountry Management Plan provides guiding policy for corridor and other trails in the park's more remote reaches (NPS 1988; see also the map on page 77). For example, overnight use limits for backpacking were established by the plan. Furthermore, it clearly notes that the number of daytime contacts a backcountry user has with other people is an important indicator of quality for visitor experience. While limits for overnight parties were implemented by the 1988 plan, day-use levels were not explicitly addressed. Still, use levels in the corridor have remained an issue in recent decades. Grand Canyon's 1995 General Management Plan noted overcrowding on corridor trails as a planning issue (NPS 1995) and the park's 2010 Foundation Statement referred to the 1988 Backcountry Management Plan as outdated and in need of review (NPS 2010).

Given that decades of research reveal that solitude is an important motivation among visitors to Grand Canyon's backcountry (Towler 1977; Underhill et al. 1986; Stewart 1997; Backlund et al. 2006), and that the park's 1988 backcountry management plan emphasizes limited daytime contacts among backcountry users as integral to the visitor experience, in 2013 park planners chose to reassess use levels and related visitor perceptions along corridor trails.

The study

This study was designed by park staff to address three questions. First, it would estimate what use levels along corridor trails *actually are*. Second,

NPS/PETER PETTENGILL

Figure 1. Use of the three main trails of the Grand Canyon corridor is on the rise with an increase in endurance day hiking and trail running and consequences for the visitor experience.

it would consider visitor perceptions of what use levels along corridor trails *should be*. Third, it would focus on a further understanding of issues along corridor trails and visitor perceptions of management interventions that could be used to address them.

We concentrated on inner canyon trail segments of the Bright Angel and South and North Kaibab Trails. Specifically, we studied the Bright Angel Trail from Indian Garden to Silver Bridge; the South Kaibab Trail from Tipoff to Black Bridge; and the North Kaibab Trail from Manzanita Rest Area to Clear Creek Junction (see map on page 77). Each of these trail segments begins approximately 5 miles (8 km) into the canyon and ends outside of Phantom Ranch. We chose inner canyon trail segments based on a reasonable expectation for relative solitude given distance from trailheads, and excluded the Phantom Ranch area based on its design as a place for people to gather, relax, and spend time.

Grand Canyon NP Visitor Use Monitoring Form
Return completed cards to Peter Pettengill—SRM

Date:	Start Time (military):	End Time (military):

Trail Segment Hiked: Check only one			Direction Hiked Check only one	
☐ SKT	☐ BAT	☐ NKT	☐ IN	☐ OUT

# of People Encountered:	Personnel (your name):

SKT = South Kaibab Trail from Black Bridge to Tipoff
BAT = Bright Angel Trail from Silver Bridge to Indian Garden
NKT = North Kaibab Trail from Clear Creek junction to Roaring Springs residence

Figure 2. The study involved a questionnaire to be completed by a member of a trail user group and a monitoring form, shown here, to be filled out by park staff and volunteers.

Methods

We applied two separate methods to estimate use levels along corridor trails. The first employed automated visitor counters to approximate trail use volumes. Counters were established approximately 5 miles (8 km) into the canyon along each trail to coincide with the study area. Each counter consisted of an infrared sensor linked to a small memory unit that stored count data. The unit registered a count each time the sensor detected an infrared signature of a warm moving object. Count data were collected from 9 May to 5 July 2013.

The second approach involved park staff and volunteers collecting descriptive data regarding use levels along inner canyon trail segments. Staff and volunteers systematically counted the number of people they encountered while walking along inner canyon trail segments. They used hand counters and monitoring forms to record their observations. This form included such attributes as the date, start and end times of their hike, and the trail segment and direction hiked (fig. 2). Given limited resources for the study, we employed an opportunistic sampling plan in which staff and volunteers participated as their duties and free time allowed. While some bias may be acknowledged here, it was important to park researchers that sampling not be encouraged during the heat of the day. Exposure to extreme heat is a safety issue, and we thought that trail users would have also been less active during these time periods anyway. Monitoring forms were made available beginning 15 April and collected on 1 June 2013. An additional 16 forms were collected on this trail segment in spring 2014, and 14 more in fall of the same year. (The final study report at https://www.nps.gov/grca/learn/management/upload/Grand-Canyons-Corridor-Trails-Report-July2016.pdf details all data collection along all trail segments.)

We also designed an evaluative visitor survey to measure perceptions of what use levels along these trails should be and what management interventions should be used to address them. Approval to administer the survey was received in advance from the Office of Management and Budget. We administered the normative survey to a representative sample of hikers at Manzanita Rest Area along the North Kaibab Trail, at Indian Garden along the Bright Angel Trail, and at Phantom Ranch along the South Kaibab Trail (see map, page 77). Surveys were administered on weekdays and weekends between 27 April and 27 May 2013. We chose sampling locations strategically in order to facilitate sampling visitors shortly after they had traveled a segment of inner canyon trails.

At the start of each sampling day, surveyors stationed at each sampling location approached the first visitor group to arrive and asked a member of their group if he or she would be willing to participate in the survey. Visitors who agreed were given the survey instrument and provided verbal instructions about how to complete the questionnaire. Those who were unwilling or unable to participate were thanked for their consideration. After finishing a contact with a visitor group, the surveyor completed an entry on a survey response log and then asked the next visitor group to participate. This process continued throughout each sampling day. Of 573 people asked to participate in the study, 477 agreed. The overall response rate for the survey was 83%. We note that a full report of this research includes more comprehensive information on methods and results (Pettengill 2015) and that these sections have been condensed here for the purpose of this article.

Results

Total daily use was variable over the course of the study period, as estimated from data recorded by the automated counters (fig. 3). Use peaked on 18 May, the first Saturday after the North Rim opened for the season, and was highest during weekends in the month of May. Overall, use began to taper off after Memorial Day weekend and during the warmer months of June and July. Though the counter does not discern among user types or specify the exact number of people on inner canyon trails each day, it does provide general estimates of total use along corridor trails and valuable information regarding overall use patterns and trends. The automated counter data are corroborated by visitor encounter surveys that also revealed more visitors on weekend days (Friday through Sunday) than on weekdays (Monday through Thursday; table 1). All counts are for all trail users, including day hikers, trail runners, backpackers, Phantom Ranch guests, mule trips, river exchanges, and administrative staff.

Figure 3. Visitor use counts from automated counters along the inner corridor trail system at Grand Canyon National Park, 9 May to 5 July 2013. (Data are available in a linked table online.)

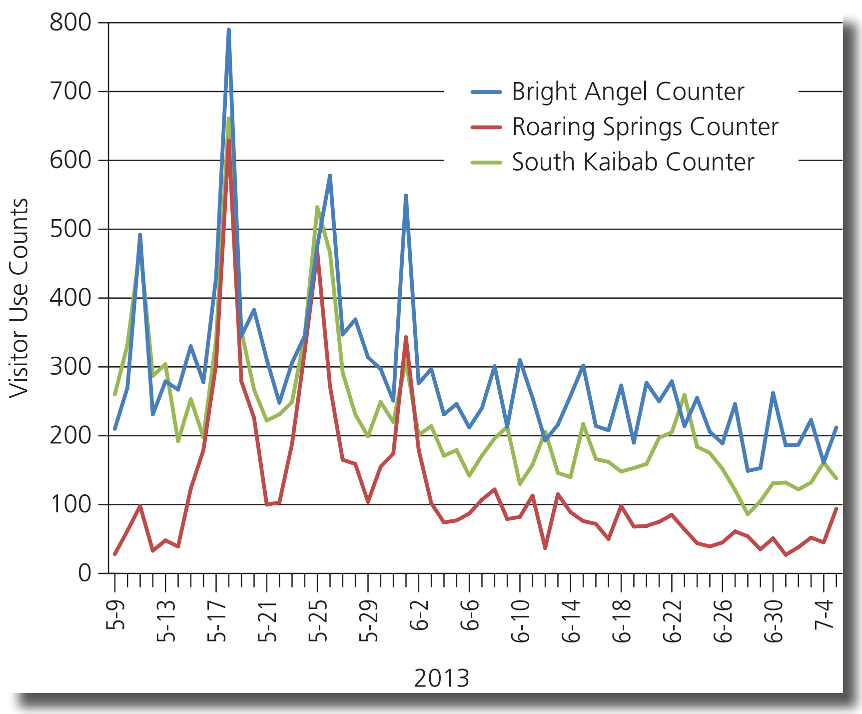

Table 1. Encounters among users of the South Kaibab Trail between Tipoff and Black Bridge, 15 April to 1 June 2013 (*n* = 44)

		Average		Observations	
Minimum	Maximum	Monday to Thursday	Friday to Sunday	>45	<15
0	143	12	38	7	24

Table 2. Degree of problems along inner canyon trail segments as evaluated by survey respondents (*n* = 448)

Type of Problem	Not a Problem	Small Problem	Big Problem	Don't Know
Too many other visitors	55%	35%	3%	6%
Rude and inconsiderate visitors	65%	18%	12%	5%
Unacceptable impacts to park resource	57%	23%	13%	7%

Results from the survey highlight visitor assessments of potential problems along corridor trails, including encounters among visitors, attitudes toward access, and perceptions of a range of possible management interventions aimed at preserving high-quality visitor experiences. For example, respondents were asked whether or not there were "too many other visitors" on inner canyon trail segments, if other visitors were "rude and inconsiderate," and if there were "unacceptable impacts to park resources." They were also asked to rate how much of a problem each of these was on a scale ranging from "not a problem" to a "big problem." Results are summarized in table 2 and reveal that more than half of respondents did not think that any of these issues was a problem. However, 38% of visitors, the most for any issue, identified that "Too many other visitors" is either a small or big problem.

