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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

SAFETY AND THE VISITOR EXPERIENCE ON HALF DOME TRAIL

- Cave discovery at Grand Canyon
- Climate research at Rocky Mountain
- Science partnerships at Golden Gate
- Sustainable tourism in gateway communities
- NPScape: Case study at Saguaro
- International park assistance: Taiwan

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From the Editor

Back to basics

After a very busy 2011 and early 2012 in which we published three thematic issues, we return to the seasonal fare that is our staple. I want to thank the many authors who waited patiently to have their work published in this edition as we bypassed a planned seasonal issue late last year in order to devote a second theme edition to the topic of climate change science, which was overflowing with good material. Along with the recent issue on wilderness science and management, those three thematic issues were among our most popular editions ever. We are beginning to plan for a thematic issue to be published about a year from now in which we will explore biodiversity discovery work in national parks. In the interim we will be getting back to basics and publishing several seasonal issues that strive to share useful and interesting examples of applied park research.

I invite your participation in filling out the pages of the upcoming fall, winter, and spring (2013) editions with pertinent reports of science applications to national parks. I encourage you to share research summaries, case studies, features, international and domestic park fieldwork experiences, and other types of articles with our readers. Please see the *Park Science* Web site for article type descriptions and page 4 of this issue for contributor deadlines. You can also e-mail or call me with any questions or ideas you have regarding preparing an article for *Park Science*. I look forward to hearing from you.

This issue explores a wide variety of topics and issues that I think you will find enlivening and influential. As editor I feel especially satisfied when an issue not only explains the research process and findings that form the foundation of usable knowledge, but also shares the personal side of the story, whether it be through descriptions of field survey experiences, park exploration, laboratory work, photography, project management, school programs, or consultative teamwork. These articles reflect a broad network of highly motivated, creative, and smart individuals who are hard at work on behalf of our national park conservation goals.

—Jeff Selleck, Editor

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

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

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

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

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

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DEPARTMENTS

ON THE COVER

Visitors ascend the Half Dome cables in Yosemite National Park, California, during a busy summer day. The photo illustrates crowded conditions on the cables, which were common prior to the park implementing its interim day use permit system in 2010.

NPS PHOTO

PARK OPERATIONS

FIELD MOMENT

FEATURES

DEANNA GRECO

JESSICA WEINBERG, NATIONAL PARK SERVICE

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NOTES FROM ABROAD

UPCOMING ISSUES

Fall 2012
Seasonal issue. December release.
In production.

Winter 2012–2013
Seasonal issue. February 2013 release.
Contributor's deadline: 15 October.

Spring 2013
Seasonal issue. May release.
Contributor's deadline: 15 January.

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

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In This Issue

NATIONAL PARKS AND OTHER PROTECTED AREAS DISCUSSED IN THIS ISSUE

Abbreviations

NBP	National Battlefield Park
NHP	National Historical Park
NM	National Monument
NP	National Park
NPP	National Park and Preserve
NPres	National Preserve
NRA	National Recreation Area

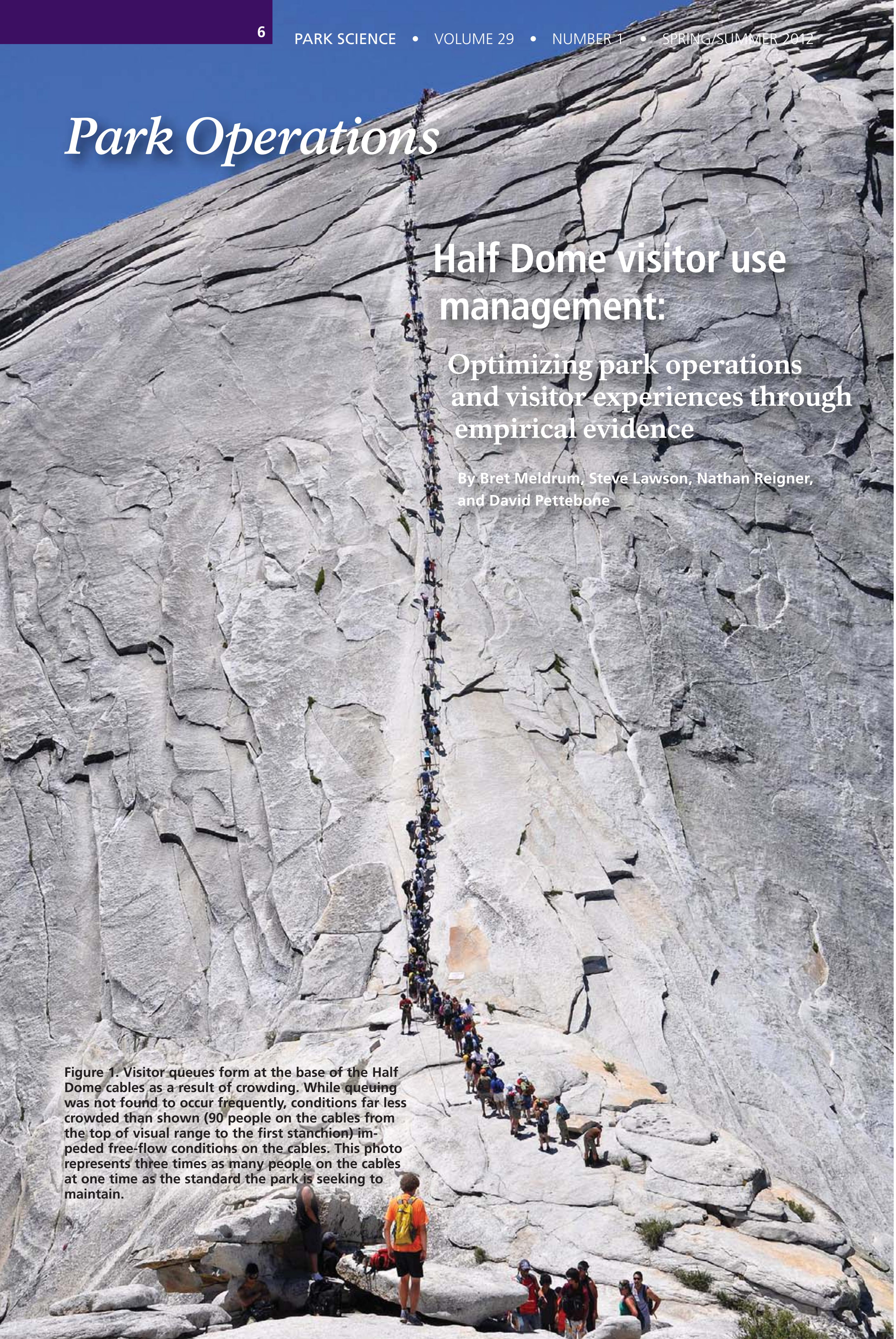
Index

Park Operations

Half Dome visitor use management:

Optimizing park operations and visitor experiences through empirical evidence

By Bret Meldrum, Steve Lawson, Nathan Reigner, and David Pettebone



NPS PHOTO

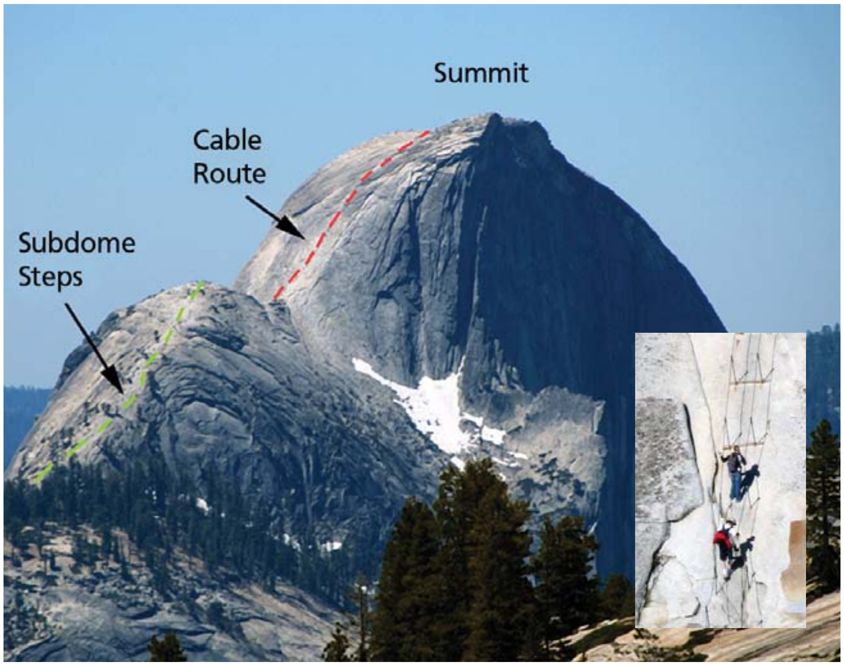
Figure 1. Visitor queues form at the base of the Half Dome cables as a result of crowding. While queuing was not found to occur frequently, conditions far less crowded than shown (90 people on the cables from the top of visual range to the first stanchion) impeded free-flow conditions on the cables. This photo represents three times as many people on the cables at one time as the standard the park is seeking to maintain.

Abstract

The Half Dome Trail (HDT) hike has long been the setting of an iconic experience in Yosemite National Park. The trail takes visitors up the only route accessing the summit without technical climbing. Over time, it has transformed from a historic multiday wilderness experience to an ambitious, and frequently epic, day hike. This 16-mile (26 km) hike ascending 4,000 ft. (1,219 m) is a significant undertaking that ends with the last 400 ft (122 m) of the ascent exposed and on a cables structure. In recent years as visitation has increased, numerous search-and-rescue incidents have taken place on and around the cables. This trend led park management to investigate visitor use on the trail system leading to Half Dome, including behaviors on the cables. This article describes a series of scientific investigations applied to inform and further frame management of visitor use along the HDT. Notably, results from visitor use measurement, simulation modeling, and monitoring of visitor movements provide a basis for standards that frame acceptable conditions.

Key words

day use permits, recreation allocation, recreation carrying capacity, safety, science-based decision making, simulation modeling, social science, visitor experience, visitor use management



NPS PHOTO

Figure 2. The exposed section of the Half Dome Trail leads from the subdome to the summit. This route consists of pairs of heavy-gauge cables approximately 32 inches apart secured to the rock surface at varying intervals.

YOSEMITE NATIONAL PARK IS RECOGNIZED for its towering granite cliffs and surreal waterfalls. Located in the Sierra Nevada of California, the park is also renowned as a popular recreation destination that at times experiences high levels of visitation. While the experiences of most visitors are concentrated in the easily accessible areas of Yosemite Valley, high levels of visitor use are also documented on wilderness trails (Broom and Hall 2010), including the Half Dome Trail (HDT) (fig. 1, facing page).

The HDT hike has long been the setting of an iconic experience in Yosemite National Park. The trail leads visitors up the only route accessing the summit without technical climbing. The hike is 16 miles (26 km) round-trip ascending 4,000 ft (1,219 m), and is an undertaking that culminates with the last 400 ft (122 m) of the ascent exposed and on the Half Dome cables (figs. 1 and 2). This structure consists of pairs of heavy-gauge cables approximately 32 inches apart secured to the rock surface at varying intervals of 82 to 296 feet (25–90 m) in length. The cables are suspended by stanchions that vary from waist to shoulder height and provide handholds, while boards anchored to the stanchions afford footing (fig. 2 inset). The cables form a corridor that facilitates travel to the summit of Half Dome. The structure is typically installed by the trail crew in mid-May and available for use through mid-October, dependent upon weather.

In recent years this hike has transformed from what was historically thought to be a multiday wilderness experience to an epic day hike for most visitors, with an increasing number of search-and-rescue incidents. Fourteen falls and four deaths have been recorded in the vicinity of the Half Dome cables since 1969, with eight incidents occurring since 2006. Most of these falls were caused by weather events resulting from wet surfaces, but three falls occurred when the cables were down while one happened under crowded conditions.

Iconic park destinations can require extensive operations to minimize the effects of crowding, manage traffic, improve safety, protect wilderness values, and provide search-and-rescue services. This article illustrates and outlines a process in support of science-based decision making to manage visitor

Providing for free-flow conditions along the cables route is within the control of park management and is beneficial for maintaining quality visitor experiences. Freedom of movement on the cables reduces unnecessary fatigue and allows visitors better control over their own adventure and risk.

use on the Half Dome Trail. The cables section of this trail does present an additional opportunity to frame visitor experience with safety as the biggest driver in determining daily use levels. This investigative process provides rationale for decision making that maintains high-quality visitor experiences and is designed to withstand public scrutiny. The defining elements of this process are issue identification, scientific investigation, interim management measures, park planning commitments, monitoring, and operational refinements.

Visitor use research

In 2008, we established descriptive and evaluative research components to better understand visitor use and experience on the HDT. The descriptive component quantifies spatial and temporal characteristics of visitor use on the trail. These characteristics include trail use levels in terms of hikers, people at one time (PAOT) using the Half Dome cables, travel times for visitors ascending and descending the cables, and visitor densities on the Half Dome summit and subdome area (see fig. 2). The evaluative component focuses on visitors' perceptions of crowding, risk, and safety on the cables (Manning 2011; Graefe et al. 2011). These data were collected via surveys administered on-site after visitors descended from the Half Dome summit area using a combination of written descriptions and visual simulations of a range of conditions on the cables route.

An initial focus of the research was to determine experiential and use conditions on the cables associated with various daily trail use levels. Results of the evaluative survey using visual simulations of PAOT on the cables suggest visitors were willing to tolerate up to 70 people on the cables at one time. This could be called the "visitor informed crowding standard." The descriptive component of the study identifies distinct patterns between PAOT on the cables and the amount of time visitors took to ascend the cables. When more than 30 PAOT were observed on the cables route, visitors began taking significantly longer to ascend and descend the cables, often as a result of being delayed by others. This could be called the "travel time standard" (Lawson et al. 2009). Increasing time spent on the cables, particularly caused by crowding, reflects the visitor safety and experiential quality concerns that underlie this study and the subsequent park management actions. To facilitate free-flow conditions for safety and experiential qualities, the travel time standard was selected by park management. Using the relationship between PAOT on the cables and counts of hikers on the HDT, a range of daily use levels for various PAOT amounts can be estimated.

We developed a pedestrian simulation model to better understand the issue of visitor movement and the result of a few key variables of interest collected through direct observation, repeat photography, automated trail counter equipment, and survey research. This planning tool allows for a greater degree of management understanding of operational and environmental scenarios. Simulation models are flexible, responsive, and predictive planning tools that can inform decision making more than purely statistical models do (Cole 2005). Simulated use scenarios by the model explain issues that cannot be directly observed in real life, under current management. A range of daily use levels were simulated for various management scenarios, including open use, permit systems, evacuation scenarios, and special equipment requirements. Model outputs provide system measures comparable to management objectives, the 30 PAOT travel time standard in this case. Results of the simulation modeling scenarios provide additional insight into the managerial feasibility of a variety of operational considerations pertaining to field staffing, reservation system capabilities, and emergency evacuation scenarios. Through the simulations, park management decision makers were able to better under-

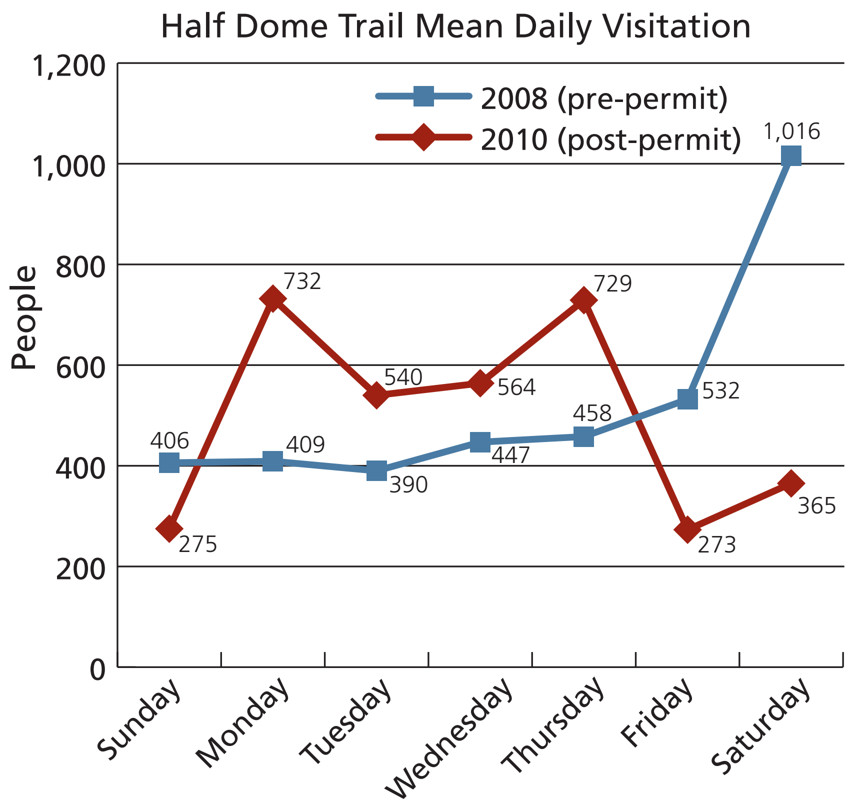


Figure 3. Mean daily visitation over study years 2008 and 2010 (applicable federal holidays removed).

stand the likely implications associated with any alternative before making a selection.

Management action

Results from the descriptive research and simulation modeling suggest that a range of 300–400 people per day could hike the HDT while maintaining park management objectives associated with freedom of movement on the cables. Park managers instituted an interim daily use limit of 400 people under the Superintendent's Compendium for Fridays, Saturdays, Sundays, and federal holidays in 2010. Initial regulations sought to minimize the burden on visitors as much as possible through the permit process. Concurrently the park committed to an environmental assessment under the National Environmental Policy Act and to monitor visitor use on the Half Dome cables with the new daily visitor use limit. The decision to implement these regulations was publicly contentious, but communicating the findings of crowding conditions from the 2008 (Lawson et al. 2009) study and the recent series of falls on the cables helped the decision withstand public scrutiny.

To allocate the 2010 daily limit, Yosemite developed a permit system on the Web site recreation.gov, the same contracted provider that allocates campground reservations for the Department of the Interior. Though establishing use limits for each day of the week was considered, park management decided instead to limit access only on known high-use days of the week and monitor the results. This strategy allowed for a communication emphasis on the pragmatism of visitor use management while recognizing the importance of recreation access. It also allowed the 2010 visitor use monitoring efforts to document the extent of visitor displacement from weekends to weekdays resulting from the new permit system.

Follow-up monitoring of visitor use conditions on the HDT in 2010 revealed that while use declined significantly from Friday to Sunday, it increased from Monday through Thursday (fig. 3). In light of these results, we concluded that visitor demand for Half Dome is certainly flexible enough to accommodate weekday travel, and in 2011, managers applied a seven-day interim permit system allowing 400 people per day to address this documented recreation displacement with the three-day/week permit system.

This incremental modification in the permit process serves as an example of and argues a need for adaptive management. Visitor use response to management actions cannot always be known before such decisions occur. Instituting a weekend and holiday permit system was thought to be the least disruptive to visitors as we sought to understand effects from the new management actions (fig. 4, next page). Without documenting changes in visitor use across years, park management cannot assess the efficacy of their actions in maintaining standards and achieving safety and experiential quality.

Conclusions

Half Dome visitor use research conducted in 2008 (Lawson et al. 2009) and replicated via monitoring in 2010 (Pettebone et al. 2011) has provided a clearer

Figure 4. A park ranger checks permits at the base of the subdome to enforce the daily recreation allocation.

understanding of visitor use, experience, and safety issues at an iconic and complex recreation setting. This approach establishes a basis for visitor use management decision making through examining and simulating relationships between visitor use levels and variables relevant to visitor experience and management operations. The investigation allows crowding to be addressed through scientifically defensible means, a practice becoming increasingly prudent in high-visibility parks. Providing for free-flow conditions along the cables route is within the control of park management and is beneficial for maintaining quality visitor experiences. Freedom of movement on the cables reduces unnecessary fatigue and allows visitors better control over their own adventure and risk. The known increases in daily use levels have been positively correlated with delays in travel times on the cables. This research development through statistical regression and simulation modeling allows the park to consider a range of daily visitor use levels that ensure freedom of movement on the most constraining experiential aspect of the HDT, the cables.

While this visitor use research approach does apply to other parks and protected area landscapes, the HDT application contains unique descriptive considerations for the development of management objectives, notably the physical performance of the cables as a system that provides for freedom of movement. The travel time standard of no more than 30 PAOT on the Half Dome cables was a more salient capacity driver than the crowding standard of 70 PAOT, because it focuses on preventing visitors from being forced to spend more time on the cables than expected. Unlike many other locations both within Yosemite and throughout the National Park System that have developed crowding standards for attraction sites and trails, the cables provide a visitor movement consideration similar to transportation service measures (i.e., number of people, travel time, and level of service). This occurrence provides a unique ability to use recreation-based simulation modeling software to understand how physical system–like characteristics of visitor use change across levels of use, space, and time. The HDT system also allows park managers to explore for a more diverse set of standards on which to base visitor use management actions.

This pressing issue for Yosemite has emphasized the complex nuances of visitor use and the need for addressing them through planning, management, and operations scenarios. It also serves as a strong argument for why visitor use and social science research is needed in the National Park Service. Equally, management actions in many cases require monitoring to understand resultant effects and necessary refinements. Though the visitor use research outlined in this article supports active visitor use management on the HDT, discretion is needed to develop operations that provide the optimal conditions for visitor movement and experiential conditions. The HDT context outlines a progression of management issue identification, research, planning, and monitoring that is useful for science-based decision making and may lead to appropriate long-term visitor use management solutions.

Acknowledgments

The authors would like to acknowledge Dr. Peter Newman, Dr. Adam Gibson, and the Warner College of Natural Resources at Colorado State University for their contributing research in establishing visitor-informed standards on the Half Dome cables.

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Field Moment

Hidden wonder

The discovery and survey of Leandras Cave, Grand Canyon National Park

By Steve Rice

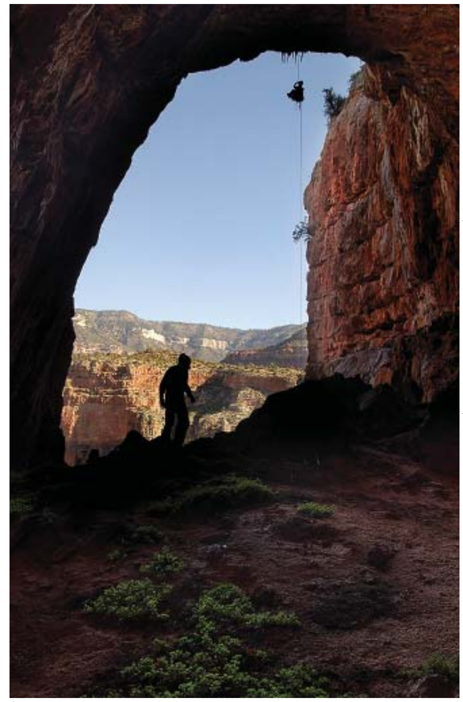

Figure 1. The rappel into Leandras Cave is seen here from the large cave entrance room with the North Rim in the background. The rappel starts along the wall of the Redwall Limestone, and then becomes a 120-foot free-hanging drop to the base of the entrance.

WHILE HIKING A REMOTE SECTION OF the South Rim in Grand Canyon National Park in 2006, longtime cave researcher Jason Ballensky noticed what appeared to be a large cave entrance across the canyon on a cliff below the North Rim. Hiking out to this area on a later trip, Ballensky confirmed that this entrance led to a large cave, later named Athenas Cave, with an 1,800-foot- (550 m) long passageway. For Grand Canyon this was an exciting find, as the cave was relatively large compared with most others in the park. Intrigued by this discovery, Ballensky subsequently surveyed the Redwall Limestone in search of additional cave entrances. Tucked into a side canyon along a 600-foot- (180 m) tall cliff face was a massive black entrance, and they returned a few weeks later eager to explore. What they discovered was beyond imagination.

Access to most caves in Grand Canyon is a strenuous endeavor, and Leandras Cave is no different. An off-trail bushwhack route drops off the rim precipitously, descending roughly 2,500 ft (760 m) over only 1 mi (1.6 km), including several tricky climbing sections and one short rappel. All water must be hiked in. The camp is roughly 4 mi (6 km) from the nearest road, and the cave is another mile from camp along a loose slope above a 600 ft (180 m) cliff of Redwall Limestone. To top it off, entry to the cave requires a 120 ft (36 m) free-hanging rappel off the edge of this cliff (fig. 1).

The cave began as a single borehole that led to an intersection where massive passages departed in different directions (fig. 2). Knowing that they had an immense discovery on their hands, the team left the cave with only a small amount of survey conducted and began planning for a return trip with a larger team. In 2007 they returned and surveyed 1.25 mi (2 km) of passage in just two days. But the scale of this cave continued to amaze. Large borehole passages often 100 ft high and 80 ft wide (30 m × 24 m) had so many perpendicular offshoot passages of a diameter that accommodated walking that they were difficult to map (fig. 3). Thus in 2008, surveyors divided into two teams and were able to increase the length of the explored portion of the cave to nearly 5 mi (8 km). The final survey was conducted in 2009 and brought the total length of the cave to 42,329 ft, or just over 8 mi (12.8 km). Leandras Cave is the longest in Arizona and likely one of the most voluminous in the western United States, with an average passageway diameter of 37 ft (11.3 m).

The scale of Leandras Cave is only part of the story, however. Unique biological and mineralogical finds add to the intrigue of this amazing discovery (figs 4 and 5). An ever present, often puzzling, and sometimes disconcerting detail about Leandras Cave is the sheer number of mummified bats found within (fig. 6). Thousands of impeccably preserved specimens line the walls and floors of the cave in certain areas, with very little evidence of current bat use. In 2009 these remains were investigated more thoroughly, and at least nine species were identified: pallid, Townsend's big-eared, big brown, Allen's lappet-browned, silver-haired, hoary, western small-footed myotis, long-eared myotis, fringed myotis, and, potentially, canyon bat. From a mineralogical perspective, many of the passages are densely decorated with incredible gypsum formations, some exceeding 4 ft (1.2 m) in

Figure 2. Extended exposure photography is necessary to fully illuminate the huge passages in Leandras Cave. Lights shine on different areas for short periods of time and the entire passage is shown in the final image.

Figure 3. Cave passage shape and substrate vary throughout, but the impressive dimensions are nearly constant. Situating the light behind the caver in this photo allows for a long-exposure shot to illuminate the full passage without washing out the photo, and provides a good reference scale for the size of the cave.

Figure 4. Delicate gypsum grass (needles) overlies gypsum flowers (white and brown curls) and gypsum crust (white material, bottom left) in Leandras Cave. Profuse gypsum decoration is found throughout the cave.

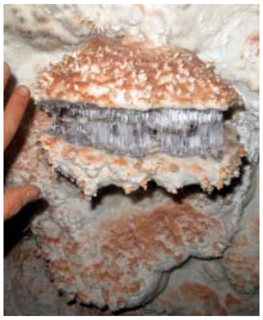

Figure 5. This feature was named the "cheeseburger" not only for its resemblance to the real thing but also for the cavers' hunger for non-freeze-dried food at the end of survey trips.

Figure 6. Thick gypsum flowers (white curls) support a mummified bat (hanging upside-down). Leandras Cave has preserved thousands of bats, which often look as if they are still alive today. Nine species have been identified to date, and future studies are necessary to determine the age of these bats.

length and likely the longest specimens of this type in the world. Additionally, many of the walls were coated in thick mammillary deposits. These deposits form just below the water table. Similar deposits from other caves in Grand Canyon have been dated to help identify when rock strata were incised to form the Grand Canyon itself.

Another impressive statistic of Leandras Cave is the number of volunteer hours associated with the survey. Several teams of highly skilled and dedicated cavers spent a combined 700 hours on cave survey, not counting the strenuous hikes to and from the cave and the travel time for many who came from other parts of the country to participate. One volunteer compiled the survey data, reviewed the sketch maps, and produced a beautiful, functional map, which accounted for an additional 500 hours of volunteer time.

The details of Leandras Cave were kept secret until the project could be completed. Compiled by volunteer Bob Richards, the map was unveiled at the 2011 National Speleological Society annual conference and was awarded "Best in Show" in the cartography competition (fig. 7, next page). A presentation on the discovery and survey was very well received and resulted in numerous inquiries by individuals and groups interested in conducting cave-related research at Grand Canyon National Park. Park staff will be updating the cave and karst resources page of the Grand Canyon National Park Web site (nps.gov/grca/naturescience) later this summer with much of this information.

All caves in Grand Canyon National Park are closed to visitation for safety and resource preservation concerns. Access is granted to some caves via a cave entry permit. Other caves and more substantial cave work (e.g., surveys) require a research permit. Cave exploration in Grand Canyon continues, and with hundreds of remote side canyons and thousands of miles of exposed cliff faces, the next big discovery is waiting to be made.

—Steve Rice, hydrologist and cave resources manager, Grand Canyon National Park, Steven_E_Rice@nps.gov.

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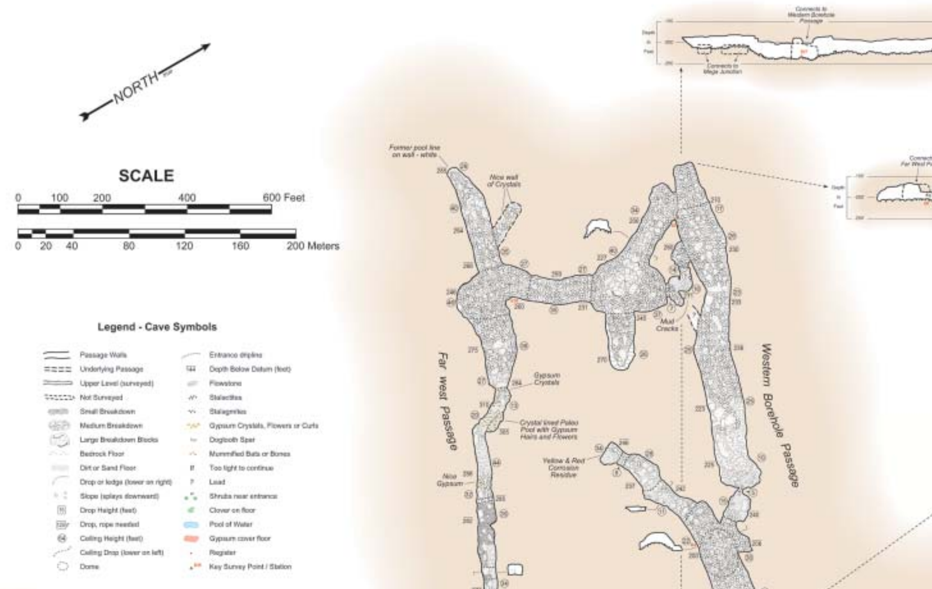


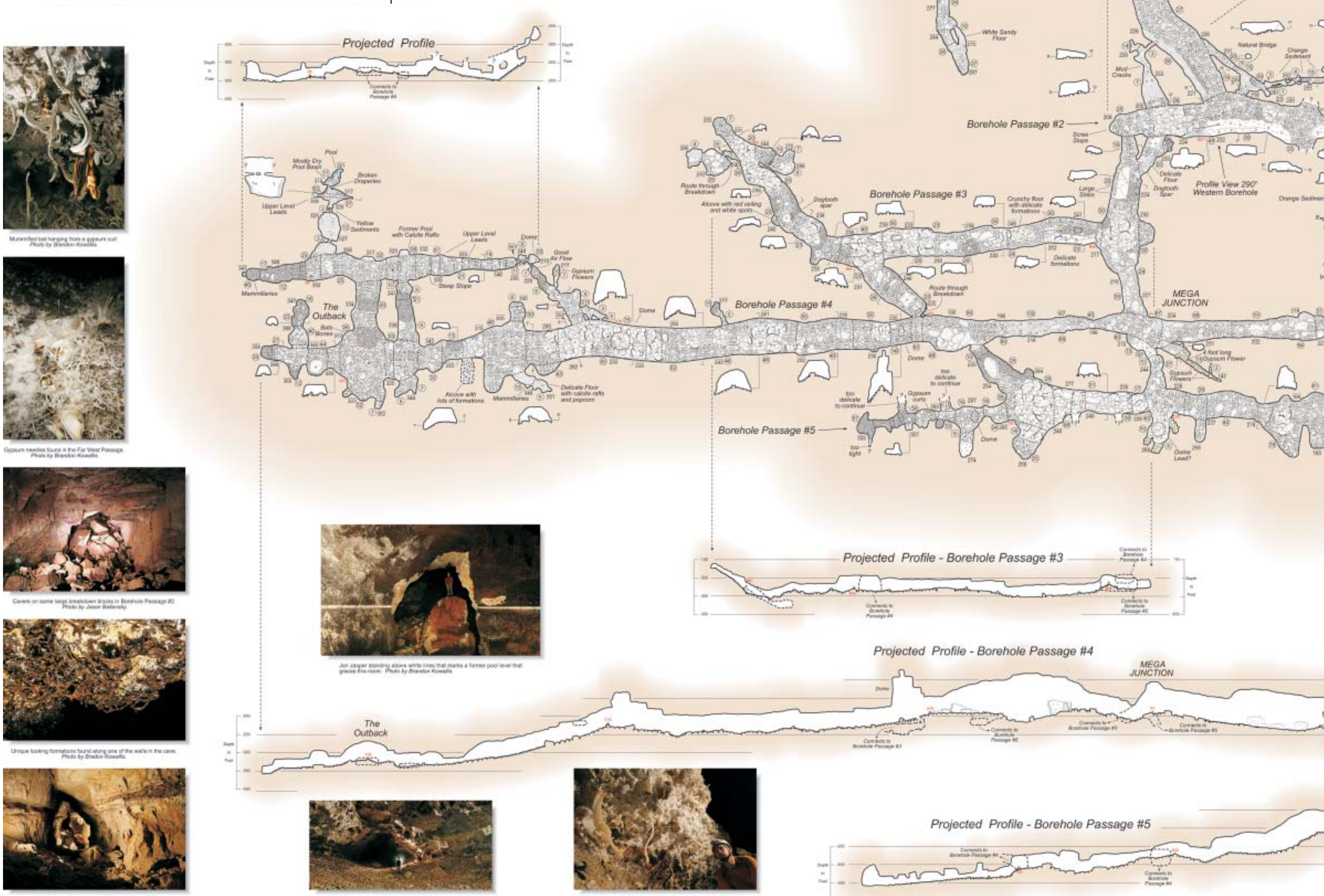
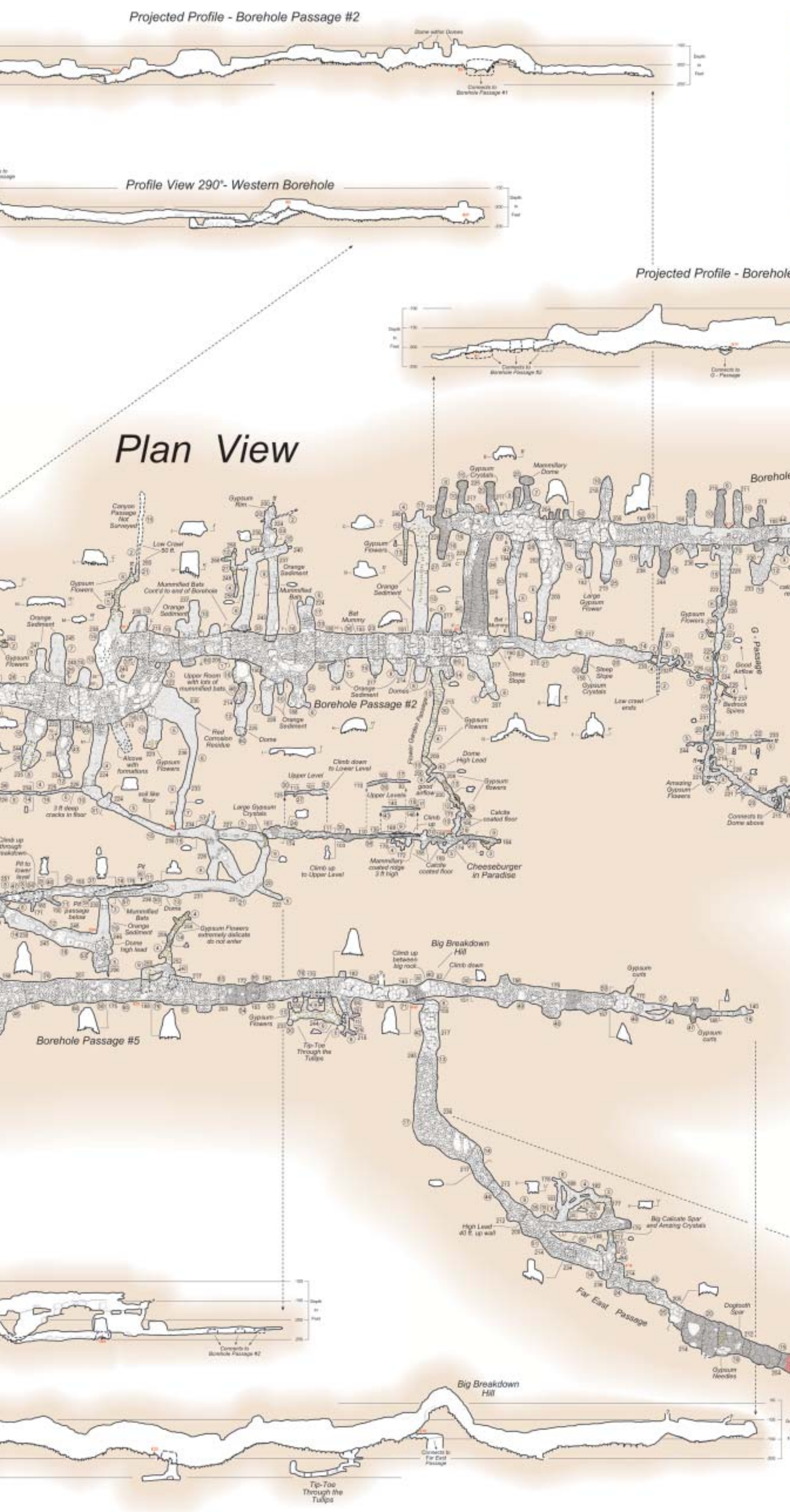
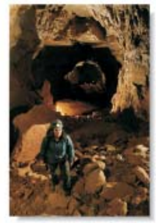
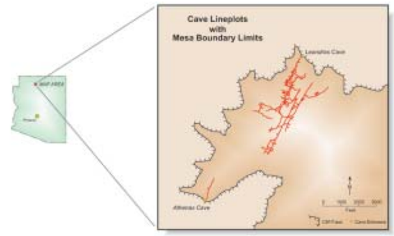


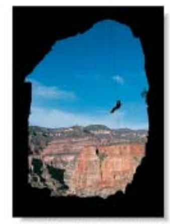
Figure 7. Poster and map developed for the 2011 National Speleological Society annual conference at which Leandras Cave was publicized.





Hattie Oswald in Borehole Passage #1. *Photo by Brandon Kowallis*

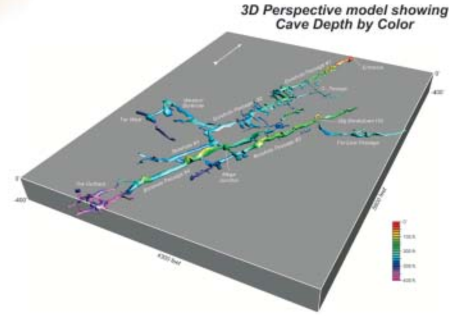




Looking out the large entrance to the cave system with caver on 120 foot rappel. *Photo by Jason Ballensky.*

Panorama view of Borehole Passage #3, a breakdown filled passageway that are common in this cave. *Photo by Brandon Kowallis.*

3D Perspective model showing Cave Depth by Color



Former pool coated these calcite formations a chocolate color. *Photo by Jason Ballensky.*

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Features

Using GIS analysis to help determine Civil War cannon locations in Manassas National Battlefield Park

By Bryan Gorsira, Rodrigo Costas De La Fuente, and Sean Denniston

Abstract
Manassas National Battlefield Park preserves and protects the land and resources associated with the First and Second Battles of Manassas. However, some park locations do not have vegetation patterns that are representative of historical conditions, and in some cases present-day vegetation directly obscures lines of sight that are critical to the interpretation of the battles. In this article we discuss how a three-dimensional analysis of lines of sight employing a geographic information system (GIS) was used to help decision makers choose locations for artillery placement.

Key words
artillery, cannon, Civil War, line of sight, Manassas, viewshed

MANASSAS NATIONAL BATTLEfield Park, Virginia, preserves and protects the land and resources associated with the First and Second Battles of Manassas. The park is located on the northern tip of the Piedmont Plateau within the Culpeper Basin (Fleming and Weber 2003). It is situated approximately 2 miles (4 km) northwest of Manassas, Virginia, and 26 miles (42 km) west of Washington, D.C. The park comprises 2,073 acres (839 ha) of forests, varying from early succession stands of Virginia pine (*Pinus virginiana*) to relatively mature oak-hickory and bottomland hardwood forests (Fleming and Weber 2003). Hay fields, abandoned fields, and a high-use administrative area account for 3,000 acres (1,214 ha) of the park.

Much of the park's vegetation patterns, particularly the arrangement of open and forested areas, are now as they were historically. However, some areas that were grassland during the battles have subsequently grown up into forest, or were already forested when acquired by the park. In these areas, the historical vistas that helped determine the strategies and locations of cannons and troops of the combatants have been blocked from view (figs. 1A and 1B). Woodlands that obstructed historical lines of sight and corresponding fields of fire are important for understanding the nature of the fighting on the afternoon of 30 August 1862. Unfortunately, the intervening maturation of forests has made interpretation of the Second Battle of Manassas, especially the fighting that occurred on 28 and 30 August, nearly impossible.

NPS PHOTO (2)

Figure 1A (above left). Original (assumed) location of S. D. Lee's cannon line and interpretive wayside exhibit, prior to GIS analysis and scene restoration. Figure 1B (above right). The view from the S. D. Lee wayside after scene restoration reveals a clearing and ridgeline at the left side of the photograph.