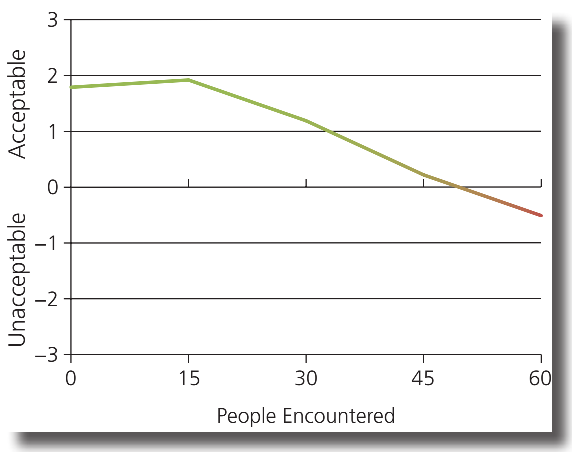

Figure 4. Acceptability of trail user encounter rates along South Kaibab Trail between Tipoff and Black Bridge as measured by surveys administered at end of South Kaibab Trail segment from 27 April to 27 May 2013. The point at which the curve crosses the zero line denotes the point at which conditions become unacceptable and indicates the trade-off between use levels and acceptability.

In order to evaluate the number of trail encounters among visitors and how this relates to perceptions of crowding we relied on two components of the questionnaire. First we asked respondents to rate how acceptable a range of descriptive simulated crowding scenarios would be if these conditions were experienced while hiking inner canyon trails. Each scenario described different numbers of visitors encountered, and respondents rated the acceptability of each on a scale ranging from 3 (very acceptable) to −3 (very unacceptable). We calculated average acceptability ratings for each scenario and plotted them on a social norm curve. As illustrated in figure 4, conditions along the South Kaibab Trail become unacceptable as hikers encounter approximately 45 or more other visitors between Tipoff and Black Bridge. Moreover, visitors prefer to experience around 15 such encounters.

The second evaluative component related to crowding involved asking respondents to "estimate the number of other visitors you saw" between Tipoff and Phantom Ranch. Approximately 25% of respondents reported observing fewer than 15 other visitors while around 28% reported seeing 46 or more; 12% reported not being able to remember (table 3).

We asked a battery of questions regarding visitor attitudes toward backcountry management priorities, particularly backcountry access. On a scale ranging from "strongly agree" to "strongly disagree," respondents recorded their feelings related to the following statements: "If people feel crowded, access should be reduced," "If visitor-caused resource impacts are high, access should be reduced," "If solitude is lost, access should be reduced," and "Access should never be reduced, even if use is high." Results are synthesized in table 4. Responses related to crowding and solitude lacked agreement. Whereas visitor-caused impacts had the highest level of agreement (73% agreed or strongly agreed), 61% of respondents disagreed or strongly disagreed with the statement that "access should never be reduced, even if use is high."

Another series of questions measured the level of visitor support for various backcountry management options. Respondents indicated on a scale ranging from "strongly support" to "strongly oppose" the extent to which they support "more education regarding trail etiquette/appropriate behavior," limiting "group sizes for day use to 11 people or less," and requiring "permits . . . for day use (limits and no fees)." Results from these questions are synthesized in table 5. The group size limit intervention lacked general support or opposition. Education intervention had the highest level of

Table 3. Number of visitors seen by survey respondents between Tipoff and Phantom Ranch along the South Kaibab Trail (*n* = 135)

Number of Visitors Reported Seen by Percentage						
0–15	16–30	31–45	46–60	61–100	>100	Can't remember
26%	27%	7%	12%	12%	4%	12%

Note: Not all survey respondents traveled along the South Kaibab Trail during their trip.

Table 4. Survey respondents' level of agreement with access-related statements

Statements	*n*	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Don't Know
If people feel crowded, access should be reduced	448	9%	28%	27%	24%	10%	2%
If visitor-caused resource impacts are high, access should be reduced	441	25%	48%	15%	6%	4%	1%
If solitude is lost, access should be reduced	437	7%	25%	31%	25%	11%	1%
Access should never be reduced, even if use is high	438	6%	11%	20%	39%	22%	1%

Table 5. Extent of support of survey respondents for a range of possible management interventions

Management Intervention	*n*	Strongly Support	Support	Neither	Oppose	Strongly Oppose	Don't Know
More education regarding trail etiquette/appropriate behavior	451	34%	42%	19%	3%	1%	1%
Limit group sizes for day use to 11 people or less	447	10%	26%	23%	21%	16%	4%
Permits required for day use (limits and no fees)	444	4%	19%	19%	31%	24%	3%

NPS/VICTORIA ALLEN AND MICHAEL QUINN

Figure 5. Example of an educational message distributed seasonally through social media and on the park's trail courtesy practices website (https://www.nps.gov/grca/planyourvisit/courtesy.htm).

We chose inner canyon trail segments based on a reasonable expectation for relative solitude given distance from trailheads.

support at 76% ("support" or "strongly support"), while permit intervention had the most opposition with 55% "opposed" or "strongly opposed."

Discussion

This study developed an increased understanding of issues related to backcountry trail management at Grand Canyon. For example, each component of the study contributed to a greater understanding of the scope of problems related to use levels and crowding. Results from the evaluative survey reveal increasing trail use levels may become unacceptable to visitors. In the case of the South Kaibab Trail, encounters of more than approximately 45 visitors per individual between Tipoff and Black Bridge help define this threshold. Results from descriptive encounter rate data reveal that visitors can, and do, experience unacceptable conditions while traveling along backcountry trails and that the extent of this issue can be considerable. The maximum number of encounters observed was 143 over the course of approximately one hour; however, the frequency with which thresholds are exceeded is relatively limited. For example, 45 or more visitors were encountered along the South Kaibab Trail only 16% of the time. Furthermore, preferred conditions (15 or fewer encounters) were observed approximately 57% of the time. Unacceptable conditions tended to occur more on weekends than weekdays during the study period, and this likelihood is corroborated by results from automated counters.

In addition to expanding understanding of visitor use, this study shed light on visitor perceptions of potential management interventions. For example, it is clear that visitors more strongly support indirect management interventions than direct actions. The strong level of support for more education regarding trail etiquette and appropriate behavior led park staff to develop an electronic media and sign campaign called "Trail Courtesy Practices That Leave No Trace" in 2014.[1] These practices were described in partnership with the Leave No Trace Center for Outdoor Ethics, and have been incorporated into outreach that includes both traditional and electronic media. Signs describing trail courtesy practices, for example, have been posted at trailheads and on park shuttle buses. A park website was developed to disseminate the information, and social media, including Grand Canyon's Facebook page and Twitter feed, have allowed park staff to emphasize educational messages electronically during the busiest times of year (fig. 5). Direct management interventions, including group size limits, day-use permits, and limiting access, clearly received less support from visitors. However, these tactics would likely be the most effective in maintaining acceptable social conditions along park trails. Further consideration of direct management actions may necessitate greater public input through the formalized National Environmental Policy Act (NEPA) process.

[1] See the website at https://www.nps.gov/grca/planyourvisit/courtesy.htm.

Conclusion

Visitor use studies provide park managers with an opportunity to further understand issues related to park resources and visitor experience. The benefits from this study involve being able to compare actual conditions, visitor perceptions of those conditions, and visitor perceptions of management options for selected segments of the popular corridor trail system at Grand Canyon National Park. However, the real strength of visitor use studies remains in continued research and monitoring. For instance, will the extent and frequency of high-use periods increase over time? Will park visitors experience unacceptable conditions along backcountry trails more often in the future? Will public support for limiting access change? The answers to these questions will help park managers protect park resources and provide for enjoyable visitor experiences, but they will not be possible without an ongoing program of visitor use research.

Each of the articles in this "In Focus" section demonstrates how research may help inform broader discussions of management reform and lead to greater awareness and education through public outreach. Furthermore, the frameworks and methods described suggest a means for monitoring impacts on park resources and visitor experience in the future. As noted in the introduction to this set of articles, recreational use of the corridor has changed over time and park officials are now reviewing comments on a draft environmental impact statement to help adapt to this change. Ultimately, sound management judgment by park officials will be needed to directly prescribe policy. A final decision regarding the draft environmental impact statement is expected in the next year.