Cannon placement and historical background

The Second Battle of Manassas is one of the few battles of the Civil War where Confederate artillery dominated the field. More than 30 guns belonging to L. M. Shumaker and S. D. Lee's artillery battalions were concentrated at Brawner Farm (fig. 2). Another four guns of Chapman's Dixie Artillery delivered a destructive raking fire from Battery Heights onto the Dogan Farm. The Confederate gunners had a clear field of fire all the way to Groveton-Sudley Road. Fitz John Porter's Union attack failed largely because of this heavy concentration of Confederate artillery fire. It has been impossible for park visitors to comprehend the advantage of the Confederate position with the woodlands blocking these historical views (Sutton et al. 2005) (see figs. 1A and 1B).

Cannons, of course, were mobile, and cannon lines were more than likely placed at numerous locations during a battle. However, the cannons on display at the park were originally emplaced for interpretive purposes based upon the findings of a local historian and assumptions about lines of sight from the Confederate position on Brawner Farm to Deep Cut, the location of oncoming Federal troops. Civil War artillery fire was based on "line of sight," that is, in order to hit a target,

Figure 2. Overall setting where the Battle of Second Manassas took place with a commanding advantage by the Confederate army.

artillerists had to see the target. The Federals at Second Manassas, for example, were limited in the effective employment of their artillery because of restrictions resulting from ground cover and terrain, not because their guns were inferior to those of the Confederates. By contrast, the Confederates on 30 August occupied an open ridge with commanding views of the field of attack and enjoyed a day of dominance with their artillery such as they rarely experienced during the war.

Using GIS to visualize cannon placement

Park staff had suspected that Deep Cut would not have been visible from Brawner Farm. Contours observed while walking through the woodlands and while looking at GIS maps indicated a ridge may have blocked the view (see fig. 1B). However, because of the forest growth, on-the-ground testing of this question was not possible. The purpose of this study, therefore, was to conduct a simple line-of-sight analysis using GIS to determine if the original placement of the Confederate cannons on Brawner Farm was correct.

Our GIS database contains 5-foot contours for the park, so we decided in 2006 to examine various locations that would have provided a clear line of sight from Brawner Farm to Deep Cut (fig. 3, next page). We used ArcGIS software and its "line-of-sight" tool and set the observer and target heights at the average height of a Civil War soldier, which was about 5 feet, 8 inches (1.7 m). We drew three primary lines of sight, one from the original placement of the cannons on the northern section of Brawner Farm just outside the 330-foot plateau down to Deep Cut, another from a refined cannon placement inside the 330-foot plateau, and one from what we thought would be the historically ideal cannon placement. We thought this last location might have been a better vantage point, avoiding the ridge between the two areas (fig. 3). The results varied significantly.

Outcome and conclusions

Based upon three-dimensional analysis of lines of sight, we were able to determine that Deep Cut would not have been visible from the northern point of Brawner Farm, the original interpretive location of the cannons (fig. 3). Deep Cut only becomes visible when the cannons are relocated to the southern edge of this plateau, as the angle of that view avoids the intervening ridge (see fig. 3). This was confirmed in 2007 when the trees were removed as part of the historical scene restoration project.

Ideally, we would have liked to move the cannons to the southernmost location indicated by the analysis. This location does provide the best view of the Deep Cut area; however, some forest within the scene restoration area had to be retained because of wetland concerns, and so the forests block the view. Therefore, this location would not allow visitors to have a line of sight to Deep Cut. We therefore adjusted cannon placement to a location that does allow for a direct line of sight, even though it is not ideal.

Epilog

In 2007 we finalized the environmental assessment, allowing us to restore much of this area to near-historical conditions. This opened up views that previously had been blocked by forest (figs. 1B and 4 [next page]). In addition, the restoration revealed that the ridge blocking views of Deep Cut was itself a very probable location for placement of some forward cannons under L. M. Shumaker of the Confederate army (fig. 5, next page), and so we placed cannons in that location as well (see fig. 4, left side).

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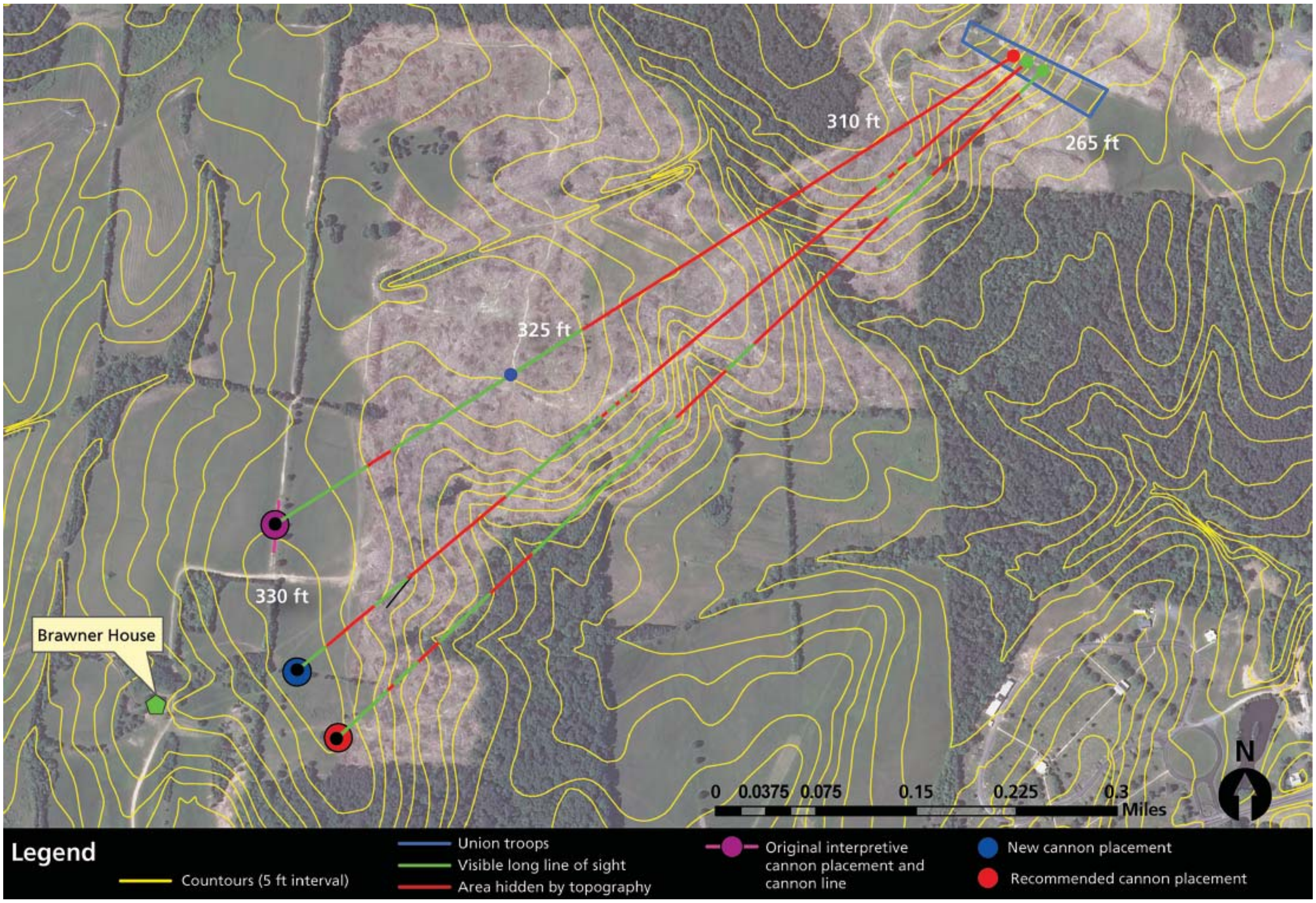

Figure 3. Topographical line-of-sight comparison among three locations; (1) previous cannon placement, (2) new cannon placement, and (3) ideal cannon placement. Green indicates visible areas; red indicates areas hidden by topography.


NPS PHOTO

Figure 4. This view from the adjusted location of S. D. Lee's cannon line reveals the Deep Cut monument in the distance (arrow). This feature was not visible from the previous location. The cannon in the distance at the left is the new cannon line placed on the forward ridge. This location was not considered prior to the clearing of forest, but became an obvious probable location when the views were restored.


NPS PHOTO

Figure 5. The view from the forward ridge reveals the Deep Cut monument and the hillside that was part of the primary target for L. M. Shumaker's guns.

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PS

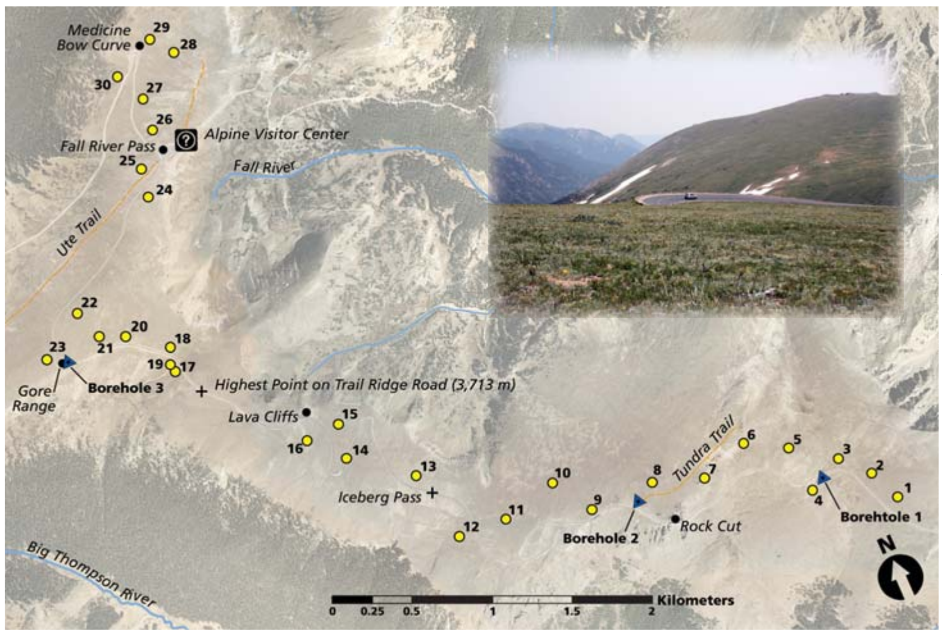
Hot research/Cool science:

An investigation of permafrost in a changing alpine environment

By Cheri Yost and Jason Janke

DR. JASON JANKE WAS SILENT ON the phone. I thought perhaps he was already calculating his costs or planning his next research move. He confessed the next day that he was just in shock. He had never had anyone call and offer to fund his research. As a staff member of the Continental Divide Research Learning Center, I had worked with scores of researchers on projects in Rocky Mountain National Park. Never had I been able to call and offer funding.

The Research Learning Center had recently convened a meeting, attended by partner scientists, to synthesize the effects of climate change on the park's ecosystems. As Ben Bobowski, the park's chief of resource stewardship, noted, "We are left with more questions than answers." But attendees gave clear suggestions for future research and monitoring efforts. One recommended priority was to "conduct field investigations of permafrost and determine its relationship to vegetation communities." We had a small amount of money and a clear need. Dr. Janke's dissertation focused on modeling the extent of permafrost across northern Colorado. I called to ask if he could check the accuracy of that model for just $10,000. He accepted. Soon our simple project of mapping permafrost had transformed into a fruitful partnership that not only tackled practical scientific research but also benefited students, park staff, and the public in unexpected ways.



INSET OF ROAD AND CAR BY JASON JANKE, USED WITH PERMISSION

Figure 1. The map and photo of Trail Ridge Road show the 30 sites and the alpine tundra environment typical of the study area.

Monitoring permafrost temperatures

Permafrost is ground that remains at or below 0°C (32°F) for at least two consecutive years. Several researchers have modeled it using geographic information system (GIS) techniques in alpine areas of the world. For his 2005 dissertation at the University of Colorado–Boulder, Dr. Janke showed that a 2.0°–2.5°C (3.6°–4.5°F) temperature increase could dramatically reduce permafrost extent by about 95% in the Front Range of Colorado. After graduating, Dr. Janke landed a position at Metropolitan State College of Denver (now Metropolitan State University of Denver), a school that serves a diverse urban population and emphasizes undergraduate education. As an associate professor of earth and atmospheric sciences, Dr. Janke was committed to involving his students in hands-on field activities, so he quickly began considering how the park's permafrost project would integrate with his teaching.

Park managers were concerned about melting ice—both aboveground and belowground—as it relates to snowpack, ground ice, and water quality. Facility managers wondered about the stability of structures and road surfaces in the alpine tundra. The park also faces increased nitrogen deposition from anthropogenic sources, which might cause plants to increase their biomass. Initially this removes some carbon from the atmosphere, but in the long term the excess biomass will decompose, which could cause soils to lose more carbon to the atmosphere. Since a large portion of Trail Ridge Road crosses suspected permafrost, park managers wanted to know if warming would lead to more localized slumping, loss of soil cohesion from melted ice, and regional subsidence. Dr. Janke agreed to take direct temperature measurements of soil along Trail Ridge Road, to refine his map of permafrost, and to monitor long-term temperature change as an indicator of changing climate.

Dr. Janke, a select group of his students, and the park's Geoscientist-in-the-Parks intern used a hand auger to install temperature data loggers at 30 sites within a half mile of the road in 2008 (fig. 1). Each site

JASON JANKE, USED WITH PERMISSION

ANDREW EVANS, USED WITH PERMISSION

Figure 2. In 2008, students, a park intern, and Dr. Janke (in grey sweatshirt, at left in right photo) used a hand auger to install temperature data loggers at 30 locations along Trail Ridge Road.

BECKY BRICE, USED WITH PERMISSION

Figure 3. Dr. Janke and students returned to the sites to download data. For many students, this was their first trip to the park—and their first field experience with applied science.

had a near-surface and a deeper sensor. The first sensor recorded temperatures at 10 cm (4 in) depth and a second sensor made recordings at depths ranging from 30 cm (12 in) to 85 cm (33 in), basically as deep as the scientists could place the sensors using a hand auger (fig. 2). They set the loggers to record temperature at two-hour intervals. At each location they measured elevation, slope, and aspect; they also collected soil samples.

Back at the college, Dr. Janke's undergraduate soil classes analyzed the properties of the soil. They measured nutrient concentrations (nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur), conductivity (a measure of the soil's salt concentration), and pH. To determine a possible relationship between soil properties and ground temperature, the students measured bulk density (a measure of the mass of a soil including pore spaces in relation to its volume), particle density (a measure of the mass of just the soil particles in relation to the volume), and porosity (a measure of the void spaces in the soil). The analysis took two semesters to complete. Each of the following summers, Dr. Janke has taken additional students to the park to download the temperature data from the sensors (fig. 3).

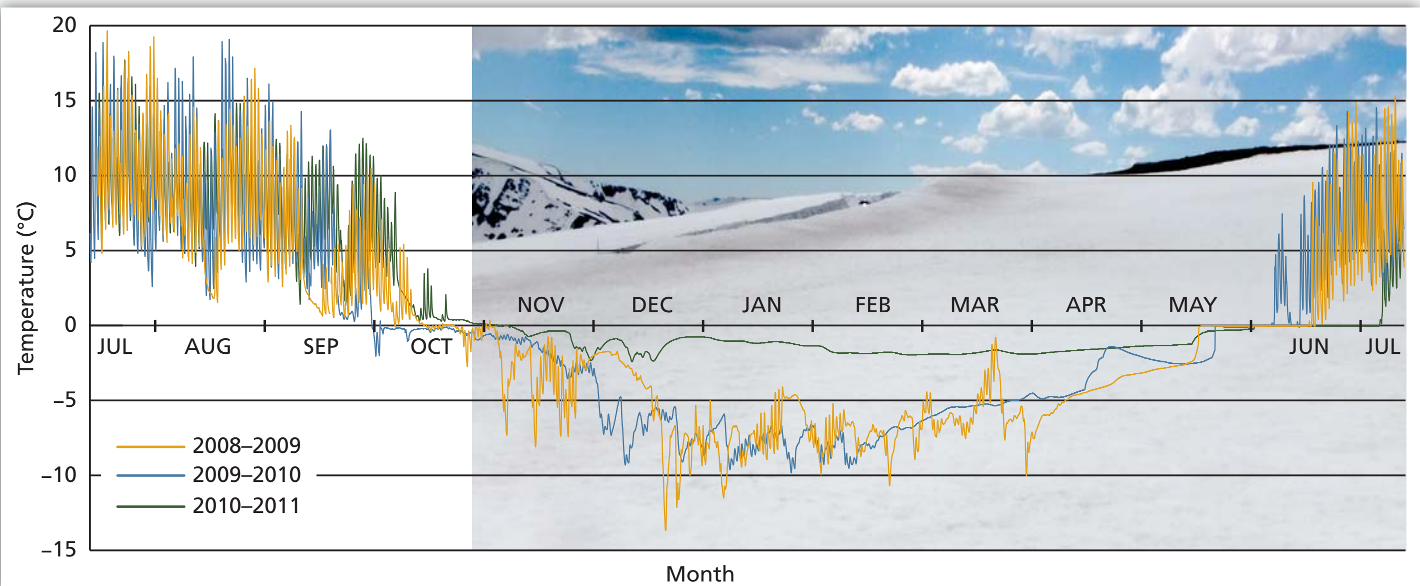
Results and discussion

Dr. Janke and the students analyzed the data and concluded that along Trail Ridge Road, permafrost is likely to be dry, sporadic, and not as abundant as previously thought. However, they found that only 2 of the 30 sites had an average temperature greater than 0°C for the near-surface sensor. Elevation, aspect, and slope as well as the aforementioned soil properties all exhibited weak correlations with mean annual soil temperature (MAST). The strongest correlation was between slope and MAST. Sites with colder temperatures tended to have steeper slopes because deep snow, which can act as an insulator that warms the ground underneath it, will not accumulate. In fact, high snowfall seems to have a greater impact on warming ground than do rising air temperatures. For example, ground temperatures during the 2010–2011 winter were about 5°C (9°F) warmer on average because of well-developed snowpack (fig. 4, next page). Dr. Janke recommended further study of a few sites that exhibited unique thermal signatures, which possibly indicate permafrost presence.

In summer 2010, the park funded ongoing monitoring of the existing data loggers and the drilling of three 6 m (19.7 ft) boreholes on the shoulder of Trail Ridge Road. A borehole temperature profile is shown in figure 5, page 22. This site, along with the other two borehole sites, did not remain continuously frozen through the year. The boreholes will continue to be monitored to determine how climate change affects soil temperature change at depths greater than those investigated at the original 30 locations.

Educational and practical benefits

Beyond addressing scientific questions, the project engaged students and informed interpretive programs at Rocky Mountain National Park. For many students, this was their first visit to the park. Dr. Janke believes that "employers seek employees who have the ability to handle tasks independently and think critically. We teach students these concepts by engaging them in active learning to convey content and weaving students into the research process. This greatly relieves the burden on me to acquire data and gives students a chance to gain some hands-on experience." Over the past three years, more than 150 students in three soil classes ana-



(PHOTO) JASON JANKE, USED WITH PERMISSION

Figure 4. An example of a near-surface temperature plot for Site 4. The green line shows warmer ground temperatures during the winter of 2010–2011. Snowpack was approximately 1 m (3.3 ft) during mid-June 2011. The background photo is from mid-June 2011 and illustrates the unusually deep snowpack. Also, notice the snow ridges near the road from plowing and throwing snow.

lyzed the samples, with a subset of these coming to the park each year to check the data loggers and analyze findings.

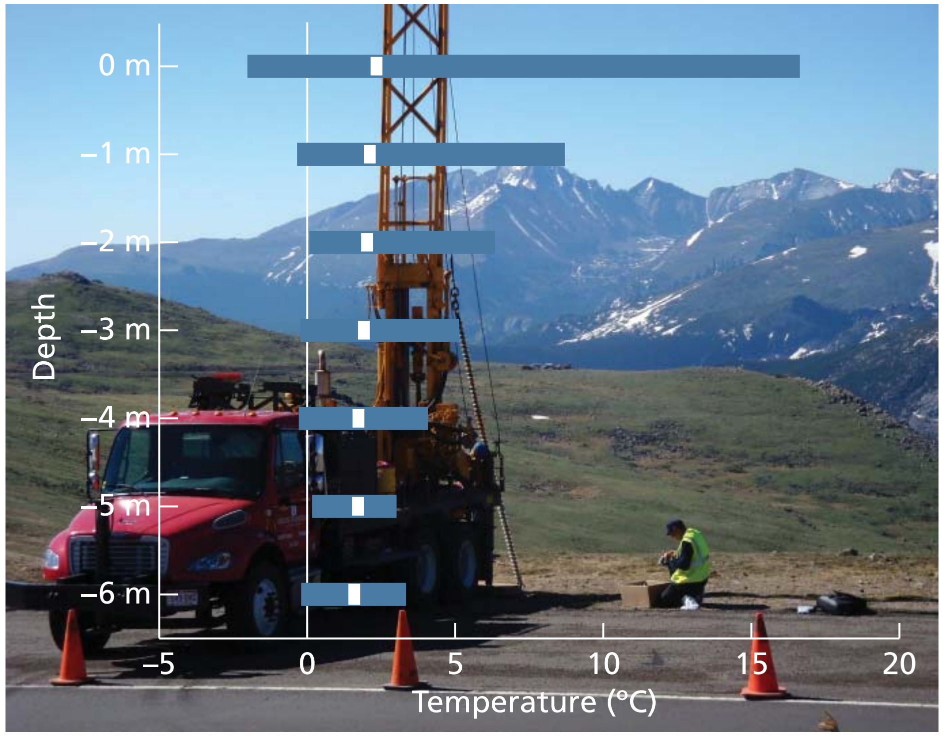
The permafrost project along Trail Ridge Road was good for demonstrating how applied research results are used by land managers. In summer 2010, the Continental Divide Research Learning Center, with additional support from the Rocky Mountains Cooperative Ecosystem Studies Unit (RMCESU), hosted a daylong alpine tundra field school for students and park staff. These connections—among scientists, students, and staff—were important links to a successful research learning program. The park has selected two of Dr. Janke's former students as its climate change interns for the past two summers; one of their duties was to collect temperature logger data, ensuring continuing monitoring of the soil. Another student, based in part on her project involvement, accepted an internship in the Colorado River District as a park interpreter and has recently accepted a part-time position with the National Park Service.

> ***[In considering permafrost and tundra soils,] park managers were concerned about melting ice—both aboveground and belowground—as it relates to snowpack, ground ice, and water quality. Facility managers wondered about the stability of structures and road surfaces in the alpine tundra.***

Rocky Mountain National Park's interpreters have been especially interested in this project. As Kathy Brown, district naturalist, noted, "Visitors know about the melting of arctic permafrost attributed to climate warming and they are surprised to hear that Rocky Mountain National Park tundra is also underlain by frozen ground." By participating in Dr. Janke's presentations and field day, park staff learned to use frozen ground processes as a "tangible" effect of climate change on park resources. Dr. Janke made his results readily accessible to park staff by creating a Web site and making presentations to the public and staff when requested. When the permit modification for drilling boreholes came up for review, park staff in all branches worked collectively to expand the project without damaging resources.

Partnership expansion

Both Rocky Mountain National Park and Dr. Janke plan to continue their partnership. The park sponsored a 2011 project focused on nitrogen and carbon soil dynamics on the tundra that involved funding two undergraduate researchers to analyze the genetic makeup of soil microbes. The project has expanded to



(PHOTO) CLINTON WHITTEN, USED WITH PERMISSION

Figure 5. A temperature profile for Borehole 1. The borehole was drilled to a depth of 6 m (19.7 ft). Blue bars show the range of temperature measurements from 2010 to 2011; white boxes indicate the mean annual temperature, which are all above freezing. Temperature generally decreases with depth but does not remain continuously frozen throughout the year; therefore, this site does not contain permafrost. The background photo shows the equipment used to install the borehole.

> ***"We teach students these concepts by engaging them in active learning to convey content and weaving students into the research process. This greatly relieves the burden on me to acquire data and gives students a chance to gain some hands-on experience."***
>
> ***—Jason Janke***

support other Metro State faculty; Dr. Joanne Odden of the Biology Department is supervising students performing the DNA analysis of soil microbes; Dr. Andrew Evans has begun investigating the fate and transport of phosphorus through alpine soils. Metropolitan State University of Denver was recently accepted as a member of the RMCESU, a big step for a lesser-known university that only recently added graduate programs to its offerings. This membership in the consortium will allow Metro State to be part of the larger research and education community in the Rocky Mountain region. The university supports Dr. Janke's research involvement with the associated opportunities for applied learning. Dr. Janke noted, "The dean has funded the purchase of a freeze-thaw chamber to run undergraduate research projects on campus. We are planting the seeds of change!"

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PS

Live Interactive Virtual Explorations provide students with glimpse of life at the Old Point Loma Lighthouse in the late 1800s

By Kimberly Bruch, Hans-Werner Braun, and Susan Teel

Abstract

Many national parks are participating in Live Interactive Virtual Explorations (LIVE), which uses video-conferencing software and wireless technology to connect hard-to-reach science and history sites, such as Cabrillo National Monument in San Diego, to students across the country. A LIVE pilot project was first implemented in 2006 at Cabrillo in partnership with the High Performance Wireless Research and Education Network (HPWREN), which is funded by the National Science Foundation. LIVE programs focus on three objectives: (1) exploration and understanding of hard-to-reach science and cultural sites, (2) provision of a medium for traditionally underserved students and other students who do not have transportation to access sites in the National Park System, and (3) preparation of students going on field trips to such sites. LIVE broadcasts enable National Park Service scientists and historians to share science and educational information remotely with people who are otherwise unable to visit the site. This article explores a LIVE activity between Cabrillo National Monument's Old Point Loma Lighthouse and a third-grade classroom.

Key words

Cabrillo National Monument, distance learning, Old Point Loma Lighthouse

LIVE INTERACTIVE VIRTUAL Explorations (LIVE) uses video-conferencing software and wireless technology to connect hard-to-reach science and cultural resource sites, such as Cabrillo National Monument in San Diego, to students across the country. A LIVE pilot project was first implemented in 2006 at Cabrillo in partnership with the High Performance Wireless Research and Education Network (HPWREN), which is funded by the National Science Foundation. LIVE programs focus on three objectives: (1) exploration and understanding of hard-to-reach science and living history sites, (2) provision of a medium for traditionally underserved students and other students who do not have transportation to access sites in the National Park System, and (3) preparation of students going on field trips to such sites.

For several years, the LIVE project team, which consists of researchers from HPWREN, San Diego State University, and the Southern California Research Learning Center, has worked with National Park Service (NPS) staff to experiment with ways in which distance learning projects like LIVE can assist park sites in connecting youth to America's great outdoors and promote participation in science, technology, engineering, and mathematics– (STEM) based activities on federal lands. The LIVE project team has collaborated with staff at Cabrillo National Monument to integrate the LIVE technology with best-practice interpretive techniques and experiment with various combinations of equipment. LIVE equipment, including the LIVE backpack (fig. 1, next page), allows NPS scientists and historians at the park to remotely share science and educational information with people who are otherwise unable to visit the site in person. Worn by the presenter, the LIVE backpack holds a laptop computer that is wirelessly connected to the Internet, a camcorder, and a headset. This arrangement allows the presenter untethered freedom of movement in the field.

On 15 November 2011 the LIVE team worked with NPS interpreter Emily Floyd and eight-year-old student and NPS volunteer Elizabeth Bruch on a pilot LIVE activity that connected 17 third graders at a San Diego elementary school to the Old Point Loma Lighthouse at Cabrillo National Monument (fig. 2, page 25). An Apple iPad2 with an internal microphone and camera was deployed at the lighthouse while the school used an Apple MacBook-Pro; the Internet-based video-conferencing freeware Skype served as the software interface for this activity. Both the school and the park sites were equipped with broadband connections, thus facilitating the video-conference at VHS quality. Specifically, the lighthouse connected to the HPWREN while the school connected to the district's broadband connection.

Prior to LIVE activities, students were given print materials related to the Old Point Loma Lighthouse, including a photograph of the site, a map depicting their school's location in relation to the lighthouse, and an image showing the various rooms inside the lighthouse. The students were also given a small container of heavy whipping cream, which their teacher explained would be used during the LIVE activity. As the program began the students were welcomed to the lighthouse by their classmate Elizabeth, who was dressed in period clothing and situated in front of the lighthouse (fig. 2; additional photos can be found at http://www.signonsandiego.com/photos/galleries/2011/nov/15/point-loma-lighthouse-156-birthday/). Park Ranger Emily (also dressed in period clothing) asked how many students had been to the lighthouse; several raised their hands and shouted "yes!" Park Ranger Emily then gave an overview of the lifestyle of a lighthouse keeper and his family during the 1880s and answered a few questions posed by the students. After Emily explained the layout of the lighthouse, the children were led via LIVE into the kitchen and given a glimpse of a butter churn. At this juncture the students were instructed to start shaking their cream to make their own butter in the classroom—just as cream was churned into butter in the 1800s!

While the children in the classroom were shaking their cream, Emily and Elizabeth continued the tour of the lighthouse, showing the students the living room. The children asked questions such as "What did children do for fun?" "Elizabeth, where are your glasses?" And "Elizabeth, why do you have twine in your pigtails instead of your usual ponytail holders?" The answers provided by Ranger Emily fascinated the children, who were especially intrigued by the fact that children of the 1800s jumped rope just as they do, but were quite surprised that not everyone who needed glasses was able to wear them, as spectacles were a privilege in this era. Additionally, the third graders were interested in learning how Elizabeth got to be a volunteer for the National Park Service at the Old Point Loma Lighthouse while they were in their classroom. By this time the cream that the children had been shaking turned into butter and was then enjoyed as a classroom snack with saltine crackers following the LIVE activity.

Overall the LIVE program was well received by the students, although the teacher reported that the video appeared choppy at times and the audio was delayed and degraded by interference from strong wind at the park. These problems were likely caused by the addition of unrelated multiple users of the broadband connections at the school, which reduced available bandwidth, resulting in audio latency. The majority of the students agreed that the LIVE activity had prompted them to ask their parents to take them on a field trip to the lighthouse.

HPWREN

Figure 1. Untethered and free to move about, a ranger at Cabrillo National Monument investigates a tidepool along with her off-site audience during a LIVE presentation. The backpack holds a laptop computer that is configured to connect wirelessly to the Internet while transmitting video in real time from the handheld camcorder and commentary from the headset.

Natural resource uses of LIVE

LIVE activities are not restricted to school programs, but can also be designed for many other applications. For example, scientists at Cabrillo National Monument use the LIVE programming to share real-time images with university students studying the park environment who are unable to travel to the southern California coastline. Another application of the LIVE technology is used by geologists at Mammoth Cave National Park in Kentucky, where DSL-connected laptops equipped with video-conferencing software are used to share their experiences studying the world's longest cave system with education and research communities throughout the United States. Yet another example of LIVE activities is demonstrated at Biscayne National Park, Florida: scientists, archaeologists, and interpreters located at the park's Atlantic coast visitor center have broadcast to audiences at scientific confer-

Figure 2. Volunteer Elizabeth Bruch, dressed in period clothing, participated in the LIVE activity along with an interpretive ranger at the Point Loma Lighthouse.

ences, as well as to the Cabrillo National Monument visitor center in order to compare the coastal ecology of parks on the Atlantic and Pacific coasts. LIVE has also been used for "science lectures from the field" where NPS natural resource staffs at parks discuss science and monitoring subject matter with graduate students or faculty at universities.

Park staff who are interested in learning more about the LIVE activities can attend workshops offered annually by the National Park Service and HPWREN. These workshops take place at various national park sites and include detailed instruction on how to use the LIVE backpacks, host LIVE activities, and install basic wireless (Wi-Fi) systems in parks. The workshops also include a module outlining proposals for entry into Project Management Information System (PMIS) to fund LIVE programs that directly benefit visitors. Announcement of the LIVE workshops and materials from previous workshops can be found on the Sea to Shining Sea LIVE Web site at http://seatoshiningsea.org/news.html.

Acknowledgments

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Boston Harbor Islands All Taxa Biodiversity Inventory

Integrating science, education, and management in an urban island park

By Jessica Rykken and Marc Albert

Figure 1. A robber fly from the Boston Harbor Islands, *Albibarbefferia albibarbis*.

FROM 2005 TO 2011, HARVARD University collaborated with the National Park Service and others in the Boston Harbor Islands Partnership to conduct an All Taxa Biodiversity Inventory (ATBI) at Boston Harbor Islands National Recreation Area, Massachusetts. This first phase of the ATBI has focused on the vast diversity of insects and their arthropod relatives that comprise what renowned entomologist and Harvard professor emeritus Dr. E. O. Wilson has affectionately termed the "microwilderness."

An urban island park may seem like an unlikely place to conduct an ATBI. After all, the 34 islands and peninsulas that make up this park have been heavily influenced by humans over the past few centuries, serving as sites for military forts, farms, schools, hospitals, sewage treatment plants, and, until quite recently, a landfill. This is no hot spot of biodiversity. However, the park's location in the heart of New England's most densely populated metropolis couldn't be better for engaging a large and diverse audience. Like most ATBIs, our inventory has three complementary objectives: (1) to catalog insect biodiversity in the park (fig. 1), (2) to educate and excite the public about local biodiversity, and (3) to use biodiversity data to inform park management.

Biodiversity does exist in an urban park. In our pitfall and malaise traps, bee bowls, nets, beating sheets, and at UV lights, we have collected an impressive array of taxa, including more than 170 species of native bees, 15 species of millipedes, and 52 species of ants (more than twice as many as predicted by Dr. Wilson himself!). In total, more than 65,000 specimens representing approximately 1,800 species populate the ATBI database—and that doesn't include the vast majority of superabundant and hyperdiverse flies and parasitic wasps still sitting on the shelf (see sidebar). Among the identified species, we have documented many new state and regional records, and even a few new introductions to the United States, including *Laemostenus terricola terricola* (Herbst), a ground beetle from Europe; *Myrmica scabrinodis Nylander*, the common elbowed red ant, also from Europe; and *Hishimonus sellatus* Uhler, a mulberry-feeding leafhopper from Asia.

Discovering patterns: Nonnative species and island biogeography

Boston is one of the nation's oldest active ports, and presumably has long been a point of entry for introduced species. Although comparable data sets for most taxa are not available for the mainland, where they do exist the ATBI allows us to assess whether the number of introduced species as a proportion of all species on the islands is high relative to that of the mainland. A recent catalog for Rhode Island (Sikes 2004) allows comparison for beetle families. Among the four most diverse families on the islands, the percentage of introduced species in the park is markedly higher than in Rhode Island. For example, 14% of all ground beetle (Carabidae) species found in the park are introduced, compared with 6% in Rhode Island. The same pattern holds for weevils and bark beetles (Curculionidae; 39% vs. 21%), rove beetles (Staphylinidae; 24% vs. 9%), and leaf beetles (Chrysomelidae; 22% vs. 8%). Among other taxa in the park, percentages of introduced species range from 95% for millipedes to just 4% for bees. We hypothesize that these proportions relate to taxon mobility, functional group (i.e., herbivore vs. predator), and other life history traits. For example, the high proportion of introduced millipedes may also hold true for other sedentary, soil-dwelling decomposers.

In an island park it is also interesting to consider patterns of species richness in relation to island size and isolation as a test of the theory of island biogeography, which predicts that smaller and more isolated islands will have relatively fewer species (MacArthur and Wilson 1967). At Boston Harbor Islands, there is a strong positive relationship between island size and species richness (i.e., bigger islands have more species), but an island's distance from the mainland does not appear to be a strong predictor of species richness, regardless of mobility. With the most isolated island being only 3.2 km (2.0 mi) from shore, distances to islands appear to be short enough that even sedentary

The challenges of documenting biodiversity

All ATBIs have special challenges, but there are several issues common to all inventories that truly include “All Taxa” and, thereby, are dominated by invertebrates. Any sort of invertebrate sampling will inevitably bring in overwhelming numbers of specimens that need to be processed, identified, and ultimately stored somewhere. Each of these three steps can pose huge difficulties for parks, in terms of processing labor and lab space, finding taxonomists willing to share their expertise, and finding museums willing to house large collections of park material. As biodiversity discovery activities gather momentum across the country, it will be important for each park to consider and address these challenges in its own planning process. A new Taxonomists-in-Parks program is being developed that will provide guidance at a national level. For more information, contact the author, Jessica Rykken, or Sally Plumb (sally_plumb@nps.gov), NPS biodiversity coordinator.

species, such as millipedes, can colonize near and far islands via drift or human transport. As the islands (most of which are deposits of glacial till) were connected to the mainland approximately 9,000 years ago, some native species may have arrived before isolation and persisted. Habitat diversity appears to have a very strong influence on species diversity, especially the presence of freshwater, which is a scarce resource on the islands. Small islands with even a small freshwater seep have many more species than their size alone would predict.

Public education and engagement

Outreach and education have been integral components of the ATBI since its inception. We want to instill an awareness that “biodiversity” is not restricted to the tropics or defined only by colorful birds and large mammals in wild, remote parks, but rather that everyone can “explore the microwilderness,” even in a small urban park. You can’t expect people to appreciate what they can’t see, and therefore we have worked to bring insects up to a scale where their bizarre forms, beautiful colors, and fascinating bits and pieces can be seen clearly using high-resolution images generated from state-of-the-art imaging software at Harvard. Aside from each species having a full gallery of images in the ATBI’s online database, we have produced eye-catching posters of the ants, leafhoppers, bees, weevils, and other denizens of the park (fig. 2) as well as an award-winning PredatOR-Prey playing card game and foldout field guides to commonly encountered “Creatures of the Microwilderness.”

The ATBI has also stimulated the development of insect-themed, curriculum-based school programs for fifth through eighth graders. The field and classroom activities were developed through collaboration among project scientists, NPS education rangers, and Thompson Island Outward Bound Education Center staff, and have thus far reached more than 4,000 students in the Boston area. The curricula and materials, including almost 200 specimens embedded in clear resin, and several wheeled suitcases full of insect-collecting and -observing gear, are intended to long outlast the ATBI itself.

In addition to educating people about insect diversity, the ATBI has been a catalyst for getting people involved in the process of biodiversity discovery (fig. 3, next page). The project has relied on a small army of high school and college students, interns, volunteers, youth groups, retirees, skilled amateurs, and citizen scientists to do much of the day-to-day work. This includes tending traps on the islands and, even more importantly, sorting, pinning, labeling, and databasing tens of thousands of specimens in the lab. We have gotten new park records from the nets of fifth graders, and we have had almost every staff person at the park spend a day in the lab marveling at bee diversity through the microscope. An added benefit of the project is that their new appreciation and enthusiasm for insects make students, citizens, and park staff alike ideal ambassadors and advocates for the microwilderness.

Figure 2. A poster featuring predators and their prey found in the microwilderness.

Practical applications

Managers might wonder, aside from getting baseline knowledge of biodiversity in the park and looking out for potential pest or rare species, how we can make use of distribution information for 1,800 invertebrate species. Documenting “hot spots” of biodiversity within the park is one way, including habitats that we already know to be important for other wildlife and plants (e.g., freshwater) and microhabitats that might otherwise be overlooked (e.g., sandy south-facing banks that provide nesting

NPS PHOTO

Figure 3. Families out on Spectacle Island collecting insects for the ATBI during a Family Fun Days program.

We want to instill an awareness that "biodiversity" is not restricted to the tropics or defined only by colorful birds and large mammals in wild, remote parks, but rather that everyone can "explore the microwilderness," even in a small urban park.

habitat for solitary bees). Another opportunity is to select appropriate taxa to serve as indicators of ecosystem integrity for long-term monitoring, especially in the face of large-scale disturbances such as climate change. To this end, Boston Harbor Islands has piloted a bee monitoring project with a robust sampling design that will allow detection of relatively small changes in bee abundance and richness over five-year intervals. The sampling itself is very simple and replicable, and volunteers can easily be trained to collect bees in the field and process them in the lab, leaving only the task of species identification for the scientists.

A fruitful partnership

As more parks across the country become interested in conducting various kinds of biodiversity discovery activities, it will be useful to have different models from which to draw. Available resources, location, and other factors all figure into designing a successful project. In the Boston Harbor Islands model, a close collaboration between one university and the Boston Harbor Islands Partnership, including the capacity to leverage NPS funding with private donations, has resulted in a remarkably successful ATBI. Total project funding over six years will include approximately $225,000 from NPS sources and $213,000 from private donations. Harvard University benefits directly from this collaboration by adding more than 100,000 local specimens to its invertebrate collections, and the ATBI has provided opportunities for more than 15 Harvard students to learn field, lab, and taxonomy skills, and for some to pursue honors thesis projects. The park, in turn, has benefited from having university scientists coordinate the entire scientific endeavor, which has provided access to other scientists (for specimen identification), lab space and equipment, library resources, imaging and printing equipment, collection facilities, and personnel support for Web site and database maintenance, imaging, and design of outreach products. This model has worked especially well for a small urban park to which scientists are not easily enticed to come and collect for themselves, given the relatively low overall biodiversity and the lack of park facilities such as lab space and accommodations.

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Paleoblitz: Uncovering the fossil record of the national parks

By Vincent L. Santucci, Justin S. Tweet, and Jason P. Kenworthy

Collectively, fossils from the national parks span more than 1 billion years and represent major stages in the evolution of life on Earth.

OVER THE PAST DECADE, A team of National Park Service (NPS) paleontologists and partners has been helping to uncover and record a 1-billion-year fossil record of life preserved throughout the National Park System. Fossilized remains or traces of ancient plants, invertebrates, vertebrates, and microbes have been documented in at least 237 national parks in this first system-wide paleontological resource inventory (fig. 1, next page). Through intensive research and data mining that could be regarded as "paleoblitzes," scientists have been collecting, compiling, and synthesizing baseline paleontological resource data, greatly expanding our knowledge and understanding of the scope, significance, and distribution of national park fossils. Additionally, this inventory work addresses provisions of the Paleontological Resources Preservation Act (2009) that enhance our abilities to manage, protect, interpret, and better undertake scientific research on park fossils.

The National Park Service initiated this system-wide paleontological resource inventory in 2001, based upon a plan to incrementally and systematically survey the 32 networks of parks in the Inventory and Monitoring (I&M) Program. As surveys progressed scientists wrote paleontological resource inventory reports for each I&M network, summarizing fossil resources for each park in the network. These summaries highlight park geology, known and potential paleontological resources, fossil specimens kept in NPS museum collections or at outside repositories, resource management issues, comprehensive bibliographies, and a list of recommendations for future work aimed at conserving these resources. In 2002, the first such report—for the Northern Colorado Plateau Network—was completed. Last December the Central Alaska Network was the final piece and now all 32 networks have been inventoried. As a result of this work, the number of parks in the National Park System identified with paleontological resources essentially doubled.