References

Backlund, E., W. Stewart, and Z. Schwartz. 2006. Backcountry day hikers at Grand Canyon National Park. Technical Report. On file at Grand Canyon National Park. University of Illinois, Champaign, Illinois, USA. Available at https://www.nps.gov/grca/learn/management/upload/Backcountry_Day_Hikers_Final_Report.pdf.

National Park Service (NPS). 1988. Backcountry Management Plan. National Park Service, Grand Canyon National Park, Arizona, USA. Available at https://www.nps.gov/grca/learn/management/upload/1988_BCMP.pdf.

———. 1995. General Management Plan. National Park Service, Grand Canyon National Park, Arizona, USA. Available at https://www.nps.gov/grca/learn/management/upload/GRCA_General_Management_Plan.pdf.

———. 2010. Foundation Statement. National Park Service, Grand Canyon National Park, Arizona, USA. Available at https://www.nps.gov/grca/learn/management/upload/grca-foundation20100414.pdf.

Pettengill, P. 2015. Grand Canyon's corridor trails: A study of visitor use and experience. Report. National Park Service, Grand Canyon National Park, Arizona, USA. Available at https://www.nps.gov/grca/learn/management/upload/Grand-Canyons-Corridor-Trails-Report-July2016.pdf.

Stewart, W. 1997. Grand Canyon overnight backcountry visitor study: Use of diary-like techniques. Report submitted to Grand Canyon National Park through cooperative agreement INT-92733-RJVA. Grand Canyon National Park, Grand Canyon, Arizona, USA.

Towler, W. L. 1977. Hiker perception of wilderness: A study of social carrying capacity of Grand Canyon. Thesis. University of Arizona, Tucson, Arizona, USA.

Underhill, H., W. Stewart, R. Manning, and E. Carpenter. 1986. A sociological study of backcountry users at Grand Canyon National Park. Technical Report 17. National Park Service, Cooperative Parks Studies Unit, University of Arizona, Tucson, Arizona, USA.

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PS

NPS/MATT JENKINS

Figure 1. Phantom Creek, a popular canyoneering route, is located approximately 1 mile (1.6 km) north of Phantom Ranch off the North Kaibab Trail and is in the corridor use zone.

Canyoneering at Grand Canyon National Park: Monitoring pockets of wilderness in the canyon corridor

By Matt Jenkins

Abstract
With the growth in popularity of outdoor adventure sports and the publication of a comprehensive Grand Canyon canyoneering guidebook, technical canyoneering at Grand Canyon National Park, Arizona, has surged in popularity. Because of this rapid expansion in use and the outdated management framework in place at the park, park managers are adopting new tools to protect park resources and visitor experiences. In this article, I describe a case study of fixed anchor placement in Garden Creek, which exemplifies one of the challenges of managing park resources and visitor experiences within the corridor of Grand Canyon National Park.

Key words
adventure sports, canyoneering, corridor, fixed anchor, Grand Canyon National Park, wilderness

VISITORS TO GRAND CANYON NATIONal Park (Grand Canyon) associate the area with breathtaking vistas and the 277-mile (446 km) stretch of the Colorado River that flows within the boundaries of the park. However, tucked deep below the canyon's north and south rims is an extensive network of rugged gorges and slot canyons replete with vast natural beauty and cultural resources and the potential for a lifetime of adventure for intrepid explorers. In particular, four spectacular side canyons, Garden Creek, Pipe Creek, Phantom Creek, and Ribbon Falls, are mostly "hidden" in plain view of three of the most popular hiking trails in the National Park System (see map on page 77). These pockets of scenic wilderness require technical canyoneering skills to reach, and have remained relatively untouched until recently (fig. 1). In this article I outline the growth of canyoneering at Grand Canyon and current management frameworks used to study the related impacts. I also present a case study that characterizes challenges related to visitor experience and resource protection.

The rise of canyoneering at Grand Canyon

Outdoor activities with elements of risk and challenge have been growing in popularity nationwide, and they are anticipated to continue to expand (Access Fund 2008; Cordell 2012; White et al. 2014). This growth can be attributed to a variety of factors, including newer, safer, and more easily available equipment; an increase in college and university outdoor programs that offer adventure recreation curricula; new instructional texts and videos; the growth of commercial guide and instructional programs; and the widespread availability of information on recreation areas through guidebooks and the Internet (Access Fund 2008). This rise in adventure recreation is mirrored by the increasing popularity of canyoneering at Grand Canyon, which has been documented by park rangers, reported in backcountry use statistics, and evidenced by the increasing number of social media–related trip accounts posted on the Internet by park visitors.

Canyoneering is a multidisciplinary activity that emerged in the 1960s as distinct from mountaineering and rock climbing, although it has similarities to both, particularly with regard to the use of ropes and anchors to facilitate rappelling and provide protection from falls. It developed primarily in southern Utah in areas near Zion Canyon, the Escalante River, and the San Rafael Swell but has now spread to Grand Canyon where participants explore, traverse, and descend the park's remote canyon tributaries (fig. 2).

In 2011 Todd Martin published *Grand Canyoneering: Exploring the rugged gorges and secret slots of the Grand Canyon*, the first guidebook to feature technical canyoneering routes in the park. The influential guide documents 105 canyoneering routes within park boundaries of which 68 require rappelling, 63 necessitate swimming or wading, and 78 usually take more than one day to complete. Many of the routes also require the use of pack rafts—small, lightweight,

COURTESY OF RICH RUDOW

Figure 2. Backcountry ranger and article author Matt Jenkins descends Garden Creek during a winter monitoring patrol.

inflatable boats—to navigate the Colorado River in order to facilitate a return back to one of the canyon rims. In addition to the routes described in *Grand Canyoneering*, I have concluded from analysis of other publications, NPS GIS data, and informal personal communications that approximately 200 more routes could exist in the park.

These routes vary in popularity likely because of length, type, approach, difficulty, crowding, quality, scenic value, distance from urban population centers, area ethics, regulations, and need for specialized gear (Access Fund 2008). Studies of rock climbers, for example, revealed that the two most important factors affecting their choice of a climb are quality and difficulty of the route. Murdock (2010, p. 117) determined that "climbers are seeking a high return, or a high quality climbing experience that also matches difficulty requirements, for their hiking investment in wilderness." In that study of climbers at Joshua Tree National Park, all selected routes ranked at least 2 on a 0–5 quality scale, and the great majority were only moderately difficult (Yosemite Decimal System 5.7–5.9).

ILLUSTRATION ADAPTED FROM LIME AND STANKEY (1971) BY NPS/MATT JENKINS

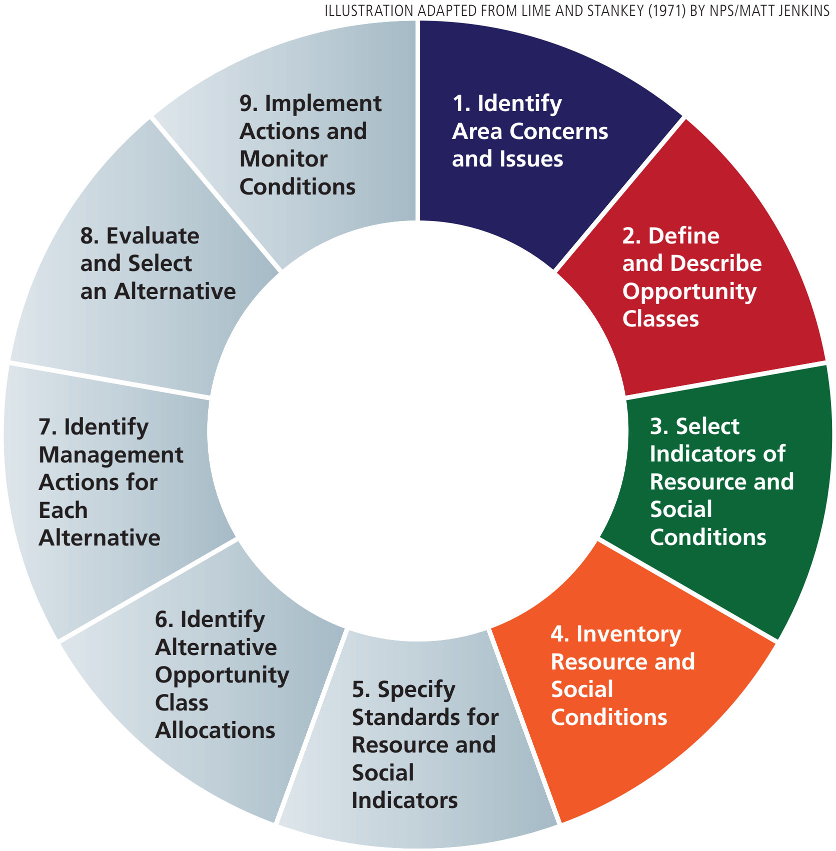

Figure 3. The nine-step Limits of Acceptable Change process (Lime and Stankey 1971) is helping managers at Grand Canyon evaluate resource and social impacts from the recent rise in popularity of canyoneering. The first four steps have been completed at the park.