Inventory highlights

Collectively, fossils from the national parks span more than 1 billion years and represent major stages in the evolution of life on Earth. From primitive microbial mounds (stromatolites) high in the mountains of Glacier National Park (Montana) to the Ice Age remains of plants and animals preserved in caves deep within Grand Canyon National Park (Arizona), an extraordinary and diverse fossil record is preserved throughout the National Park System. A few milestones and notable examples of new information and discoveries resulting from the inventories follow:

- The first described and illustrated fossil specimen from the Western Hemisphere was collected in the late 1600s from an area that is now likely within Colonial National Historical Park (Virginia).

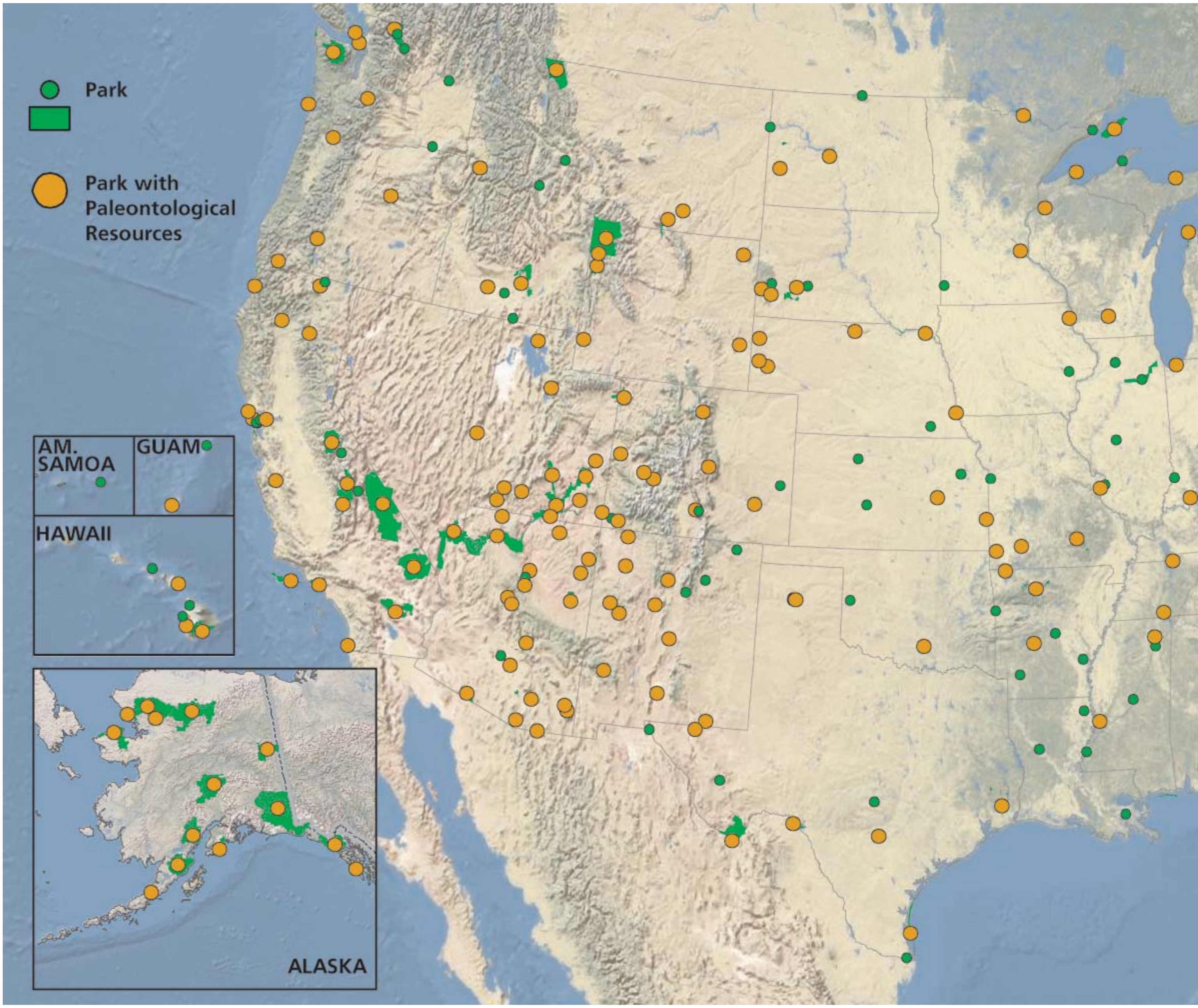
- Fossilized footprints of dinosaurs and other prehistoric vertebrates are documented in at least 35 units of the National Park System.

- The Smithsonian National Museum of Natural History assisted with preparation and identification of a rare and important fossil whale specimen discovered along the Suitland Parkway (Maryland), part of National Capital Parks East.

- The U.S. Geological Survey and the Smithsonian National Museum of Natural History possess important unpublished field notes and archives related to tens of thousands of fossil specimens that were collected from areas now administered by the National Park Service.

- Fossil marine invertebrates recently discovered in Silurian Period rocks (about 430 million years old) at Glacier Bay National Park and Preserve (Alaska) are helping to reinterpret the park's geologic history and revise the park's geologic map.

- The National Park Service maintains many examples of paleontological resources that occur in association with cultural resources, including fossils found at archaeological sites, those contained in building stones of historical structures, and references to fossils in historical journals and other archives.



Alaskan national parks are recognized as frontiers for paleontological studies, and recent fieldwork there has yielded a wealth of important new fossil discoveries. Paleontologist Tony Fiorillo is helping to uncover new information on Alaskan dinosaurs based on his documentation of fossil dinosaur tracks at Aniakchak National Monument, Denali National Park and Preserve, and Wrangell–St. Elias National Park and Preserve. A team of paleontologists led by consulting geologist Robert Blodgett is helping to reinterpret the geology and paleontology of the Silurian and Devonian periods at Glacier Bay National Park and Preserve. Blodgett has discovered and is in the process of describing several new genera and species of marine invertebrate fossils from the park (fig. 2, page 32). Of particular importance to the geologic history of the area, the Glacier Bay fossils exhibit characteristics that are similar to those found in Siberia. This suggests that these Paleozoic rocks and fossils originated in Asia and were transported to the West Coast of North America.

The paleontological inventories have helped to identify thousands of holotype fossil specimens derived from national parks. A holotype is a specimen upon which a new species is based and described in the literature. National parks from which holotype specimens have been discovered include Florissant Fossil Beds National Monument (Colorado), where

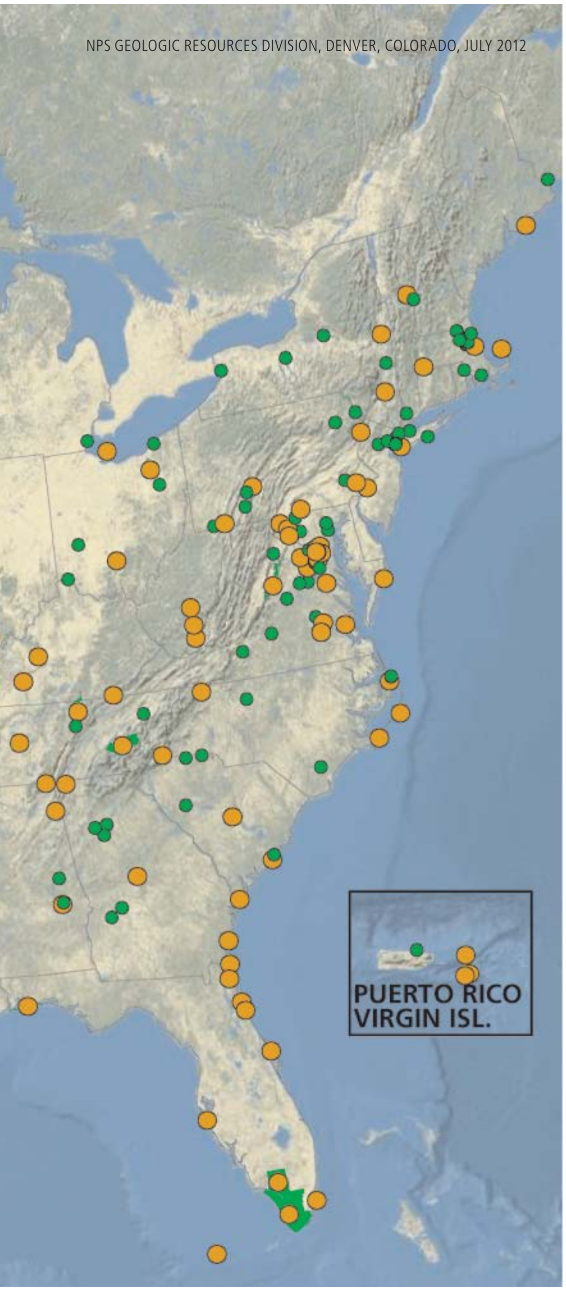


Figure 1. At least 237 areas of the National Park System (gold dots) preserve fossils in a variety of contexts. A systematic, system-wide inventory of paleontological resources over the past 10 years more than doubled the number of units with recognized fossil resources.

many specimens have been found; Guadalupe Mountains National Park (Texas); Grand Canyon National Park (Arizona); Yellowstone National Park (Wyoming, Montana, and Idaho); John Day Fossil Beds National Monument (Oregon); and Yukon–Charley Rivers National Preserve (Alaska). National Park Service fossil collections are maintained in museum institutions throughout the United States and are frequently featured in fossil exhibits and educational displays. The Smithsonian National Museum of Natural History maintains expansive collections of fossils from the national parks and serves as the principal repository for many of the national park holotype specimens.

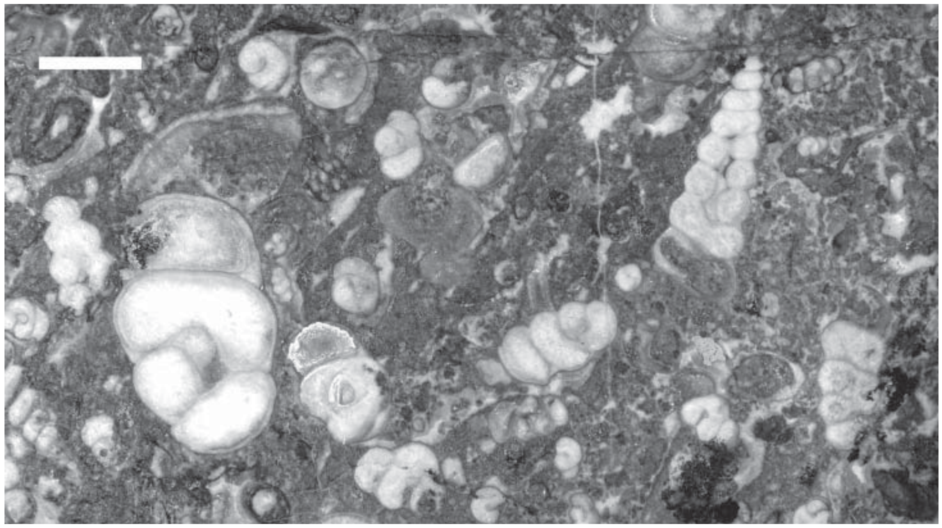
The rich fossil heritage of the National Park System also contributes scientifically to our knowledge of past climate changes, ancient environmental conditions, evolution, shifts in paleobiodiversity, and biogeographic distribution of modern plants and animals. For example, why did the bison survive the megafaunal extinctions in North America at the end of the last Ice Age while the mammoth, sloth, camel, horse, saber-toothed cat, and other animals did not? Careful analysis of fossils preserved in sequences of rocks from the fossil parks and other areas around the world often yields useful information to construct complex and fascinating stories of change over time. To the paleontologist, the dynamic history of Earth, along with changes in climate and sea level, is illustrated by patterns in the fossil record—sometimes revealing migration, sometimes adaptation, and sometimes extinction as outcomes.

National parks also provide excellent opportunities for public education related to fossils. For example, many parks enable visitors to encounter fossils in a natural state and in a geologic context—a markedly different experience from viewing fossils on display in a museum. In 2010, a seven-year-old girl on vacation from Georgia discovered an important saber-toothed cat skull while participating in a Junior Paleontologist program at Badlands National Park (South Dakota). This discovery made national headlines and the skull is now the centerpiece of a new fossil site and preparation laboratory, where visitors to Badlands can watch paleontological fieldwork in action. Also in 2010, the National Park Service was instrumental in the establishment of "National Fossil Day" as a nationwide partnership to promote the scientific and educational values of fossils.

As nonrenewable resources, fossils require specific management strategies to enhance their preservation. Frequently, fossils are documented and maintained in the rocks in which they are preserved, a condition referred to as "in situ." When fossils are maintained in situ at a park, periodic monitoring of these resources is recommended. Just as biological inventories preceded the establishment of resource monitoring programs in national parks over the last 15–20 years, the paleontological inventories of the last decade are giving rise to fossil monitoring in some national parks. In 2009, Glen Canyon National Recreation Area (Utah and Arizona) was selected as the prototype park for paleontological resource monitoring. Hundreds of dinosaur tracks documented along the shores of Lake Powell are intermittently submerged as the lake level fluctuates. A small team of paleontologists collaborated to develop a paleontological resource monitoring plan for the park. Through their effort, the park staff is able to assess the stability of in situ fossils, determine rates of change of fossil sites, and better evaluate both natural and human-related impacts on fossils. Monitoring activities since 2009 not only have documented loss of fossils along the shores of Lake Powell, but also have led to the discovery and documentation of recently exposed fossils (fig. 3, next page).

Although the NPS "paleoblitz" has taken a decade to complete, this period is a mere moment from a geologic time perspective. The data gathered through the baseline paleontological resource inventories are

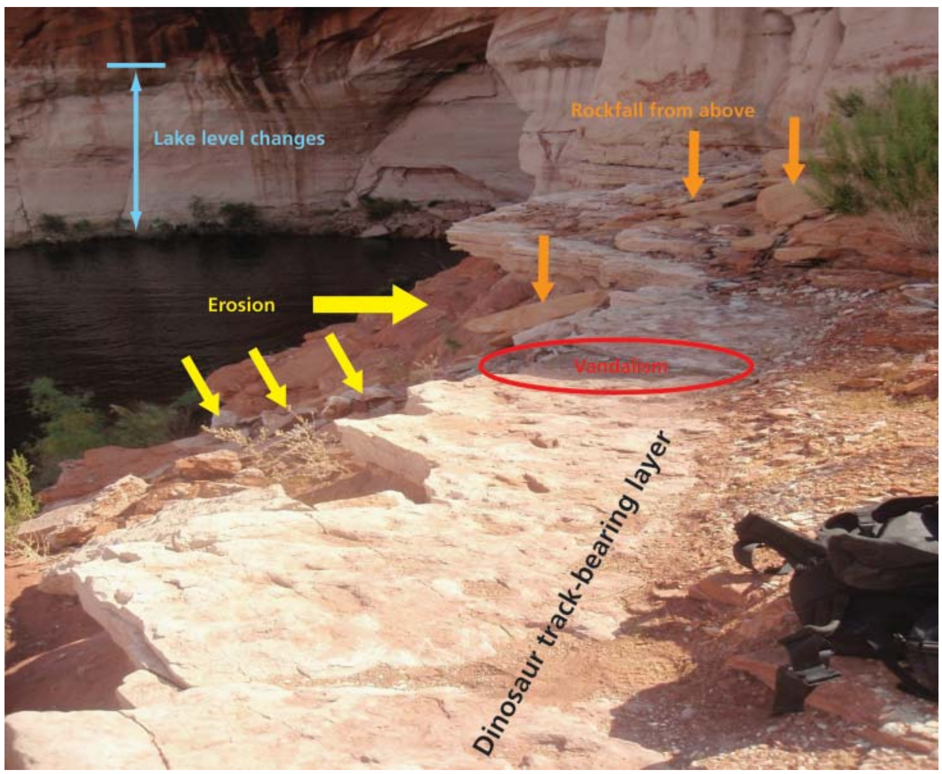
Figure 2 (right). Marine invertebrate fossils from Glacier Bay National Park and Preserve provide clues to the geologic history of Alaska.



COURTESY OF ROBERT BLODGETT

helping scientists make exciting new discoveries about the history of life, sometimes answering questions and in other cases generating new ones. The inventories have helped to increase the awareness of park managers and visitors alike as to how paleontological resources are linked to park environments today and have imparted a more holistic view of natural resource management in the national parks. The composition of park ecosystems has been shaped by, and is essentially the sum total of, the geologic, biologic, and climatic events of the past and present. Paleontology provides temporal perspectives on and other insights into biological resources, ecosystem management, and even climate change that may not be available from other fields of study.

The next step for fossil resource management in national parks is the completion of a comprehensive database of the inventory data. The NPS Geologic Resources Division is collaborating with the NPS Resource Information Services Division to develop the database of fossil resource information primarily for use by NPS parks, regions, networks, and other offices. Over the next year the database will be finalized and populated. A variety of Web-based materials will also be developed and made available outside of the National Park Service. Access to this compilation of the vast information gleaned from the paleontological inventories will be a critical tool to better facilitate science-based management, protection, interpretation, and research of NPS paleontological resources. Ultimately the legacy of the paleontological inventory will be an enhanced ability to share the meaning and wonder of fossils preserved and discovered in our national parks.



NPS PHOTO

Figure 3. With a diversity of fossil resources and resource management issues, Glen Canyon National Recreation Area (Utah and Arizona) was selected as a prototype park for paleontological resource monitoring. The dinosaur trackway shown here is affected by lake level changes, erosion, rockfall, and vandalism.

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Notes from Abroad

International workshop on conservation and management of Taroko National Park, Taiwan

Article and photos by Deanna Greco

TAROKO NATIONAL PARK IS A RUGGED mountain landscape in central Taiwan that was established in November 1986 as this country's first national park (fig. 1). This beautiful area features a deep, scenic gorge that is very popular as a tourist destination. Tectonic activity, coupled with the local geology and climatic variables such as typhoons, has produced an environment in the gorge that is extremely dynamic. Thus the natural processes of landslides and rockfalls have collided with the social values and human uses of the area. Millions of people come to Taroko annually for its scenic beauty and recreational opportunities, and the multitude of landslides and falling rocks have resulted in safety concerns for visitors.

With Taroko's 25th anniversary approaching in 2011, the park enlisted the support of 20 experts from around the world to study management issues relating to geohazards and conflicts between recreational uses and landscape conservation. Specifically, Taiwan Parks requested the assistance of the U.S. National Park Service (NPS) to investigate geologic conditions in the park, make recommendations for improving visitor safety, and provide guidance on geomorphic restoration. In June 2009 I was contacted by the NPS Office of International Affairs to see about my interest and availability for this assignment. At the time I was employed as a geologist in the Geologic Resources Division and, because I had worked in a number of U.S. national parks on the

Figure 1. Taroko National Park, Taiwan.

very issues that the Taiwanese were seeking assistance with, they invited me to participate. They also enlisted the help of another NPS employee, Mike Martin, a hydrologist with the Water Resources Division.

Mike and I flew to Los Angeles in October and then on to Taipai, Taiwan. We were greeted by our Taiwanese contacts and interpreters and whisked away to Taroko National Park. There we met up with a team of experts from Australia, China, and the United States, as well as a range of experts from Taiwan. Over a span of 20 days, I participated in a series of field site visits, seminars, workshops, and group discussions designed to elicit international perspectives on the management, planning, administration, and restoration of Taroko National Park.

Taroko's geologic setting and the challenges it presents

Around 4 million years ago, predominant deposits of marble along with strata of gneiss and schist began rising out of the ocean when the Eurasian tectonic plate collided with the Philippine plate. As what would become the Central Mountain Range of Taiwan uplifted, the Liwu River eroded into the rock, gradually creating a deep gorge. Because marble is hard and does not erode easily the process resulted in the near-vertical-walled valley known today as Taroko Gorge. The first 12 miles (19 km) of Taiwan's Cross-Island Highway follow this 2,000-foot-deep gorge. The road is heavily used for transportation and also serves as the route for one of the nation's premier tourist attractions. The natural hazards associated with this section of road are found around a series of tunnels and the adjacent gorge walls.

Subjected to frequent seismic activity, the rock comprising the gorge walls is highly deformed and prone to failure. That the area has a tendency to get annual typhoons that can average more than 3 feet (0.9 m) of rainfall within a short duration presents no surprise that the gorge undergoes a cycle of severe geomorphic responses. The heavy rainfall initiates rockfalls and landslides and leads to widespread flooding, and cascading water spills onto the roadway from the adjacent cliffs. As a result, damage to vehicles and infrastructure is very common.

Of more serious concern is the not uncommon occurrence of injuries and fatalities from rockfall. Managers have attempted engineering solutions and awareness programs to mitigate the hazard. The current safety measures, including providing visitors with hard hats, have not solved the problem. In the year prior to our visit, three rockfall events resulted in injuries to visitors. In 2005, rockfall killed one and wounded 10. Approximately three months after our trip, a Chinese tourist was killed by a falling rock while boarding a tourist bus at the Tunnel of Nine Turns. Local officials were obviously concerned for the health and safety of park visitors, but added that reports of deaths caused by falling rocks would result in enormous damage to the reputation of Taiwanese tourism.

Field trips, meetings, and individual assignments

The first week of the trip comprised mostly meetings. Team members made presentations on a variety of topics, ranging from architectural features of park buildings and geologic hazards to the development of recreational opportunities such as founding of a mountaineering school to be hosted by the park. Intermingled between the presentations were field excursions, the majority of which consisted of an entourage of 10–15 people of various abilities, attire, and knowledge of the outdoors. Once my Taiwanese counterparts were convinced that I could handle myself in the backcountry, they sent me out with two of the park's rangers. They requested that I look at an aboriginal trail that was being considered for upgrade and hiking use and wanted my opinion and recommendations based on how trails are developed in U.S. national parks. The assignment turned out to be a challenge, requiring a combination of bushwhacking through jungle vegetation, rappelling down short steep cliffs, and hand-over-hand roped climbing to make our exit. Compared with earlier field trips with the large groups, this was a welcome change, as I enjoyed being with a small group of park staff. Interestingly, in terms of skill and personality the Taiwanese rangers were very much akin to NPS backcountry rangers.

We were shadowed by a documentary film crew for the duration of our time in Taiwan. At first this was

Figure 2 (right). Hard hats and rockfall reduction canopy on Tunnel of Nine Turns Trail.

Figure 3 (far right). Large fracture in pillar at west entrance of Tunnel of Nine Turns.

intimidating, but after a few days I forgot about the cameras, got to know the crew, and made friends with them. We often worked 12- to 14-hour days. Between jet lag, language barriers, and the sheer volume of work, the assignment was very stressful at times. For the purposes of drafting a report and recommendations we decided to distribute the workload, concentrating on the most pressing issues and making assignments based on areas of expertise. I was tasked with assessing three different areas of the park: Tunnel of Nine Turns, Swallow Grotto, and quarry sites.

Spectacular scenery coupled with big problems: The Tunnel of Nine Turns (Chiucyudong Trail)

The Chiucyudong Trail is part of the original Cross-Island Highway constructed from 1956 to 1960. To alleviate traffic concerns involving pedestrians and vehicles, a new tunnel was constructed in 1996. After completion, the Tunnel of Nine Turns was converted to pedestrian-only use. This enables visitors to enjoy the spectacular beauty of this part of the gorge without having to interact with automobiles and buses (fig. 2). This 1-mile trail is one of the most frequently visited sites in the park and takes visitors through what many consider to be the most spectacular scenery in Taroko Gorge.

On either end of the tunnel, a small parking lot serves as a drop-off/pickup area for shuttling visitors to and from the site. While vehicular traffic is not an issue on the tunnel trail, both ends of the tunnel are very congested and this problem only worsens during holidays. Tour buses are often lined up to drop off or pick up walkers. The buses waiting to pick up visitors on the east side of the tunnel often block an entire lane of traffic through the tunnel on the Cross-Island Highway, slowing traffic and increasing vehicular exposure to rockfall.

During inspection of the Tunnel of Nine Turns we noticed faults, joints, and folds in the marble, indicating that the rock is inherently unstable. The rock in the tunnel is highly fractured, and continued rock failures are noticeable from the scattered rock fragments on the trail surface. We also witnessed seepage, which can be an indicator of weak points in the rock. At the western bus drop-off location, a large fracture in the asphalt shows potential for slope failure. Additionally, a big fracture in the support pillar at the beginning of the tunnel shows signs of imminent collapse (fig. 3).

Past rockfalls are also evident in the numerous pit marks on the asphalt trail surface, the dented trail handrails, and the boulders scattered on the slope below the tunnel. Large rockfalls occur less frequently and can often be attributed to typhoon and earthquake activity. Often these large rockfall events are acknowledged only when they impact trails or other park facilities. Many more small rockfalls occur and usually go unnoticed.

Since the Tunnel of Nine Turns is one of the most popular destinations in the gorge, the massive volume of pedestrian traffic on the trail increases

Figure 4. Rock bolts and metal netting at Swallow Grotto west entrance.

the likelihood and potential for injuries and even fatalities. The park has installed several protective canopies, and a policy of encouraging hard hat use by visitors provides some defense against small rockfall–related injuries (see fig. 2). However, for any rock larger than a golf ball, these measures only marginally provide any real protection and could actually be a detriment since visitors may develop a false sense of safety and tend to pay less attention to their surroundings.

The hazards continue: Swallow Grotto (Yanzihkou)

The Swallow Grotto Trail runs about 0.3 mile (0.5 km) to its end at the Jinheng Bridge and is the next logical stop for visitors after the Tunnel of Nine Turns. It affords views above the Liwu River and hot springs scattered along the lower parts of the cliff walls. The trail is separated from the highway by a concrete divider and a two-lane tunnel that allows visitors to walk the trail without dealing with traffic. This area too is very congested with buses lined up waiting to drop off and pick up visitors.

Though the hazard is less severe than that of the Tunnel of Nine Turns, the geologic setting of this trail is quite similar, with exposed joints and folds in the rock and fractured marble. Rocks have pitted and marred the asphalt surface here. The park has responded with standard engineering solutions, but unfortunately these have been ineffective. For example, the metal netting installed with rock bolts at the entrance of the trail is insufficient to prevent rockfall from landing on the roadway (fig. 4).

Restoration potential with hiking opportunities: The quarries

The last area we investigated was a large quarry complex developed by an Australian company for concrete aggregate (fig. 5). The road leading up to the quarry follows a steep mountain creek and has developed gullies about a foot deep. According to park staff the creek was much smaller before the quarry was developed. The increased runoff caused by the road and the quarry has amplified the rate of erosion, down-cutting and widening the creek. The road also has acted as a pathway for nonnative plant infestations in the watershed, with numerous species growing along this corridor.

The quarry walls are terraced and average approximately 30 feet tall, with the upper wall reaching a height of about 50 feet. These walls are fairly stable with the exception of those on the northern side, which are highly fractured, weathered, and most prone to failure. The lower quarry area was once the main processing site. Piles of crushed rock are still present and this site bisects the upper drainage of the creek. The steep slopes have led to massive erosion features emerging from the lower processing area down the hillside and onto the old roadbed.

Figure 5. High walls of the quarry, looking to the east.

Engineering or simplified solutions to complex problems

We consolidated our recommendations for all three sites in a report of findings and suggestions for mitigation and restoration. For the Tunnel of the Nine Turns and Swallow Grotto, both of which have very similar hazards, the prudent approach outside of developing costly engineering solutions would be to reduce the number of visitors using the trails. The sheer volume of visitation, coupled with the rockfall hazard, presents odds that injuries and fatalities will continue to be an issue for the park. Additional efforts at implementing a better transportation system, conducting educational outreach on geologic hazards and the need for restricted access, along with a more controlled trail experience, would help decrease the hazard.

Despite the multitude of afflictions owing to Mother Nature at Taroko National Park, the quarry is relatively safe from a geologic perspective. The site has great restoration potential; however, full restoration to natural contours would be very expensive. Additionally, actions required for full restoration would denude the site of its current vegetation and could potentially increase sediment yields in the watershed until large woody vegetation could stabilize the area. Though we provided a range of alternatives, the simplest solution would be the installation of erosion control measures such as stair-step structures and rolling dips at the old processing site to help reduce surface runoff and increase sediment capture.

The simplest solution also presents an opportunity: convert the old quarry road into a loop trail and provide a picnic area. The lower quarry area provides spectacular views of the Pacific Ocean. Making the old road into a trail and connecting it to the Cingshui Cliffs Trail would produce a hike with outstanding vistas. From there, a trail that continued to the top of the ridge would offer a challenging activity and rewarding view not only of the Pacific but also of the Cingshui Cliffs, and provide for a hiking loop. Additionally, trail development could help to spread out visitor use, away from congested areas of the park.

Conclusions from "Great Crayon"

During the trip my Taiwanese hosts asked me to give a presentation on management planning for the "Great Crayon." It took me a few days to realize that they had used language translation software that converted "Grand Canyon" into "Great Crayon." In the process of researching the presentation, I came across a UNESCO World Heritage Site document naming Taroko Gorge for consideration as a worldwide natural protected area. This information compared Taroko Gorge to the Grand Canyon.

Ironically, less than a year after traveling to Taiwan I took a new position at Grand Canyon National Park as the Physical Science Program manager. Every day I now face challenges similar to those of park managers at Taiwan's oldest national park, namely difficult management decisions related to the area's geology and the potential for erosion. Both of these parks receive almost 5 million visitors per year, and because the park environments are so dynamic, altering human behavior is one of the few management options available. By applying best management practices that include restricting access to the most hazardous areas, improving transportation systems, and offering alternative hiking opportunities, managers can achieve a safer environment for park visitors. Often our best approach is to understand and respect the natural processes at work and adapt management as new techniques and information come to light.

About the author

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PS

In Focus

Science partnerships at Golden Gate National Recreation Area

Articles by Michelle O'Herron

WHILE NOT A PANACEA, PARTNERSHIPS SHOULD NOT BE underestimated as a powerful means to expand science in the parks. We describe three successful partnership-based, park science programs: the Golden Gate National Parks Conservancy's Golden Gate Raptor Observatory, Native Plant Nurseries, and Park Stewardship Program, which also receive support from the Presidio Trust. Combined, these programs illustrate how carefully crafted and effectively run partnerships can help expand the depth and breadth of park science. While these programs are all a part of the Golden Gate National Parks Conservancy—the nonprofit partner of the Golden Gate National Recreation Area—the partnerships described here are not just among organizations, but also between the park and the cadre of committed volunteers who dedicated nearly 514,000 hours to the park in 2011 alone. These volunteers constitute a community of park supporters and advocates, ranging from high school students to PhD scientists, whose impact extends far beyond park boundaries.

Key words

California red-legged frogs, citizen science, endangered species, Golden Gate, hawks, mission blue butterflies, native plants, nurseries, raptors, San Bruno elfin butterflies, volunteers

Dedication

These articles are dedicated to the memory of Brian O'Neill, former general superintendent of Golden Gate National Recreation Area. Brian was an enthusiastic and adamant supporter of NPS volunteerism and a champion of community-driven conservation in the parks.

About the author

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ALLEN FISH, GOLDEN GATE RAPTOR OBSERVATORY

Veteran hawk counter Bill James surveys the eastern skies at Golden Gate National Recreation Area for migrating raptors.

Counting hawks and winning hearts

A quarter century of citizen science in the Golden Gate National Recreation Area

NPS/ JESSICA WEINBERG

WALTER KITUNDU, GOLDEN GATE RAPTOR OBSERVATORY VOLUNTEER

NPS/ JESSICA WEINBERG

Left to right: GGRO interns Robyn Smith and Brittney Wendell teach a junior high school class how to identify raptors in flight. Misha Semenov sets a banded merlin back on its migration path. Bander Ari La Porte deftly extracts a young sharp-shinned hawk from a vertical net.

By Michelle O'Herron

IT IS ALMOST ALWAYS WINDY ON HAWK HILL. AND IT IS also often foggy. Really, really foggy.

But when it clears, you never know what you might see. These sunny moments of possibility—and the raptors that may choose that particular window of celestial clarity to go soaring past—sustain the more than 300 volunteer hawk watchers and banders of the Golden Gate Raptor Observatory (GGRO).

The GGRO is part of the Golden Gate National Parks Conservancy, the nonprofit partner of the Golden Gate National Recreation Area (GGNRA) in California. Now in its 28th year, the GGRO has only three full-time staff members, and so relies heavily on volunteers to meet its mission to study migrating birds of prey along the Pacific coast and to promote public awareness of the state of raptor populations.

The GGRO is now regarded as an international model of community engagement and citizen science. That's a long way from its humble beginnings in 1983 when National Park Service (NPS) natural resource specialist Judd Howell, longtime bander and falconer Will Shor, and a handful of volunteers trapped and banded enough hawks to show that Hawk Hill, a prominent point in the Marin Headlands just north of the Golden Gate Bridge, would be a good place for a long-term fall raptor migration study site.

Two years later, with a grant from the San Francisco Foundation, Judd challenged the volunteers to make the program their own and hired Allen Fish as director. They began their annual fall hawk count the following year. By 1991, the scientific potential of the GGRO was such that research director Buzz Hull was hired to help advance data collection and management, volunteer coordination, and training. The next year, Allen and Buzz launched a docent program to accommodate the skyrocketing public interest in the migration.

Combined, these efforts have contributed more than 25 years' worth of data on raptor health, numbers, and migration, as well as public outreach that the Golden Gate National Recreation Area would not otherwise have been able to afford. However, the initial decision to engage volunteers for this program was not entirely financial; Judd and Will also sought to create a constituency of informed and inspired supporters for the park, for citizen science, and for raptors.

It seems to have worked.

The citizen science of the GGRO

Counting

From mid-August to December, teams of volunteer hawk watchers spot and identify 19 species of raptors. Each year brings between 20,000 and 40,000 raptor sightings, for a grand total of 634,215 since the program began. These counts capture information about species, age, sex, color morph, time, date, and weather that helps elucidate trends and patterns in hawk populations over time. These trends, in turn, are indicators of the health of the broader ecosystems in which the raptors live.

In 1989, GGRO hawk watchers created the Quadrant System—a consistent and systematic method that allows data from different years to be compared. Hawk counters standing within clear earshot of each other monitor a particular cardinal direction of the sky for an hour at a time. They call out information about the species and age of raptors spotted in their quadrant in as much detail as possible to a data recorder. The raptors are then "passed" to the hawk watcher in the next quadrant, who responds with a loud verbal confirmation if he or she too sees the same bird, thus minimizing double counting.

In the early years the GGRO struggled to find a methodology that would yield such reliable results. The technique they started with—basically just to look up and count—generated almost as many questions as answers. For example, how far away do you count a raptor? Should you wait until it gets closer? What if it never does? What if the Cooper's hawk you just counted flew behind a hill, and then a few minutes later a Cooper's hawk comes flying out from behind the other side? How do you know you haven't counted that hawk before?

Allen and the hawk watchers wrestled with this particular question until 1988, when they finally came upon the answer: you can't. However, they realized counting individual birds was not really what they were doing. They were actually measuring the rate of visible raptor activity in the area. Based on this new understanding they established guidelines about when to count a raptor, and set up their new methodology.

Certain aspects of this methodology have since been adopted elsewhere, like counting raptor sightings as opposed to individual birds, and focusing on raptors per hour rather than absolute numbers. However, few have managed to replicate the level of volunteer engagement seen at the Golden Gate Raptor Observatory.

Banding

Since 1983, specially trained GGRO volunteers have banded more than 33,000 birds of prey. They trap, band, measure, and then release hawks, working quickly to get as much information as possible while minimizing stress to the bird. Because of the raptors' migratory nature, samples taken at this one site provide data from much broader populations.

More than 1,100 bands have been recovered, some from as far away as British Columbia and southern Baja California. Each band has a unique identification number and a phone number for the U.S. Bird Banding Laboratory. The lab sends periodic band recovery reports to GGRO, whose staff and volunteers then follow up with the person who located the bird to learn more about where it was found and under what circumstances. Unfortunately, most recoveries come from birds that are injured, sick, or dead, but the information they provide helps answer questions about the geographical ranges of Bay Area raptor populations, and offers insights into the causes of injuries and deaths.

None of the 19 monitored raptor species is clearly declining, although American kestrel numbers (a species of concern in the Northeast) have dipped during the last five years.

How are these data used?

Research

Research director Buzz Hull works closely with volunteers and researchers at local universities and agencies to collect, analyze, and synthesize GGRO data. Monitoring and research results are also used by a variety of state, federal, and private wildlife agencies. As of 2011, the GGRO had produced 82 scientific articles and presentations, a third of which had a volunteer as primary author.

Examples of research projects the GGRO has cooperated on:

- Population genetic studies of red-tailed, red-shouldered, and sharp-shinned hawks
- Using genetic analysis to verify sexes of red-tailed, red-shouldered, and Cooper's hawks based on measurements
- Documentation of molt cycles in raptor species
- Size relationships and human misidentification of forest hawks
- Raptor disease research on avian malaria, West Nile virus, and avian influenza

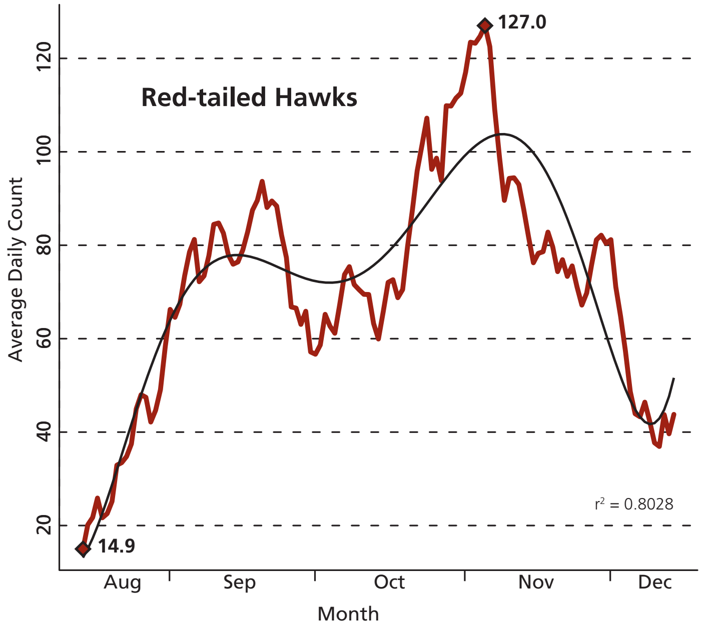

Figure 1. Red-tailed hawks move in two waves. One innovative GGRO analysis incorporated hawk counts, banding, radiotracking, and genetics to study differences between the red-tailed hawks of the two peaks of fall activity seen here. It was determined that the September peak is primarily central California redtails, and the November peak contains a larger proportion of the Great Basin genetic type. Also, more of the early-peak hawks move south for the winter than do the later-peak hawks. (Hull, J. M., et al. 2009. Differential migration between discrete populations of Red-tailed Hawks. Auk 126:389–396.)

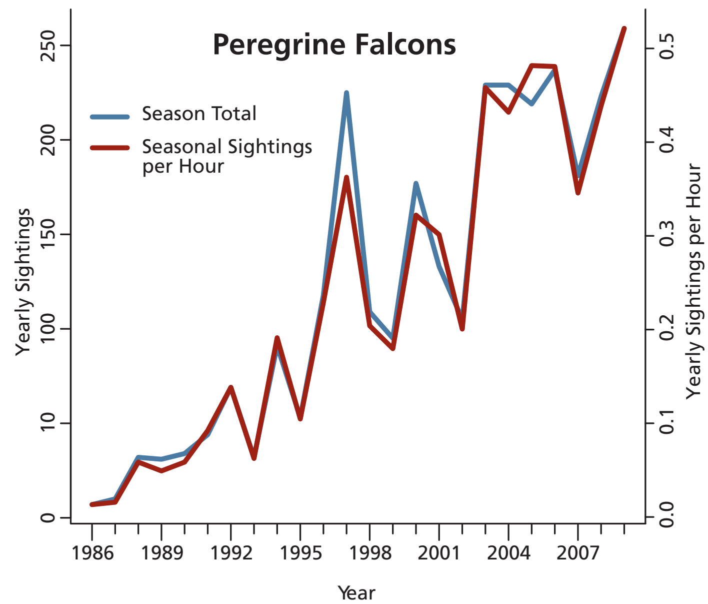

Figure 2. Peregrine falcons rise tenfold at the Golden Gate, reflecting the population trend for nesting peregrines in the Pacific states. In spite of numerous local biases such as wind, visibility, and observer ability, raptor migration counts have been shown to capture population trends if made consistently over a long period. By the late 2000s, it was clear that GGRO counts had tracked the known post-DDT increase in peregrines.

Illuminating trends

Only a long-term monitoring program such as this can provide enough raptor migration data to allow trends to emerge. After a quarter of a century, it appears that each raptor species has a unique migration profile with distinct peaks and troughs (fig. 1). Data have also reflected at least one known trend: the rise in peregrine falcon numbers in California (fig. 2). Merlins and red-shouldered hawks have also increased over the past 25 years. None of the 19 monitored raptor species is clearly declining, although American kestrel numbers (a species of concern in the Northeast) have dipped during the last five years.

Costs and benefits

Time commitment and cost

According to Allen, it's a mistake to think of volunteers as cheap labor. "Quite the opposite," he says "Volunteers are costly, but what you are buying is community engagement, which in turn buys you an intelligent, passionate, local constituency." Indeed, GGRO staff spends much of its time managing volunteer programs, but because volunteer day leaders also run their own teams, this staff time investment is multiplied many times over. The park provides office and storage space, a vehicle, overhead, and other operating costs, and in return gets the equivalent of roughly 22 full-time employees' time.

Public outreach

In addition to research publications, the GGRO has helped the park meet its goals of communicating science to the public through local media coverage as well as newsletters, brochures, Web sites, docent talks, banding demonstrations, and the continuous recruitment and education of citizen scientists.

Volunteerism and passion for park resources

Since 1983, GGRO volunteers have contributed nearly 1 million hours of raptor counting and banding, as well as data entry and docent programs that the GGNRA has received for free. They have also generated new methods and approaches for studying birds of prey.

While helping with wildlife research in a stunning natural setting has its appeal, the reality is that the weather on Hawk Hill can be harsh and changeable and the time commitment is significant. Volunteers also have to be able to concentrate on raptor-shaped specks in the sky while simultaneously listening to the shouts of other counters—no small feat when raptors are ripping by at a rate of one per minute during peak migration. When things are slow, it can be hours on end of waiting in the cold for even a glimpse of a few hawks.