At Grand Canyon National Park, backcountry patrols have documented increasing canyoneering activity over the past several years. The most popular routes are scenic, accessible, moderately difficult, and can be completed in a day with gear that most canyoneers already own. These routes are within a one-day drive of popular tourist hubs such as Phoenix, Flagstaff, and Las Vegas, and are located in popular backcountry use areas with large campgrounds. Thus canyoneering has become a priority for park management because of the need to balance recreational use opportunities with adequate resource and visitor experience protections.

Management context

More than 1.1 million acres (94% or 0.4 million ha) of Grand Canyon National Park qualify for wilderness designation, and are managed as "proposed wilderness" to protect the character and suitability of these lands for possible inclusion in the National Wilderness Preservation System (USDI 1995; US Wilderness Act 1964). Although none of the side canyons discussed in this article are located in designated or proposed wilderness, they are nonetheless untrammeled and undeveloped, with a primeval character that park policy protects.

This setting contrasts with much of the corridor trail system where bridges, buildings, utilities, and other improvements mark the landscape. Murdock's (2010) conclusions about climbers' route selection and observations by Grand Canyon backcountry rangers suggest that the side canyons associated with the corridor trail system present several canyoneering routes that entice those who have not learned low-impact ethics specific to technical canyoneering. This is important because inexperienced canyoneers may go on to alter the character of other routes located throughout the proposed wilderness of Grand Canyon (Miller et al. 2001).

Grand Canyon National Park's 1988 Backcountry Management Plan outlines three long-range goals that apply generally to canyoneering: (1) maintain and perpetuate natural ecosystem processes, (2) protect and preserve historical and prehistoric cultural resources, and (3) provide and promote a variety of backcountry recreational opportunities that are compatible with resource protection and visitor safety (USDI 1988, p. 4). In 1995 the park's General Management Plan added five objectives to help meet these goals for the management of undeveloped areas. First, visitor use and park resources are to be monitored and managed to protect resources, ecosystem processes, and wilderness experiences, and a primitive experience should be preserved in areas that are not proposed wilderness. Second, indicators are established so that management actions can be initiated as resource conditions fall below a certain threshold. Third, opportunities for primitive types of recreation are provided, consistent with NPS policy. Fourth, administrative activities such as search and rescue are conducted as needed. Fifth, user conflicts are minimized (USDI 1995).

Limits of Acceptable Change (LAC)

LAC is a wilderness planning framework (fig. 3) that is suitable for management of conflicting goals and concerns about change in resources, social conditions, or management. It is fundamentally similar to the Visitor Experience and Resource Protection (VERP) framework, and both work well in situations where recreation conflicts with resource preservation, as is the case with canyoneering (Dawson and Hendee 2009; Lime and Stankey 1971; Hof and Lime 1997).

In 2012, park managers completed the first and third steps in the LAC process (fig. 3), identifying issues and concerns related to canyoneering, and selecting indicators of resource and social conditions. Step 2, which defines an area's "opportunity class," or management zone, is addressed in the backcountry and general management plans. Grand Canyon National Park has four opportunity classes: corridor, threshold, primitive, and wild. The corridor zone is characterized by structures, maintained trails, and the availability of potable water, whereas the wild zone lacks routes and reliable water sources. The threshold and primitive zones are the middle two opportunity classes and vary by the degree to which routes and water sources exist or are difficult to locate (i.e., more difficult in the primitive zone).

These opportunity classes were designed with traditional backcountry uses, such as day hiking, backpacking, and stock use, in mind and they do not translate directly to canyoneering. All of the side canyons are rugged, pristine, and inaccessible even though they may be located in any of the four opportunity class zones. Moreover, at present, regulations and permitting are the same for canyoneering routes regardless of opportunity class.

By going through the process to analyze limits of acceptable change and in consideration of management objectives, the backcountry rangers implemented a canyoneering monitoring program in 2012. This program serves as the foundation of a revised management strategy for addressing the rising popularity of canyoneering. Program staff completed an initial survey of 36 canyoneering routes from March 2012 to January 2013 and identified indicators of resource and social conditions. Since then, we have formally monitored numerous other canyoneering routes as part of LAC step 4. We gathered data on route characteristics such as use levels; social impacts on the route, approach, and exit (table 1); natural resource features such as soil, springs, and wildlife; and cultural resource conditions.

Through continued monitoring managers hope to answer questions of how canyoneering affects wildlife habitat (particularly bighorn sheep), how to minimize the unnecessary placement of fixed anchors, and what the best strategies are for avoiding conflicts between user groups. Although recreational climbing has been managed for many decades at many levels of government throughout the country, few precedents exist for the management of technical canyoneering and its broader implications for wilderness character. The following case study illustrates a primary concern related to canyoneering at Grand Canyon National Park.

Table 1. Social impacts monitored as part of the canyoneering monitoring protocol

Impact	Detail	How Measured/Documented
Rope		**Number** of abandoned ropes, excluding hand lines, on route
Hand line		**Number** of abandoned hand lines on route
Anchor	Unnecessary	**Number** of unnecessary anchors on route
	Removed	**Yes/No** (Monitor removes unnecessary webbing and rope)
	Notes	**Narrative** provided by monitor about abandoned technical gear encountered
Social trails		**A, B, or C,** as follows: A = none, B = 1–5 visible social trails, C = more than 5
Cairns		**A, B, or C,** as follows: A = none, B = 1–5 cairns, C = more than 5
Graffiti		**Yes/No**
Litter	Nonorganic	**Yes/No** (Includes tape, adhesive bandages, plastic bags, and similar items)
	Organic	**Yes/No** (Includes banana peels, apple cores, and similar items)
Human waste		**Yes/No** (Monitor notes improper disposal of human waste in canyon)

Case study: Proliferation of fixed anchors in the corridor

In 2011 Todd Martin, author of *Grand Canyoneering*, described Garden Creek as "a hidden gem located in close proximity to the most popular trail in Grand Canyon National Park." He also indicated surprise that "more people hadn't discovered the canyon." Still a gem, it has since been discovered.

Initially descended in the 1990s, the Garden Creek canyoneering route remained relatively dormant because of high-volume waterfalls, challenging down-climbs, and a lack of publicly available information. In approximately 2010, canyoneers installed a single rappel anchor, a bolt (fig. 4), midway down the largest waterfall. Before the addition of this bolt, at least 700 feet (213 m) of rope was needed to descend Garden Creek because of a 350- to 400-foot (107–122 m) rappel halfway through the canyon. The addition of the bolt divided the rappel into two shorter sections and diminished the amount of rope necessary for the rappel to 400 feet (122 m), a more affordable and common length of rope.

Next, *Grand Canyoneering* was published in 2011. This widely distributed book describes every available rappel anchor on the 105 documented routes, including the aforementioned bolt. In a matter of months, the simple combination of a more convenient rappel point and publicity of the route made Garden Creek one of the most popular and sought-after canyoneering routes in the park.

Rappel anchors are given substantial scrutiny by resource managers compared with other social impacts of wilderness adventure sports. Some of the most popular hiking and climbing routes in the National Park System, such as the famous Cable Route hike on Half Dome and the Nose climb on El Capitan in Yosemite National Park, depend on fixed anchor placements. However, controversy revolves around them because fixed anchors remain in place, often for long periods, and are considered installations or improvements (American Safe Climbing Association 2001). This has ramifications for areas managed as wilderness or for retention of primitive recreational values because fixed anchors can either be permitted as a minimum tool or prohibited as an installation (Murdock 2010). Table 2 (next page) outlines different fixed anchor management policies in various units of the National Park System. At Grand Canyon, the guidelines in Director's Order 41, Section 7.2, are followed with respect to fixed anchors (USDI 2013).

An alternative to a fixed anchor is a small loop of removable nylon webbing slung around a natural feature (fig. 5), and this is the most common form of anchor found in Grand Canyon. Bolts, pitons, and other metal hardware are used less frequently because of the need for special equipment, the expenditure of time, and the physical effort required for their placement (Access Fund 2008). Most uses of removable nylon webbing are considered "clean" anchors, while hardware such as bolts and pitons are considered "fixed." Table 3 (next page) shares the total number of anchors per canyoneering route in Grand Canyon, and table 4 (next page) illustrates the different types of anchors.

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Figure 4. A bolted rappel anchor consisting of two bolts, two hangers, a rappel ring, and a chain are shown with a canyoneering rope and carabiner in Garden Creek in 2013. This Specific fixed anchor configuration was placed at numerous locations in 2013.

Figure 5 (far right). A clean rappel anchor in Garden Creek in 2012.