Yet hundreds of people come back for more every year. Ron Berg is one of them. He describes why as he recalls seeing two peregrine falcons pirouetting in front of the Golden Gate Bridge. "They swooped up and dove down, frolicking in the breeze for at least 30 minutes. Then they were gone. When I was a boy, I hoped in my lifetime to someday spot a peregrine. Never in my wildest imagining did I ever think I'd see such a thing as this, but you never know at Hawk Hill."

These are the passionate park stewards and raptor advocates Judd and Will were hoping for.

However, despite their best intentions, even the keenest volunteers may not be the best scientists. The GGRO has instituted multiple levels of quality control to ensure that the data being collected are reliable and accurate.

Oversight and quality control

Supervision

Highly trained volunteers called day leaders run volunteer teams, reducing the burden on GGRO staff. Less experienced volunteers are partnered with more experienced counterparts. Banding teams also have site leaders, who are in charge of a banding blind on a particular day. Site leaders and day leaders are in turn closely supervised by Buzz and Allen through special meetings and trainings. Finally, lengthy "Experiential Checklists" track what new volunteers have mastered in the field and what they have not yet encountered.

Training

Rigorous trainings prepare both novice and experienced volunteers for the fall migration. Hawk-watch apprentices receive exhaustive training manuals and attend classes on raptor identification, data recording, team communication, scanning for hawks, and equipment use. Occasional live-release identification studies of banded raptors give volunteers extra practice, and also provide GGRO with a better estimate of identification error rates. Banders go through additional intensive hands-on trainings, and site leaders have a training and certification process that includes field and written evaluations.

Limits on what a volunteer can do

Only experienced hawk watchers record data, and data are double-checked as they are collected, again during data entry, and yet again afterward. Because they are handling live animals, banders have even stricter limits. Banding apprentices are constantly supervised, and their methods and data are double-checked until everyone is comfortable with their skill level.

Is it worth it?

The consensus is that the benefits of this citizen science program have far outweighed the costs to the park. GGNRA chief of Natural Resources Daphne Hatch agrees: "What the GGRO has provided the park in terms of data and research has been impressive, but their ability to channel the energy of people who are dedicated and passionate about wildlife in the park is truly priceless."

For more information about GGRO, please see http://www.parksconservancy.org/programs/ggro/.

Growing good science and strong partnerships through park native plant nurseries

By Michelle O'Herron

THE MORNING FOG IS STILL THICK THROUGHOUT THE Presidio of San Francisco, but Michele Laskowski is already busily setting up her latest set of germination experiments and preparing for the day's incoming volunteer crew. Michele is just one of the many dedicated staff members, interns, and volunteers who work at the six native plant nurseries that grow plants for restoration operating as a partnership of the Golden Gate National Recreation Area, its partner organization the Golden Gate National Parks Conservancy, and the Presidio Trust.

What these six small nurseries have been able to accomplish for the park is truly astonishing. From 1999 to 2011 they grew 1.6 million plants, which, if stacked end to end, would reach past the International Space Station. In 2012, they will grow approximately 230,000 plants for 53 different park restoration projects using funding from park project budgets.[1]

Though these accomplishments are impressive, the nurseries are about more than just growing plants; they are also about transforming park habitats and building a supportive community. Through the nurseries and their 2,000 volunteers, seeds become plants, and degraded natural areas are renewed. But big restoration projects can also mean big changes. As park managers well know, not everyone likes change, especially to places that they love. By encouraging direct public participation in the restoration process, the nursery volunteer program has helped create a community of people who have a better understanding of changes in the park and a stronger personal connection to restored areas.

Each year, nursery staff and volunteers painstakingly collect more than 1 million seeds from across the park's 80,600 acres (32,643 ha) and mind-boggling array of different habitats and microclimates. To preserve the unique genetic mix that has evolved at each site, they collect seeds from the same watershed where they will be planted. Comprehensive seed collection guidelines help ensure that genetic diversity is maximized and wild seed stocks are not depleted. Other nursery protocols address how to avoid artificial selection for particular traits; properly germinate, transplant, and care for seeds and propagules; and follow National Park Service policies.

MICHELE LASKOWSKI, PRESIDIO NATIVE PLANT NURSERY

Trays of native plants line the nursery in this 2008 alternative germination media study.

The nurseries have cultivated an incredible 377 different native plants and, despite the extra effort required to grow so many different species, Michele believes it was worth it. "Having a broader restoration palette allows the park to create more natural and functional habitats," she explains. "We're showing how you can make that work." But, she says, propagation methods for many native plants are either not recorded or are simply unknown. To try to bridge this information gap, the nurseries have undertaken research projects to create and document successful cultivation protocols,[2] and also to increase their sustainability. These include:

1. Seed treatments

Experiments on many difficult-to-grow species have attempted to mimic the natural processes and conditions the seed would be exposed to in the wild. Treatments, including exposure to moist or dry heat, mechanical scarification, and natural acids (e.g., strong coffee or lime juice), and extended exposure to moist, cold

1 The cost of running all six nurseries is about $970,000 per year, but nursery director Betty Young estimates that most parks could meet their planting needs (about 10,000 plants per year) with a part-time nursery manager and about $50,000. A detailed overview of how to determine nursery costs and needs is available in "Planning and Building a Native Plant Restoration Container Nursery" at http://www.sfnps.org/nurseries/chapter_2.

2 Successful propagation methodologies are documented on Species Information Sheets, many of which are available at www.nativeplantnetwork.org.

By encouraging direct public participation in the restoration process, the nursery volunteer program has helped create a community of people who have a better understanding of changes in the park and a stronger personal connection to restored areas.


JACKIE BERGQUIST, PRESIDIO NATIVE PLANT NURSERY

Electrical conductivity monitoring is done on native sticky monkey-flower (*Mimulus aurantiacus*) during a 2009 fertilizer study.


MICHELE LASKOWSKI, PRESIDIO NATIVE PLANT NURSERY

A variety of organic fertilizers were tested on native sticky monkey-flower (*Mimulus aurantiacus*) in this 2008 trial.


MICHELE LASKOWSKI, PRESIDIO NATIVE PLANT NURSERY

Molly McClary measures out a mixture for a 2011 alternative germination media experiment.

conditions have been methodically tested to see which improve germination rates.

2. Peat-free germination media
Many germination mixes include peat moss as an ingredient, but because peat stocks are being depleted faster than they can regrow, the nurseries are experimenting with more sustainable (and more local) alternatives like rice hulls, worm castings, and sifted compost.

3. Organic fertilizers
Seven organic and one chemical fertilizer were compared—as was a range of frequencies for applying liquid and pelleted fertilizers—by measuring the plant growth factors and overall biomass production in a common native plant.

4. Water use
A number of experiments have been done to find the most efficient sprinklers and watering regimes.

Learn more about the Golden Gate National Recreation Area native plant nurseries at http://www.parksconservancy.org/programs/nurseries/ and http://www.sfnps.org/nurseries.


MICHELE LASKOWSKI, PRESIDIO NATIVE PLANT NURSERY

Nursery staff Chelsea Dicksion and Molly McClary sow Mount Tamalpais manzanita seeds as part of a germination experiment.

PS

Teaming up to track down endangered species

By Michelle O'Herron

Figure 1. An endangered male mission blue butterfly nectars on a newly blossomed native yarrow plant (*Achillea millefolium*).

AS THE LONGTIME PARTNER OF THE GOLDEN GATE National Recreation Area, the Golden Gate National Parks Conservancy's Park Stewardship Program has contributed tens of thousands of hours of staff and volunteer time to the park. In 2011 alone, they planted 39,323 plants, managed 188 acres (76 ha) of invasive species, and engaged 7,045 volunteers who gave 61,734 hours.

Impressive though these numbers are, there is another side to the Park Stewardship Program that few people know about: its contributions to park science. Data from the program's long-term monitoring of endangered mission blue (*Icaricia icariodes missionensis*) and San Bruno elfin (*Callophrys mossii bayensis*) butterflies and threatened California red-legged frogs (*Rana daytonii*) have been used to inform park management decisions and assess the success of restoration projects aimed at helping these species.

Mission blue butterflies

Each spring, National Park Service (NPS) and Golden Gate National Parks Conservancy biologists and trained interns walk established transects through the park's scrub-laced grasslands looking for mission blue butterflies at some of the few remaining places where this species can still be found (fig. 1). Seventeen years of mission blue monitoring in the Marin Headlands north of San Francisco, and at Milagra Ridge to the south of the city, have revealed wide fluctuations in butterfly numbers, but an overall decreasing trend at both sites.

Program staff also maps mission blue habitat and tracks outbreaks of a fungal pathogen that, in a wet year, can decimate entire swaths of the butterflies' preferred lupine host plant. Data indicate that periodic, dramatic dips in mission blue population numbers may be related to these pathogen outbreaks.

As a result, the National Park Service and the Conservancy have begun a project to diversify single species lupine stands by interplanting two other lupine host plant species that are less susceptible to the pathogen. Future monitoring should help reveal if this provides a buffer for the butterflies during the next pathogen outbreak.

CHRISTINA CROOKER, GOLDEN GATE NATIONAL PARKS CONSERVANCY

Figure 2. An endangered San Bruno elfin caterpillar and its Pacific stonecrop host plant make a colorful pair along windy northern slopes in the Golden Gate National Recreation Area.

JOHN CAMPO, SAN FRANCISCO RECREATION AND PARKS DEPARTMENT

Figure 3. Federally threatened California red-legged frog egg masses like these are counted by NPS and Golden Gate National Parks Conservancy staff members throughout park lands.

San Bruno elfin butterflies

Widespread development and habitat loss have forced the San Bruno elfin butterfly into just a few isolated places along the San Francisco peninsula where rocky, wind-swept northern slopes support their preferred host plant, Pacific stonecrop (*Sedum divergens*) (fig. 2). Since 1999, monitoring of San Bruno elfin caterpillars on park lands by Conservancy staff and volunteers has tracked wide population fluctuations, including an apparent local extinction of the species in 2007–2009.

In 2010, relieved monitors found a handful of caterpillars, and in 2011, counts jumped to numbers never before seen at the site. It is too soon to tell if this increase signals a turning point for the San Bruno elfin or if it is merely part of a natural population cycle.

Survey results are sent to the National Park Service, the U.S. Fish and Wildlife Service, and local land managers who are keeping a close eye on this species. Photo monitoring points will help track the condition of San Bruno elfin habitat, but because the butterflies seem to be making a comeback, no further management actions are planned at this time.

California red-legged frogs

In the winter, Conservancy and NPS staff monitors trends in abundance of threatened California red-legged frogs by counting egg masses in park ponds and slow-moving waters (fig. 3). These data are used to track breeding population size over time and have been helpful in assessing the success of wetland habitat enhancement projects.

Monitoring results from the southern end of the park at Mori Point have shown that with the construction of new ponds, egg mass numbers increased from just three in 2003–2004 to 128 in 2010–2011. Egg mass data and juvenile surveys from NPS monitoring north of San Francisco also indicate that there are small breeding populations in two recently restored watersheds.

For more information contact bill_merkle@nps.gov (mission blue butterflies), ccrooker@parksconservancy.org (San Bruno elfin butterflies), or darren_fong@nps.gov (California red-legged frogs).

Research Reports

Mitigating encroachment of park experiences: Sustainable tourism in gateway communities

By Desmond Lee and Dean Reeder

Abstract

There is a misperception that the National Park Service has no or little connection to the tourism community and that what goes on outside parks can be left to gateway communities to be decided without park managers' influence. This approach can prove detrimental to both park resources and visitor experiences. Since the president issued an executive order to highlight and increase visitation to America's public lands and to enhance job growth, the urgency to engage the tourism community has been heightened. Additionally, the increased recognition of park tourism as a form of community economic stimulus presents the Service with opportunities to become more involved with decision making at the local, state, and national levels. This article presents a perspective that the relationship between parks and the tourism community is interconnected in resource management responsibilities and stewardship. In this case, resource management is expressed in socioeconomic, cultural, and ecological terms. These elements are key in the discussion of balancing tourism growth in gateway communities with their respective capacity to host visitors. Four studies reviewed here demonstrate empirical evidence suggesting a potential equilibrium of economic activity and preservation in gateway communities. Furthermore, park visitors mixing park perceptions with experiences outside parks can be detrimental to park resources. Nevertheless, tools for mitigating negative impacts of tourism are available, so that good resource management practices align with socioeconomic goals.

Key words

authenticity, economics, enjoyment, experience, incentives

Introduction

The National Park Service's obligation to balance visitor use and enjoyment of parks with resource preservation, along with the overarching need to maintain relevance with the American public, gives credence to a concept known as sustainable tourism. Holistic in nature, sustainable tourism is an approach to tourism development that fosters deliberate and strategic regard for the social, natural, and economic environments of a community (including the park). Park managers may use and encourage sustainable tourism principles to safeguard resources while enhancing the marketability of the destination's cultural and natural characteristics.

This article provides park managers with a comprehensive definition of sustainable tourism and key principles that differentiate this approach from that of unsustainable (mass) tourism. Given that park gateway communities—particularly in rural areas—increasingly look to tourism to enhance their economic potential, parks are exposed to threats: gateway communities that demonstrate unsustainable characteristics can dilute both the NPS brand and visitor experiences in parks. This justifies a mutually beneficial approach: sustainable tourism. Using sustainable tourism principles and the management and marketing tools derived from them, park managers will be better equipped to provide education and leadership to tourism partners.

Definition and principles

According to the United Nations World Tourism Organization, sustainable tourism is "tourism which leads to management of all resources in such a way that economic, social, and aesthetic needs can be fulfilled while maintaining cultural integrity, essential ecological processes, biological diversity, and life support systems." In addition, this type of development is described as a process that meets the needs of present tourism and host communities while protecting and enhancing needs in the future (Shah et al. 2002). It places great emphasis on mitigating negative impacts of tourism while maximizing positive growth, diversity, and equitable distribution of benefits among all stakeholders.

Sustainable tourism requires a multidimensional approach to cultivating equilibrium between growth and capacity. It adds incentive to preserve ecology and to increase community livability and community self-worth. Financial benefits include increases in public revenue from local products, goods, and services. Moreover, the community presents its unique character, folklore, customs, and heritage.

Contrary to a mass tourism approach, which often demonstrates minimal regard for local natural and cultural experiences, the principles of sustainable tourism require that tourism development consider factors such as the special attributes of the community; the status of current infrastructure; benefits that exceed costs; and improvements in social, ecological, and economic conditions as prerequisites to development (fig. 1). This method requires community engagement and therefore must include citizens, businesses, nonprofit organizations, and national, state, and local governments. In other words, the community becomes a partner initially and permanently in an ongoing, sustainable tourism development process.

Geotourism is a form of sustainable tourism that has been gaining traction in the National Park System, particularly in western states. Geotourism is defined as "an emerging niche market within sustainable tourism and is centered on sustaining and enhancing the geographical character of a place" (Stokes et al. 2003). In 2008 the National Park Service, along with other Department of the Interior bureaus, the USDA Forest Service, and National Geographic Society, signed an agreement to promote geotourism on federal and Indian lands.

A study conducted by the U.S. Travel Association and National Geographic Society helped to define the principles of geotourism and found that stakeholder engagement, particularly from local residents, is a valued component of its development. Specifically, a finding of the study indicated that 99% of the 3,608 respondents agreed that local people should be included in any tourism planning process; 96% felt that tourism must contribute to the integrity of the community; 95% agreed tourism must build cultural pride within a community. At the same time, 91% expressed concern that tourism could have negative impacts on a community if not implemented correctly. These findings help support an argument for the adoption of sustainable tourism principles in the National Park System.

In the context of the National Park Service (NPS), the concept of sustainable tourism and its guiding principles can be used to include gateway communities in tourism development and safeguard "NPS brand" characteristics and park experiences. The term "gateway community" can be interpreted in two ways: as communities of place and as communities of interest. Typically, both are self-defined. Communities of place are significant to parks because of their location, often contiguous with park boundaries. An example of a gateway community of place is Mariposa County and Yosemite National Park (California). Alternatively, communities of interest claim a connection to the park, such as Las Vegas (Nevada), as a gateway to Grand Canyon National Park (Arizona).

In both communities of place and communities of interest, issues may arise that demonstrate the value of embracing a sustainable tourism approach. In the case of Las Vegas, characteristics of this destination are unlike those of Grand Canyon and may contribute to a disconnect between the park and the community. Regarding gateway communities of place, which are connected to parks and used as an entry portal and for commercial services, excessive development of commercial areas may reduce visitor utility and mischaracterize the NPS brand.

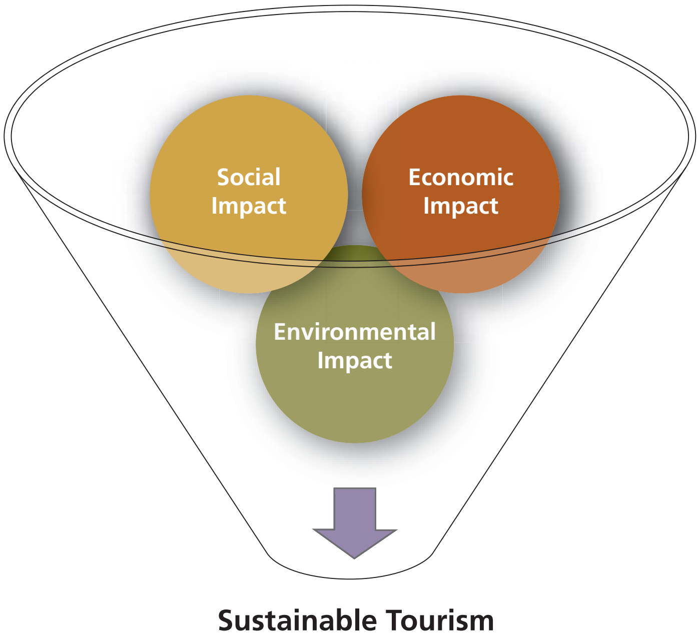

Figure 1. The illustration demonstrates the nexus among social, environmental, and economic considerations that make up sustainable tourism.

Park experience encroachment

"Over the past several decades it has become increasingly evident that parks cannot survive as 'islands,' and that activities and conditions outside the park boundaries affect the management of resources within them" (Steer and Chambers 1998). The park and neighboring communities are interdependent where the shared goal is a positive visitor experience. Negative implications of tourism development in gateway communities may negatively affect the physical attributes of parks and park experiences. In addition, mass tourism affects the NPS brand, for example loss of wildlife habitat, poor air and water quality, noise and light pollution, and visual obstructions (fig. 2, next page). Indeed, park units are effective in maintaining resources within the park, but often park managers have no specific authority over development outside park boundaries. This is a concern in that many visitors choose to stay overnight in gateway communities, pass through, and seek services within them, suggesting a visitor's overall satisfaction is contingent on combined park and gateway community experiences.

According to the NPS 2008–2009 Comprehensive Survey of the American Public (Taylor et al. 2010), 57% of park visitors stay overnight during a park visit, of whom 78% seek accommodations outside of park units. These numbers indicate a substantial segment of visitors potentially mixing perceptions of park experiences with those of the gateway communities to create an overall opinion of their trip experience. In addition, the survey

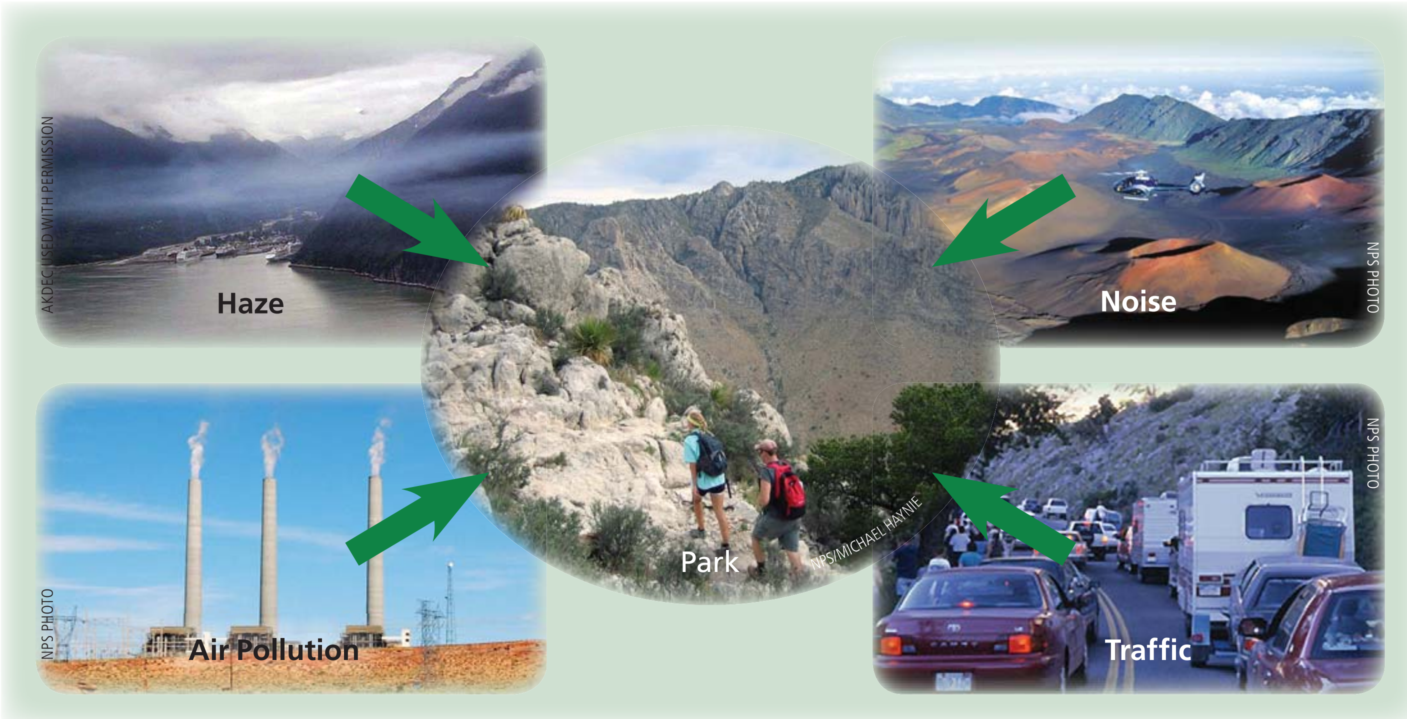

Figure 2. A variety of extraneous factors from gateway communities have the potential to affect park units.

sought responses indicating which experiences gave visitors the most satisfaction during their visit. The following percentages represent responses of "Pretty much" and "A lot": 73% wanted to get away from noise, 70% wanted to get away from bright lights, 85% enjoyed seeing unobstructed views, and 75% enjoyed sounds of nature. Adversely, these indicators of visitor satisfaction are in jeopardy from unsustainable tourism growth in gateway communities.