Table 2. Fixed anchor management strategies at various units of the National Park System

Activity and Wilderness Setting	Park							
	Arches National Park	Black Canyon of the Gunnison National Park	Devils Tower National Monument	Grand Canyon National Park	Joshua Tree National Park	Rocky Mountain National Park	Yosemite National Park	Zion National Park
Climbing	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Canyoneering	Yes	No	No	Yes	Limited	Limited	Limited	Yes
Wilderness status	Proposed	Yes	No	Proposed	Yes	Yes	Yes	Yes
Motorized drilling	Proposed wilderness: no motorized drills. Non-wilderness: Special use permit required	No	No	No	Permit required	No	No	No
Bolting	Permit for new bolts; one-to-one replacement of old bolts	Permit for new bolts; one-to-one replacement of old bolts with hand drill	No new bolts. Permit required for one-to-one replacement of old bolts with a hand drill	Permit for new bolts. Authorization for the replacement or removal of existing fixed anchors. See USDI 2013.	Non-wilderness: No permit for hand drilling. Wilderness: One-to-one replacement of old bolts; permit for new bolts.	Clean anchor ethic whenever possible	Hand drill for all new and old bolts	Hand drill for all new and old bolts

Table 3. Anchors per canyoneering route, Grand Canyon National Park

Number of Anchors	Corresponding Number of Routes
0	31
1	6
2	18
3	5
4	14
5	9
6	5
7	7
8	6
9	1
10	1
11	1
12	0
13	1

Note: Data are from *Grand Canyoneering* (Martin 2011).

Table 4. Clean vs. fixed anchors

Type	Number	Percentage of Total Anchors
Clean		
Pinch point	95	29%
Rock chock	55	17%
Boulder	38	12%
Tree	36	11%
Rock bollard	21	6%
Knot chock	15	5%
Rock horn	13	4%
Natural arch	12	4%
Deadman	0	0%
Shrub	0	0%
Total	285	88%*
Fixed		
Bolt (single)	23	7%
Bolt (multiple, with chain)	15	5%
Piton (single)	2	1%
Other	2	1%
Total	42	14%*

*Totals do not equal 100% because of rounding.

Notes: Data are for 105 canyoneering routes described in *Grand Canyoneering* (Martin 2011). Most uses of removable nylon webbing are considered clean, while hardware such as bolts and pitons is considered fixed.

Fixed anchors can either be permitted as a minimum tool or prohibited as an installation.

In 2012, a second bolt was installed next to the preexisting bolt in Garden Creek (fig. 4). Then, in spring 2013, visitors reported numerous additional bolts and a follow-up monitoring trip documented 12 new bolts installed along the route. Not only had the previously installed clean anchors been replaced by bolts, but also multiple pour-offs that had not had any kind of anchor were now bolted.

My analysis of rappel anchor data throughout the park reveals one significant finding regarding bolts and other fixed hardware placements in Grand Canyon. Once an initial piece of fixed gear has been installed along a route, more fixed gear placements are likely to follow. Several canyons, including Garden Creek, exemplify this trend.

National Park Service policy recognizes canyoneering as a legitimate and appropriate use of backcountry and wilderness (USDI 2013). Fixed anchors such as those found throughout Garden Creek should be used only rarely and they should serve as a "minimum tool" when the terrain or features limit the possibility of clean anchor use. The initial bolt placed in Garden Creek arguably was not necessary since the first party to descend the canyon did not put it there, and certainly the installation of 12 additional bolts was unnecessary and a degradation of park resources.

Conclusion

According to the American Canyoneering Academy (2002, p. 13), "Part of the attraction of canyoneering is the sense of discovery and adventure [canyoneers] feel as [they] descend each canyon for the first time. This sensation is heightened when [the canyons are] in their natural state, showing minimal evidence of previous visitors." Despite Garden Creek being located in one of the busiest backcountry areas in the National Park System, it remained relatively pristine until recently. The type and rate of impacts documented in this canyon raise concerns that are being addressed by park staff in the revision of the park's backcountry management plan. Alternatives being considered are day-use permits, group size limits, revised fixed anchor policies, and the requirement for human waste to be packed out of narrow canyons.

Park resources, visitor experiences, and wilderness values could be jeopardized if the trends continue. Dawson and Hendee (2009, p. 490) believe that "recreational use will continue to grow; and there will be more demand for day use and easy access; more demand for information; more demand for challenge, adventure, and risk-taking activities; and, a greater diversity of users."

Staff at Grand Canyon National Park recognizes that the bureau must balance resource preservation with visitor use and enjoyment. In addition to supporting long-term park planning such as the revision of the backcountry management plan, the canyoneering monitoring program is being used to increase educational and public outreach efforts. First, canyoneering-specific Leave No Trace information is distributed to all visitors who identify themselves as canyoneers during the backcountry permitting process. The data and photography collected by park employees while on monitoring patrols are being used to develop a canyoneering-specific addition to the park website. And the National Park Service has partnered with the Coalition of American Canyoneers, a nonprofit organization, on restoration and cleanup projects such as bolt and trash removal at Grand Canyon.

Garden Creek is an icon of the corridor trail system and may be a looking glass for long-term trends in resource conditions in the remote, wilderness side canyons of Grand Canyon National Park. It demonstrates that resource and social conditions can degrade quickly through the careless acts of one group or the cumulative effects of many well-intentioned groups. Implementation of new management strategies, including the canyoneering monitoring program, revision of the backcountry management plan, and increased education and outreach, will help ensure that the National Park Service's mission of resource preservation and visitor enjoyment will be maintained in Grand Canyon's tributaries, such as those in the corridor.

References

Access Fund. 2008. Climbing management: A guide to climbing issues and the development of a climbing management plan. The Access Fund, Boulder, Colorado, USA. Available at https://www.accessfund.org/uploads/ClimbingManagementGuide_AccessFund.pdf.

American Canyoneering Academy. 2002. Canyoneering. Accessed 12 August 2012 at http://www.canyoneering.net.

American Safe Climbing Association. 2001. Climbing history and the ethics of bolting. Available at http://www.safeclimbing.org/conservation_bolthist.htm.

Cordell, H. K. 2012. Outdoor recreation trends and futures: A technical document supporting the Forest Service 2010 RPA Assessment. General Technical Report SRS-150. Southern Research Station, USDA Forest Service, Asheville, North Carolina, USA. Available at http://www.srs.fs.usda.gov/pubs/40453.

Dawson, C., and J. Hendee. 2009. Wilderness management. Fulcrum Publishing, Golden, Colorado, USA.

Hof, M., and D. W. Lime. 1997. Visitor experience and resource protection framework in the National Park System: Rationale, current status, and future direction. Pages 29–36 *in* S. F. McCool and D. N. Cole, compilers. Workshop proceedings: Limits of acceptable change and related planning progress. General Technical Report INT-GTR-371. Rocky Mountain Research Station, USDA Forest Service, Ogden, Utah, USA. Available at http://www.treesearch.fs.fed.us/pubs/23907.

Lime, D., and G. Stankey. 1971. Carrying capacity: Maintaining outdoor recreation quality. Pages 174–184 *in* E. vH. Lason, editor. The Forest Recreation Symposium, State University of New York College of Forestry. USDA Forest Service, Northeastern Forest Experiment Station, Syracuse, New York, USA. Available at http://www.treesearch.fs.fed.us/pubs/14579.

Martin, T. 2011. Grand Canyoneering: Exploring the rugged and secret slots of the Grand Canyon. Todd's Desert Hiking Guide, Phoenix, Arizona, USA.

Miller, T., W. Borrie, and J. Harding. 2001. Basic knowledge of factors that limit the practice of low-impact behaviors. Draft report INT-97068-RJVA on file at Rocky Mountain Research Station, Aldo Leopold Wilderness Research Institute, University of Montana, Missoula, Montana, USA.

Murdock, E. 2010. Perspectives on rock climbing fixed anchors through the lens of the Wilderness Act: Legal and environmental implications at Joshua Tree National Park, California. Dissertation. University of Arizona, Tempe, Arizona, USA.

United States Department of the Interior (USDI). 1988. Backcountry Management Plan, Grand Canyon National Park. National Park Service, Grand Canyon National Park, Arizona, USA.

———. 1995. General Management Plan, Grand Canyon National Park. National Park Service, Grand Canyon National Park, Arizona, USA.

———. 2013. Director's Order 41: Wilderness stewardship. National Park Service, Washington, DC, USA. Available at https://www.nps.gov/policy/DOrders/DO_41.pdf.

US Wilderness Act of 1964. Public Law 88-577. 78 Statute 890. 3 September 1964.

White, E. M., J. M. Bowker, A. E. Askew, L. L. Langner, J. R. Arnold, and D. B. K. English. 2014. Federal outdoor recreation trends: Effects on economic opportunities. National Center for Natural Resources Economic Research, Working Paper Number One. US Forest Service, Washington, DC, USA. Available at http://www.fs.fed.us/research/docs/outdoor-recreation/ficor_2014_rec_trends_economic_opportunities.pdf.

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PS

Preventive success! Grand Canyon's response to search-and-rescue overload

By C. J. Malcolm and Hannah Heinrich

Key words
corridor, emergency services, EMS, Grand Canyon National Park, heat threshold, preventive search and rescue (PSAR), search and rescue (SAR)

THERE WAS NO DOUBT IN ANYONE'S mind that search-and-rescue events (SARs) were skyrocketing in the 1990s at Grand Canyon National Park (fig. 1). In a 13-year span from 1983 to 1996, SARs doubled. The critical tipping point for this dangerous trend occurred in summer 1996. That year, the park set records for search and rescues that remain in place to this day. Five heat-related deaths, 300 heat-related search-and-rescue incidents, and 482 total SARs devastated families and stressed responding rangers to their limits. On average, SARs during the late 1990s at Grand Canyon National Park cost taxpayers $1 million per year (Malcolm and Heinrich 2012). Something needed to change.

Ken Phillips, retired branch chief of Search and Rescue for the National Park Service and chief of Emergency Services at Grand Canyon National Park, recounts the experiences of a Grand Canyon ranger during these challenging years.

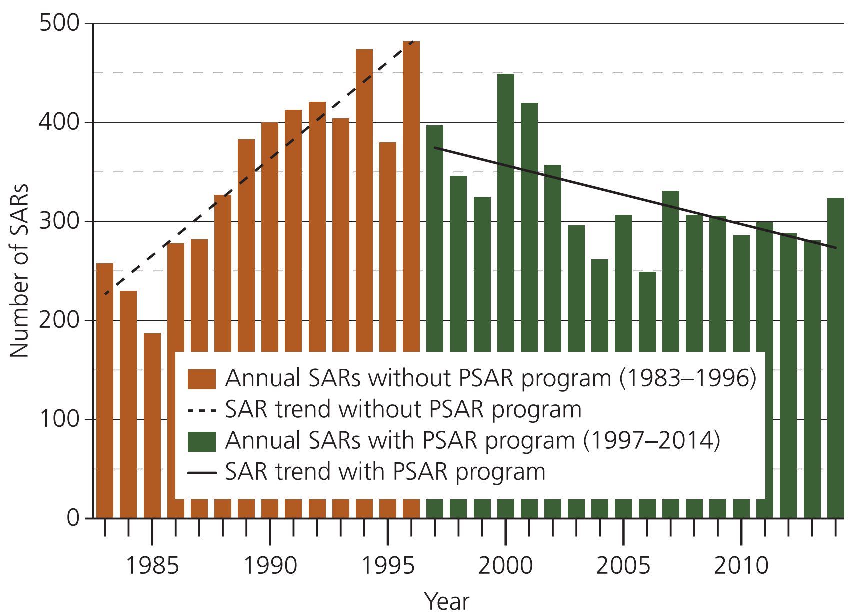

Figure 1. The graph details the number of search and rescues at Grand Canyon National Park from 1983 to 2014. Trends diverge after 1996, the year the park implemented the Preventive Search and Rescue Program.

> In the summer months, the hottest months, we were totally in a reactionary mode and everything was based off the South Rim—unless a call was close to Indian Garden or Phantom Ranch. As soon as SAR Shift or back then, "SAR On-Call," . . . would receive a hiker-in-distress call, they would start looking around for someone to send down the trail. This happened every day, day in and day out; and if you have a couple of those calls a day, which we did, you start burning people out. You're just running out of resources to do that. For our responding rescuers the cumulative fatigue factor was insane because you have got to rush down there; these were vague reports, "Somebody collapsed on the trail . . ." Well is that a cardiac arrest or is that somebody just sitting in the shade? We didn't know. But you can't delay your response. Oftentimes it involved running down the trail. So imagine how fast you'd chew up responders running down the trail at the hottest time of the year. You get down there and you're sweating all over the patient, you're tied up on this call, and you're spent for the rest of the day. That's how the normal process went down before we were able to pre-deploy, before PSAR . . . This took an unbelievable toll on the staff.

After a decade of reactionary responses and the exigent year of 1996, rangers were exhausted and disheartened. The constant summertime requests for assistance created an environment of rescuer fatigue, burnout, and a deadened sense of situational awareness. Hazardous work conditions were accepted and managed. As a result, park leadership commissioned a planning group of 10 rangers with the goal of improving visitor safety on Grand Canyon's many hiking trails and backcountry terrain. Their recommendation and call to action created the Preventive Search and Rescue (PSAR) team.

Preventive search and rescue was established . . . with the mission of reducing visitor injury, illness, and death during the hottest summer months.

Evolution of PSAR: Best practices

Preventive search and rescue is a movement that promotes safety in arduous environments. For example, Yosemite National Park (California) focuses on educating visitors to use backcountry common sense, swift water safety, and public enjoyment of waterfalls from a distance. Yosemite implemented a permit system for climbing the popular Cable Route up Half Dome in summer 2010 in response to multiple fatalities from overcrowding. Delaware Water Gap National Recreation Area (Pennsylvania and New Jersey) uses PSAR to address water safety and proper use of personal flotation devices in an attempt to reduce the number of drownings. At Grand Canyon, PSAR was established in 1997 with the mission of reducing visitor injury, illness, and death during the hottest summer months.

The original PSAR crew consisted of four rangers who patrolled the Bright Angel and South Kaibab Trails. It is unclear how much time they dedicated to patrolling these trails, but according to original reports and corroborating interviews, PSAR rangers were either on the trail, interviewing hikers at trailheads, or staging at the Ranger Operations building. A strong volunteer force was also organized to augment the seasonal rangers for both trail patrols and rescue response.

NPS PHOTO

Figure 2. Used in the late 1990s, the original PSAR sign delivered the message, "STOP, Heat Kills."

In addition to the newly established staff of PSAR rangers, the park launched a media campaign with a "STOP, Heat Kills" message (fig. 2). Rangers posted signs along the corridor trails and distributed pamphlets, flyers, and general information to the visitor centers, backcountry office, and other informational areas throughout the park. Additionally, managers decided to close the South Kaibab trailhead to visitor parking, requiring the use of the Grand Canyon shuttle bus to access the popular trail. The lack of water availability in combination with this trail's precipitous gradient and extreme sun exposure generated frequent rescues before creation of the PSAR program.

Bill Vandergraff, longtime backcountry ranger and SAR expert, said the closing of the South Kaibab trailhead to private vehicle traffic was instrumental in reducing the number of unprepared hikers from reaching this more problematic and challenging trail. "Prior to this closure," Ranger Vandergraff stated, "people would drive in there, walk to the edge, look down, and get sucked right in. With the closure in place there is effort required to get out to the South Kaibab Trail; the road is closed and you need to take the shuttle bus. This has significantly reduced distress calls on the South Kaibab Trail."

Nineteen years later, the PSAR team has evolved into a close-knit group of rangers who are dedicated to inner canyon public safety through the application of emergency response skills and science-based planning. Over the last two decades, advances in technology, improved hiking gear, and

Figure 3. Signs and media were updated between 2000 and 2010 with more realistic and tangible messaging. The "STOP, Heat Kills" sign was replaced by one that relays the more positive yet cautionary message to "Hike Smart."

increased availability of backcountry information have shaped the playing field on which PSAR operates. Today, preventive search and rescue has adopted the team mentality and consists of seven seasonal rangers and one full-time supervisor. In addition to paid rangers, the program staffs 60 trained volunteers who supplement and amplify outreach efforts. Volunteers attend a two-day training at the end of April followed by two to three days of shadowing rangers on trails, for a total of 30–40 hours of preparation for the busy time of year.

The PSAR season runs from April through October, with the bulk of trail patrols occurring from May to mid-September. The team now regularly patrols the Bright Angel, South Kaibab, North Kaibab, and Hermit Trails. Every day during the season, several rangers and volunteers deploy onto corridor trails and slowly patrol down into the canyon. They take positions at natural bottlenecks on the trails close to common rest areas; their goal is to educate visitors descending farther into the canyon on topics such as personal preparedness and safe hiking practices. Many hikers have well-planned trips and many do not. Over the years, the original message of "STOP, Heat Kills" has evolved into "Hike Smart," a more personalized and positive messaging campaign (fig. 3). Prevention is achieved through signage in conjunction with face-to-face encounters as rangers and volunteers patrol the corridor trails.

"Prevention through education" is PSAR's primary mission, although responding to down-trail medicals and SARs is just as important. When the program was first established, PSAR rangers typically practiced at the first responder level. Today, all PSAR rangers are trained and certified to operate as EMTs or paramedics in the backcountry, developed area or "front country" ambulance settings, and helicopter medevac environments. Rangers are also trained in search and rescue, technical rescue, and many other emergency response skills (figs. 4 and 5, next page). The combination of patrolling Grand Canyon's trails one day and staffing the ambulance the next generates a rich blend of experience, judgment, and skill. PSAR rangers need to be self-sufficient, educated, and prepared to lead or guide those who are in harm's way. Ranger Vandergraff commented on the progression of PSAR over the past decade: "The level of professionalism by setting standards based on certifications, a ranger's training, and in-service group trainings has greatly improved our professional response—an important component of public safety."

Search and rescue: A discretionary function

What is a SAR? While there are many definitions, search and rescue is the search for and provision of aid to people who are in distress or imminent danger. A SAR may be as simple as assisting an individual with a sprained ankle to return safely to a trailhead, as perilous as rescuing an injured climber on Rocky Mountain National Park's "Diamond" traditional climbing route, or as involved as multiday searches for individuals lost at sea or in wilderness settings. Saving lives is the ultimate goal of all search-and-rescue personnel.

The National Park Service further delineates SARs as major or minor, distinguished only by cost: major SARs accrue costs greater than $500 while minor SARs are less costly. Furthermore, expenses associated with major SARs are recoverable through annual reimbursement by Congress. Staff hours, equipment replacement, and helicopter medevacs are typical items that can rapidly inflate the expense

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Figure 4. Helicopter medevac rangers wheel a litter up the Bright Angel Trail for a major medical evacuation.

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Figure 5. PSAR rangers and helitack staff rescue a hiker on the Bright Angel Trail. This individual tripped, breaking his leg, and was litter-carried to an awaiting helicopter.

of a rescue. The Park Service spends nearly $5 million annually rescuing visitors.

Is a park obligated to provide search and rescue? In a 1992 landmark decision, the 10th Circuit Court of Appeals ruled in *Johnson v. US Department of the Interior* that search and rescue is a "discretionary function" of government that is protected under general rules of exception of the Federal Tort Claims Act at 28 U.S.C. § 2680(a). Mr. Johnson, described as an inexperienced mountain climber, fell to his death on Buck Mountain in Grand Teton National Park. His family subsequently sued the Department of Interior claiming the park failed to properly warn him of the dangers of climbing and failed to initiate a rescue attempt within reasonable time. The 10th Circuit legally affirmed NPS testimony that "(1) the inherent dangers of mountain climbing are patently obvious; (2) both manpower and economic resources should be conserved . . . during emergency situations; (3) it would be impractical if not impossible to test competency, monitor equipment use, or 'clear' the mountain given limited available manpower and economic resources; and (4) many park visitors value backcountry climbing as one of the few experiences free from government regulation or interference." The 10th Circuit Court of Appeals ruling further clarified a search-and-rescue team's duty to respond, as follows:

> No statute imposes a duty to rescue, nor are there regulations or formal Park Service policies which prescribe a specific course of conduct for search and rescue efforts. Instead, the decision if, when, or how is left to the discretion of the SAR team. Therefore, the rangers must act without reliance upon fixed or readily ascertainable standards when making a search and rescue decision in the field.

This judgment reaffirms that backcountry dangers are "patently obvious" and safety of an individual is a personal responsibility. Nevertheless, the National Park Service ardently strives to educate the public about wilderness dangers through solid preventive messaging.

Incorporating science

In 2011 a movement was initiated in preventive search and rescue to expand the team's awareness and understanding of Grand Canyon hikers. We began to capture specific weather indicators and trail data to serve as benchmarking tools for year-to-year PSAR analyses and accountability. Rangers

Figure 6. Daily patrol logs are filled out by PSAR staff following their patrols and provide information for evaluating and refining strategies designed to prevent trail mishaps.

PSAR Patrol Log

ID#:

Date: ______________________ **Name:** ______________________

Patrol Start Time: ______________ **Patrol End Time:** ______________

Trail: ______________________

Contacts		
Type	**Description**	**Number**
General	Face to face with public. Everyone you speak with is counted.	Count every face-to-face contact!
Preventive Action	Visitor contact for unprepared/unsafe itinerary. Advice is given. Corrective action is advised.	Any form of advice, education, or redirection given is counted. Visitor does not have to show compliance to be counted. Every member of hiking group is counted! Be sure to include these numbers in the "General Contact" section also!
Hiker Assist	Any time a visitor needs some sort of physical, psychological, or medical intervention: food, water, cooling measures, repairs (duct tape), minor first aid, hike assist to rim, etc.	Fill out a Hiker Assist form for any of these actions and for each hiker. Each person in a hiking group who needs assistance is counted as a hiker assist, but only one Hiker Assist form needs to be filled out per group.
Major Medical	Any hiker assist that turns into a general SAR: ambulance transport, helicopter medevac, or patient refusal of treatment. EMS chart is filled out.	Count any of these events! **Include SAR #:**

Notes: ______________________

and volunteers now complete daily patrol logs documenting key data components: trail hours, patrol times, trails patrolled, general contacts, preventive actions, hiker assists, and major medicals (fig. 6, previous page).

During patrols, members of the PSAR team record the number of hikers they interact with on the trail. This is called a "general contact." A "preventive action" is recorded each time a ranger determines the need to further educate a visitor, offering some form of corrective advice based on poor personal preparedness: hiking beyond one's abilities, inadequate food and water, improper clothing or gear, or lack of area knowledge and plan. When a preventive action is recorded, a general contact is counted as well (see fig. 6). The ratio of general contacts to preventive actions highlights two indicators: PSAR outreach and the level of preparedness among those hiking in the canyon. A "hiker assist" documents each time a visitor requires physical, medical, or psychological intervention by PSAR rangers or volunteers. Last, a "major medical" involves paramedic-level interventions that often require a litter-carry or helicopter medevac (see figs. 4 and 5).

Statistics on Grand Canyon's annual SARs and hiker assists are kept as separate figures; for example, an average of 300 SARs and an additional 530 hiker assists occur per year. Hiker assists characteristically are similar in scope to minor SARs, but are separated demographically to hikers in distress on corridor trails. However, when combined with Grand Canyon's annual SARs, they demonstrate the overwhelming response of park personnel to backcountry travelers in need.

Throughout summer 2015 the PSAR team contacted 117,267 people hiking down Grand Canyon corridor trails (table 1).[1] Of these, 28,478 (24%) required some form of directive advice in the delivery of a preventive message and safe hiking education. Three hundred fifty of those general contacts required assistance hiking out of the canyon, a "hiker assist." This type of assistance ranges from simple equipment repairs (e.g., shoes falling apart) to major heat illness interventions, such as rapid cooling, hydrating, and other advanced life support measures. PSAR rangers record hiker assists in more detail on a separate form. A number of demographics and variables are gathered, such as age, gender, location, need for assistance, and treatment or care rendered. Ranger hours spent patrolling trails are also trended and compared to annual park visitation, general contacts, and other indexes (table 2).[2]

[1] Table 1 reveals a decrease in hiker assists in 2014—a trend that continued into the early 2015 hiking season. One possible explanation for the decline is that the PSAR training in 2014 was greatly enhanced, improving the skills and confidence of the patrol rangers and trail volunteers.

[2] Table 2 reveals a decrease in patrol hours in 2014. In particular, afternoon patrols were reduced along the Bright Angel Trail following installation of the new Indian Garden weather station, which allowed adjustments to be based on temperature. Along the North Kaibab Trail, patrol reductions were related to staffing and hiring problems during the first half of the year.

Table 1. Contacts between PSAR staff and hikers along Grand Canyon corridor trails

Year	General Contacts*	Preventive Actions	Hiker Assists	Major Medical Assists
2015	117,267	28,478	350	11
2014	97,654	25,420	383	26
2013	92,044	29,831	617	24
2012	72,461	27,717	621	19
2011	80,083	33,992	685	16
Total	459,509	145,438	2,656	96

*Includes preventive actions.

Notes: Data reflect trail activity from 1 May to mid-September. PSAR rangers and volunteers carry hand counters and patrol logs to tally and report daily statistics.

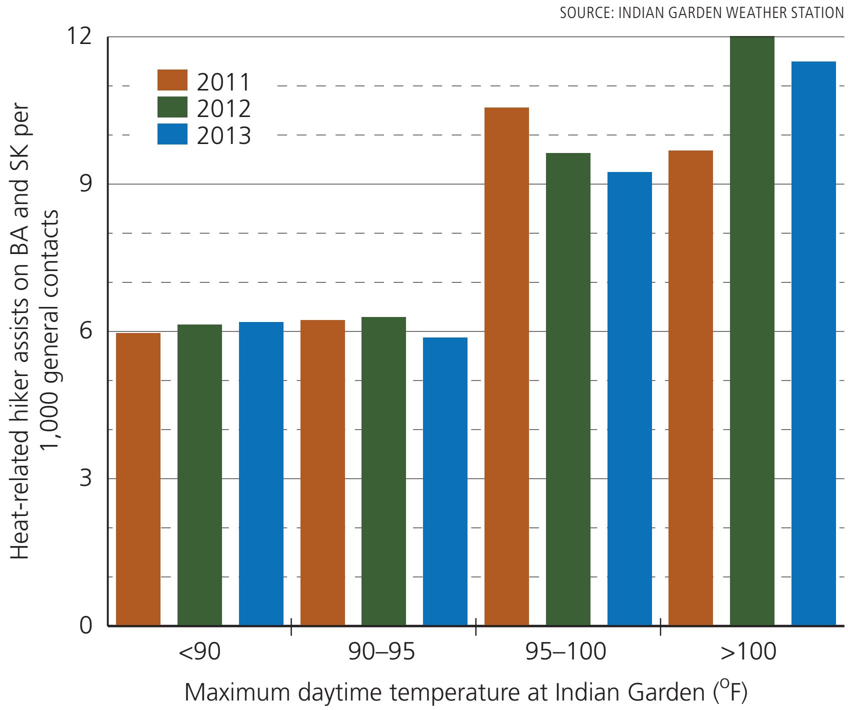

Figure 7. At 95°F (35°C) and hotter, a 71% increase in hiker assistance activity occurs. This is termed a heat threshold among Grand Canyon's hiker population. ($p < 0.001$).

In 2012, we began a comprehensive data analysis with the goal of identifying trends and validating long-standing assumptions. For example, we hypothesized that a physiological environmental temperature threshold exists in hikers who call for assistance; furthermore, at a specific temperature the PSAR team will experience a marked increase in down-trail distress calls. We then collected weather data from Indian Garden Ranger Station, a middle point in the canyon that most accurately reflects weather models along the South Kaibab and Bright Angel Trails. We compared maximum daytime highs to heat-related hiker assists along both of these trails. Subsequently, we discovered a strong relationship between heat-related hiker assists and maximum daytime temperatures.

From 2011 to 2013 a consistent pattern reveals a physiological temperature threshold spiking at 95°F (35°C) and hotter (fig. 7). Hiker assists at temperatures below this threshold occurred at a rate of 6.1 heat-related assists per 1,000 general contacts, whereas at temperatures at or above the threshold, heat-related hiker assists increased to an average of 10.4 per 1,000 general contacts, a 71% increase in distress calls. Historical weather data reveal that 1996 had the most days above 95°F of any year in the previous 25; that year holds the record for SARs (482), heat-related fatalities (5), and days above 95°F (65 days) (fig. 8, next page).

This dramatic increase in hiker assists on days above the temperature threshold has the potential to tax ranger resources to the limit. Rescuer fatigue and resource depletion are serious concerns that compound the possibility of rescuer injury or illness. As Chief Phillips acknowledged, one call and "you're spent for the rest of the day." However, with advanced warning—days predicted at or above 95°F—both PSAR staff and the visiting public can profit from improved safety and hiker assist outcomes afforded by better information gathering and planning.

A big help to the enhancement of trail safety was the 2014 installation of a new weather station at Indian Garden (EW5243) and the 2015 Phantom Ranch weather station (EW9070) replacement of outdated equipment of the National Oceanic and Atmospheric Administration (NOAA) (fig. 9, next page). These modern systems allow us to monitor real-time trail conditions with added meteorological values being measured to further refine physiological distress in relationship to envi-

Table 2. Patrol hours along Grand Canyon corridor trails as part of PSAR

	Trail						
Year	Bright Angel	South Kaibab	Hermit	North Kaibab	Other	Total	GRCA Park Recreation Visits
2015	1,785	1,217	272	407	76	3,756	5,520,736
2014	1,663	1,135	236	289	295	3,618	4,756,771
2013	1,894	1,193	253	1,133	135	4,478	4,564,840
2012	1,540	973	292	739	121	3,587	4,421,352
2011	1,373	756	70	615	36	2,851	4,298,178
Total	8,225	5,274	1,123	3,183	663	18,290	23,561,877

SOURCE: INDIAN GARDEN WEATHER STATION

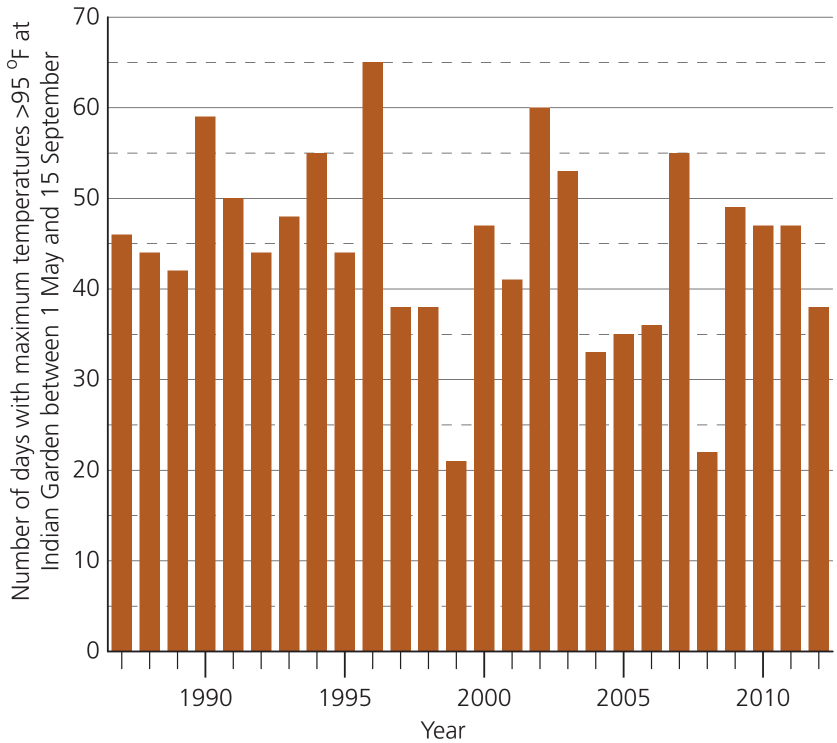

Figure 8. In 1996, Grand Canyon experienced the most days above the 95°F (35°C) heat threshold in a 25-year period and conducted a record-setting 482 search and rescues. The Preventive Search and Rescue program was established the following year.

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Figure 9. PSAR rangers install a Davis weather station at Indian Garden Ranger Station in 2014. The device records added meteorological values such as solar radiation and provides valuable microclimate data.

ronmental conditions: solar radiation (also called solar power density), which is far more important than temperature alone in order to describe the physiological burden for hikers); UV index; barometric pressure; wind speed and direction; dew point; and precipitation. Both of these weather stations are connected via a newly installed dish uplink system linked to ranger facilities on the canyon rim and ultimately to NOAA, MesoWest, and PSAR databases. This network is capable of hosting a multitude of future safety-related voice and data services in this remote and austere environment.

This innovative Canyon Emergency Information System (CEIS) was designed, built, and installed by Dr. Hannah Heinrich, longtime Grand Canyon volunteer and chief scientific PSAR advisor. CEIS is in its second year of interruption-free operation with future plans of linking weather data and other visitor safety–related messages to real-time displays at trailheads, inner canyon ranger stations, visitor centers, and backcountry permitting offices. CEIS can also provide a publicly accessible Internet presence on the corridor trails. This is a tremendous step toward providing real-time information for the five million annual park visitors.

As data analysis continues, the PSAR team will shape its upcoming staffing based on updated study results: trail patrols and hiker education will be reinforced on days above the temperature threshold. During summer 2015 (Norwil et al. 2015), the PSAR team conducted the OMB approved Hiker Hydration Study evaluating the drinking habits of hikers entering Grand Canyon. More than 1,000 hikers filled out questionnaires over three weekends with an outstanding 75% response rate. These data are now under analysis and in draft form.

The goal remains the same: we will continue to learn and anticipate Grand Canyon hiker habits and trends to reduce visitor injury and death, and

Rangers and volunteers . . . educate visitors descending farther into the canyon on topics such as personal preparedness and safe hiking practices.

we will use our workforce as efficiently as possible to promote rescuer safety and optimal response to calls for assistance.

Remaining accountable to the public

Everyday PSAR operates a step behind the public. Some visitors make dangerous plans and casually descend into the canyon with unrealistic goals in mind. Out of the more than 117,000 people our staff encountered during summer 2015, more than 28,000 required persuasion to adopt different plans. Attempting to influence individuals to change their behavior while they are happily hiking into Arizona's great chasm takes more than talent. Strong salesmanship, customer service skills, and knowledge of human behavior are cornerstone arts that PSAR rangers must master. Improved training, knowledge of the customer—the hiking public—and centering preventive strategies on scientific data remain PSAR's guiding objectives. The more we learn about the motivational values of those who descend into the canyon, the more proactive PSAR can become in developing techniques for educating hikers on improved personal preparedness. Science in concert with a learning organization approach makes this task easier.

Sources

All information in this article is derived from SAR and dispatch logs at Grand Canyon National Park, interviews with the aforementioned rangers, and findings from original studies designed by the PSAR team. Additionally the Preventive Search and Rescue Impact Report (cited below) contains much of the material for this article. PSAR rangers Emily Pearce and Joelle Baird contributed to this article. Special thanks go to Ken Phillips and Bill Vandergraff.

References

Johnson v. United States Department of Interior, 949 F. 2d 332, 60 USLW 2356 (10th Cir. 1992). Federal Reporter, Second Series. Available at http://openjurist.org/949/f2d/332/johnson-v-united-states-department-of-interior.

Malcolm, C. J., and H. Heinrich. 2012. Preventive search and rescue impact report. National Park Service, Grand Canyon National Park, Arizona, USA.

Norwil, E., C. J. Malcolm, and H. Heinrich. 2015. Hiker hydration study. Abstract and summary. National Park Service, Grand Canyon National Park, Arizona, USA.

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