Tourism as an economic driver

When visitors go to a park, they first encounter a gateway community. To meet the demands of park visitors, gateway communities supply goods, services, and infrastructure. Consequently, these communities often form the first impression of the park area. Inappropriate signage, out-of-context messages, and conflicting scenes (e.g., the commercialism of Gatlinburg, Tennessee, versus the serene views of Great Smoky Mountains National Park) may affect visitors' experience before they even arrive at the park. Consumer expectations and environmental and cultural management challenges in the community may also affect visitor experiences. Examples are rapid growth, inappropriate land use, disregard for social norms and degradation of cultural, structural, and ecological authenticity. Thus, the way in which these amenities are developed is important for visitor perceptions of parks.

These issues are more apparent in rural communities, as they increasingly look to the tourism sector as a source of major economic growth (Hodur et al. 2008). This is noteworthy, considering that more than 200 national park units are located in rural areas. According to a study by Reeder and Brown (2005) that examined socioeconomic trends of 311 rural communities in the 1990s, tourism and recreation development led to higher employment growth rates, earnings, and income levels.

Though the potential for unsustainable tourism lingers, rural areas have extra incentive to develop nature-based tourism, which should embrace a sustainable tourism approach. A study titled "Developing the nature-based tourism in southwestern North Dakota" revealed economic incentives to offering activities conducive to natural areas. From 1998 to 2002, tourism-sector receipts in southwestern North Dakota grew by 50%. This increase was attributed to consumers who sought vacation activities such as biking, wildlife viewing, working on a farm or ranch, participating in fossil digs, and stargazing. In the study, interview and focus group participants frequently acknowledged that Theodore Roosevelt National Park was a key contributor to the region's success. Alternatively, in New Mexico, state and community leaders have felt the loss of tourism revenue given significant visitation decreases at Carlsbad Caverns National Park and White Sands and Bandelier National Monuments.

A 2011 report by the McKinsey Global Institute finds that the leisure and hospitality economic sector, among six sectors studied, has the second-highest potential to affect gross domestic product

The park and neighboring communities are interdependent where the shared goal is a positive visitor experience.

and employment recovery. A key projection is for 3.3 million new jobs created in a sector that currently supports 14 million jobs. In response, the president issued an executive order charging a task force on travel and competitiveness to prepare a national tourism strategy to meet the objective of marginal increase in job creation through tourism. The question is whether or not this gives impetus to national park managers and NPS tourism partners to take advantage of sustainable tourism opportunities. You can read the National Tourism Strategy online at http://www.commerce.gov/news/press-releases/2012/05/10/administration-officials-announce-national-strategy-increase-travel-a.

Many participants stated that landowners are beginning to regard wildlife preservation as a positive factor in economic viability. This is encouraging, considering there are some who believe policies such as the Endangered Species Act inhibit job growth. Additionally, in the study, tangible outcomes from the growing demand for nature-based tourism highlight conservation. These included local efforts in planting trees, water conservation, and establishing nesting cover and food plots.

Three strategies for park managers

Retaining the distinctiveness and sustainability of a destination is key to gateway communities' comparative advantage. In addition, tourism should enhance residents' quality of life. These ideas can be demonstrated and achieved through a deliberate framework of strategic planning. To develop a framework of sustainable tourism, park managers can encourage gateway communities to use the following principles: (1) integrate tourism policies with environmental, social, and economic policies; (2) employ a three-stage evaluation process; and (3) embrace and feature local attributes.

Integrating tourism policies with other policies of community development demonstrates forward thinking; as the economic viability of tourism increases, so may the negative implications for the community. Examples are the reduction of green space, overcrowding, and crime. These impacts can be mitigated through proactive and reactive policy measures. For instance, provisions that limit where development may occur, such as around animal migratory routes, can offset policies that support increased visitation. Additionally, policies can be developed to trigger positive externalities to growth, such as dedicating revenue to social programs.

A three-stage policy evaluation process is necessary to gather current data on community and resource conditions at each phase of tourism development (Edgell et al. 2008). The process includes a formative (predevelopment) phase, developmental (midstream) phase, and summative (evaluation of long-standing policies) phase. The formative phase is the creation of new policies, also referred to as prerequisites to tourism development. In the developmental phase, unexpected issues may arise that require additional policy consideration. For example, an increase in visitors due to an effective marketing campaign may not be supported by the current infrastructure. To mitigate the negative impacts, the destination community may choose to place a policy premium on matching visitor services with visitor demand.

In the summative phase, reevaluation of long-standing policies occurs. From a wildlife management perspective, a summative policy may be consideration of current provisions to increase a specific animal population. As the result of a specific policy, the population number may have improved to an acceptable level; therefore the policy may no longer be needed. It is important to note that both the developmental phase and the summative phase are not exclusive to reactive measures. They also include proactive evaluation of the environment, as all issues may not be apparent or brought to the forefront without investigation.

The foundation of sustainable tourism is offering supply-driven products, services, and experiences that demonstrate the community's unique attributes, making it more competitive while preserving those qualities that make it unique. No two communities are identical; therefore, maintaining cultural and ecological integrity is essential for differentiating a destination's brand from others. In addition to increased marketability, embracing local attributes encourages the community to retain its historical value and social norms. Residents may develop a sense of pride, which produces respect for their heritage and traditional way of life. In many ways this may coincide with the cultural attributes of the park, as both the gateway community and the park offer stories that will complement each other. Furthermore, residents are empowered with the demand for their historical interpretation of the community's evolution.

Conclusion

For the National Park Service it is crucial to encourage ongoing engagement with the tourism community around park lands. Failure to do so may be detrimental to park stories, visitor experiences, and NPS brand characteristics. Ideally, communities would prefer a balanced mix of industry segments making up their local

Both quantitative and qualitative research have highlighted demand implications where the "ideal vacation" emphasizes real experiences, authentic places, and opportunities to partake in local foods, music, markets, and festivals.

economies. In a more dynamic and globalized economic environment, they would prefer not to be dependent on any one business sector for the well-being of their citizens. As they evaluate their options, many communities are taking a second look at tourism development. In focus groups and community meetings citizens have voiced a strong preference for models that stress retention of community values and character. At the same time, both quantitative and qualitative research have highlighted demand implications where the "ideal vacation" emphasizes real experiences, authentic places, and opportunities to partake in local foods, music, markets, and festivals (Brand USA 2012). Destinations that commission these data use them to match their unique community characteristics to the desires and preferences of prospective visitors.

Further evidence of this trend toward high-quality experiences can be found in the growth of geotourism. In the first five months of 2012, local stewardship councils have established three new geotourism regions in the United States. Communities have additional incentive to embrace local cultural, structural, and ecological attributes holistically. Considering that this growth is occurring directly outside the boundaries of national parks, it is in the best interest of park managers to proactively engage with gateway communities in adopting sustainable tourism as a productive strategy. More than ever before, the partnership prospects are improved where both partners pay attention to authentic experiences. Our joint objective is for park visitors to continue to enjoy the depth and breadth of America's natural and cultural history, both inside and outside the parks. This will require a strategic alliance between park units and the tourism community that recognizes a mutually beneficial framework of resource preservation and high-quality visitor experience.

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Developing an accessible methodology for monitoring visitor use patterns in open landscapes of Yosemite National Park

By Chelsey Walden-Schreiner, Yu-Fai Leung, Todd Newburger, and Brittany Woiderski

Figure 1. View of Yosemite Falls from Cook's Meadow, Yosemite Valley. COURTESY OF YU-FAI LEUNG 2011

Abstract

Open landscapes are common, valued park resources that serve as vital wildlife and plant habitats as well as sites for diverse visitor activities. Although the National Park Service (NPS) actively manages these resources, open landscapes are subject to a variety of ecological pressures exacerbated by anthropogenic threats, including intense visitor use that is often not well documented despite its managerial relevance. Established and valuable counting methods exist to estimate visitor use at static locations, yet open landscapes present special monitoring challenges because of multiple points of visitor access and limited or no containment infrastructure. In this article we present an accessible, replicable, and acceptably accurate method developed for monitoring visitor use and its spatial distribution in open landscapes. This method was implemented in three high-use meadows of Yosemite National Park in the summer of 2011. We highlight the data utility and analytical options, evaluate the benefits and limitations, and discuss the potential for volunteer involvement to sustain longitudinal data collection. Additionally, we provide suggestions of other open landscapes suitable for implementation of this method, such as coastal and urban-proximate units of the National Park System.

OPEN LANDSCAPES PROVIDE VITAL HABITATS FOR A DIVERSE array of flora and fauna and serve a number of important hydrologic functions. In addition to their ecological importance, open landscapes provide space for varied human activities. While different types of open landscapes—for example, meadows, dunes, and beaches—serve different ecological and social functions, key shared characteristics include high visibility, walkability, and aesthetic appeal (Falk and Balling 2010; Magill 1992) (fig. 1). The National Park Service (NPS) actively manages for both resource protection and visitor experience, yet open landscapes are still subject to external and internal threats, including climate change, altered hydrologic regimes, encroaching development, and intense visitor use.

Proliferation of visitor-created informal trails is a common type of impact associated with open landscapes. Informal trails, also called social or unauthorized trails, are visually identifiable pathways that fall outside of the park's formal trail system (Leung et al. 2002). Informal trails are often inappropriately located with respect to resource protection objectives, can cause landscape and habitat fragmentation, and can negatively affect visitor experience

Key words
behavior mapping, open landscapes, spatial patterns, visitor use, Yosemite National Park

by visually scarring the landscape (Leung et al. 2011; Marion et al. 2006; Wimpey and Marion 2011).

Informal trails are often inappropriately located with respect to resource protection objectives, can cause landscape and habitat fragmentation, and can negatively affect visitor experience.

Effective management of open landscapes, especially those subject to high use with significant informal trail presence, requires an understanding of visitor use and its spatial and temporal patterns. Quantitative information on the location and intensity of visitor use can alert managers to potential resource impacts or areas prone to crowding or other experiential impacts. This need motivated development of the monitoring methodology presented in this study. Many methods for monitoring visitor use in parks and protected areas are designed for static locations like entrance stations or trailheads. Human observers and on-site automated counters are common methods to document visitor numbers at these types of locations and are important tools for estimating use numbers (Cessford and Muhar 2003; Pettebone et al. 2010). However, open landscapes, like meadows, present special monitoring challenges because there are often multiple points of access and limited or no infrastructure to confine visitor use, reducing the effectiveness of some visitor use monitoring methods. Additionally, the inclusion of spatially explicit visitor data can lead to a deeper understanding of the relationship between visitor use and resource impacts when integrated with biophysical data like vegetation condition or water quality.

Methodological considerations

Observational methods allow for the collection of spatial and demographic information. Time-lapse photography and videography are methods that can be used in open landscapes to obtain visitor counts, use patterns, and activities. Studies using photographs or video to observe use have compared counting accuracy with other methods (Arnberger et al. 2005) or derived spatial patterns (Kinney and Clary 1988). Equipment settings, distance, or purposive blurring of images can ensure anonymity of visitors, although image quality may obscure observable characteristics of visitors (Arnberger and Eder 2007). Estimations of gender and age category may still be possible depending on resulting footage (Bradford and McIntyre 2007). While privacy concerns can be mitigated by ensuring individuals are not recognizable, photography and videography were not considered due to the time required to process the data. Other studies capturing spatial information have asked visitors to carry global positioning system (GPS) units, which can provide accurate assessments of visitor movement and be integrated with natural resource data (D'Antonio et al. 2010; Hallo et al. 2012). Spatial data are generated directly from the GPS unit, and visitor demographic data can be obtained through a brief survey or researcher observation at the time directions are administered to the visitor. However, multiple points of access inherent in open landscapes may hinder the ability to systematically intercept visitors to carry GPS units, and participant awareness has the potential to influence use. To minimize any interactions with visitors, visitor-carried GPS was not considered further. The use of human observers is also an established and common method, though accuracy and reliability are important issues to address, as variables are subject to observer interpretation (Muhar et al. 2002; McKenzie et al. 2006). Although the use of human observers requires some training as well as time in the field, it does offer the opportunity to engage volunteers in data collection. Volunteers can reduce the burden data collection places on staff time as well as provide protected areas with avenues for stewardship education and outreach.

The objective of this study was to develop an accessible, replicable, and acceptably accurate monitoring method for documenting the amount and context of visitor use and spatial distribution in open landscapes. For the purposes of this study, accessibility meant the method involved low-cost materials and could be implemented and replicated by volunteers with varying levels of technical expertise. An accessible methodology allows for greater integration into other plans for open landscape monitoring that may be operating with limited budgets or personnel resources, and provides the opportunity to engage community partners in collection of managerially relevant data. Accuracy acceptability involved determining if the proposed data uses were appropriate given the measured error. After discussions with park staff regarding the most suitable methodological application, we selected and implemented an unobtrusive observational study.

The study used systematic time scanning and visitor use mapping techniques from methods established in studies of animal behavior, physical activity, and landscape design research. We adapted these methods to address challenges pertaining to open landscapes with limited or no built features. These adaptations could allow the method to serve as a viable option for use in parks that may be working with volunteers to collect longitudinal data. It is important to note that, while the use of human observers is well established, accuracy and reliability concerns are important to address in applications of this methodology to new environments. Prior to data collection, we assessed mapping accuracy and interobserver reliability to address such concerns and provide an empirical basis for further improvement. We implemented the methodology in three ecologically and socially significant meadows located in Yosemite National Park during summer 2011.

Study area

Located in the Sierra Nevada of California, Yosemite National Park protects more than 3,026 square kilometers (1,169 sq mi) of ecologically diverse forests, riparian habitats, and glacially created landforms (NPS 2011). Yosemite Valley, the Merced River corridor, and the meadows nestled within the park are among the most iconic and highly valued landscapes of the National Park System. In particular, the meadows of Yosemite Valley provide habitats for a diverse array of plants and animals and serve as an integral part of the visitor experience.

As part of long-term research and monitoring associated with the Merced River Plan, NPS staff periodically monitors informal trail networks in eight high-use Yosemite Valley meadows using protocols developed in collaboration with researchers (Leung et al. 2011). Analysis from these monitoring efforts suggests that the number and extent of informal trails in the meadows have increased since the 1970s (Foin et al. 1977; Leung et al. 2011). Data on visitor use of informal trails may help managers understand why informal trail extent is increasing and provide insight on how to mitigate further proliferation.

Methods

To contribute to the current meadow monitoring and management efforts, three of the eight meadows monitored in Yosemite Valley were selected for this study. Researchers and park biologists chose El Capitan, Leidig, and Cook's Meadows in concert after discussions regarding visitor use levels and informal trail proliferation concerns (fig. 2, table 1, next page). We selected unobtrusive direct observation (i.e., trained human observers) for several reasons. First, it has the ability to capture both spatial and descriptive data in large areas with multiple points of access. Second, it also has proven inexpensive and adaptable to allow for adoption into existing monitoring programs. Finally, it does not unduly influence visitors by altering behavior and, ideally, does not have a sizable impact on their experience. We took steps to minimize the potential for visitor-researcher interaction through careful selection of observation locations. With relatively unobstructed views of visitor activities in open landscapes, observers can gather data on discernible variables like use of the space, visitor demographics, and environmental contexts such as trail conditions and weather that may influence use.

Two observational methods, behavior mapping and momentary time scans, were adapted from previous direct observation studies and combined for the purposes of this research. Used in landscape design and physical activity studies, behavior mapping is an objective observational method for documenting physical use of space, yielding data that support analysis of how people use different environments (Moore and Cosco 2010). This method employs a systematic scan to record the location of persons and desired descriptive data (e.g., age and activity of individuals using a picnic area) within identified target areas. Data are recorded on either electronic or paper maps before observers progress to the next target area. Originally developed for built environments, behavior mapping has included playgrounds, schools, and zoos (Cosco et al. 2010; Proshansky et al. 1976). Observers scan the target area, stopping at the first person encountered to record pertinent variables. The scan resumes from the location where it stopped and the process is repeated until the entire target area has been scanned.

In past research, once the target area has been fully scanned, the observer systematically moves to the next target area or subdivision designated for study (e.g., play equipment to greenway trail segment). However, the lack of built features from which to scan and progress to, and the expansive nature of open landscapes, required adapting the behavior mapping method for application to Yosemite. Thus we instituted successive momentary time scans

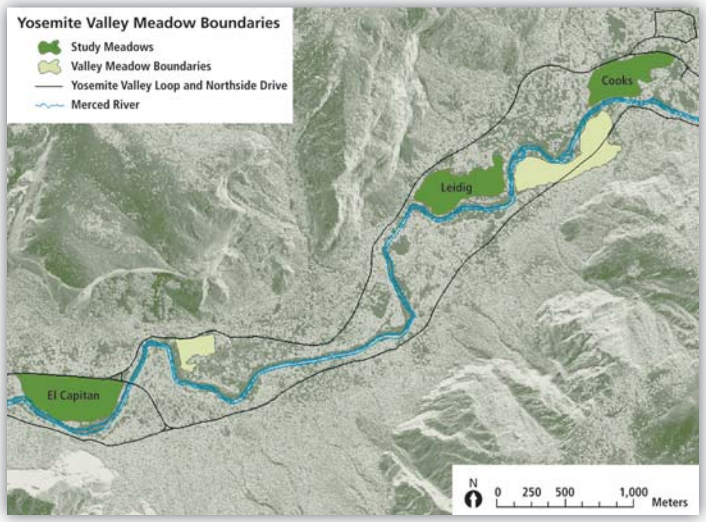

Figure 2. Location of study meadows in Yosemite Valley, Yosemite National Park, California.

Table 1: Yosemite Valley meadow attributes

Meadow	Area (m^2)	Parking availability	Formal trail in meadow? (Yes/No)	Length of informal trails in 2011 (m)
El Capitan	196,384	Roadside	No	5,417
Leidig	141,026	Parking lot	Yes	3,550
Cook's (sections A and B)	94,204	Roadside, parking lot	Yes	2,138

during which observers remained in one location to complete a 360-degree scan of a large area (figs. 3 and 4). In studies of trail use and physical activity, momentary time scans documenting demographic and activity variables using predefined codes have demonstrated acceptable levels of reliability when comparing the proportion of agreement among multiple observers (McKenzie et al. 2006). While momentary time scans have been applied in natural environments previously, the inclusion of spatial data generated from behavior mapping allows for further data analysis of use patterns and resource impacts.

During a pilot test in May 2011, we collected GPS data necessary to create maps on which to record data and established observation locations. We chose three observation sites for each meadow, whose positions were based on lines of sight and complementary visual coverage of the meadow from each location. The meadow boundary, identified by road, river, or forested areas, served as the boundary of the target area for behavior mapping scans. Maps for data collection clearly identified meadow boundaries and emphasized reference features such as easily identifiable trees, snags, and interpretive signs to aid in mapping accuracy. Maps were constructed using GIS software and also contained formal and informal trails as mapped by NPS staff and an aerial image of the study area (fig. 5).

Observers monitored each meadow for 12 hours throughout July and August 2011. They randomly selected which meadow to observe and when from a schedule dividing the sampling periods to cover both weekdays and weekends between 8 a.m. and 8 p.m. Sampling periods were not repeated. A trained observer also randomly selected from which location to make observations and conducted scans of the meadow every 20 minutes for a two-hour sampling period. Observers began the scan by facing north and rotating clockwise. For every individual encountered during the scan, observers documented the spatial location, gender (male or female), age category (youth or adult), and activity at the exact moment of observation. Individuals who reentered the scanning zone were documented again, though not linked to their previous location. The youth age category is defined as individuals age 10 and younger, while the adult category is individuals age 11 and older. These age categories reflect metabolic rate changes as determined in past physical activity research, allowing potential

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Figure 3 (top). Open landscapes serve as a vital resource for plants, animals, and visitor activity.

Figure 4 (bottom). A volunteer collects data in El Capitan Meadow using the paper-based behavior mapping method.

analysis from physical health perspectives (Floyd et al. 2008). Each scan used a new map, resulting in six maps per sampling period.

Multiple observation locations and randomized selection were designed to minimize mapping inaccuracy, caused by either excessive distance from those being observed or hindered line of sight, over time. We assessed the margin of observer error

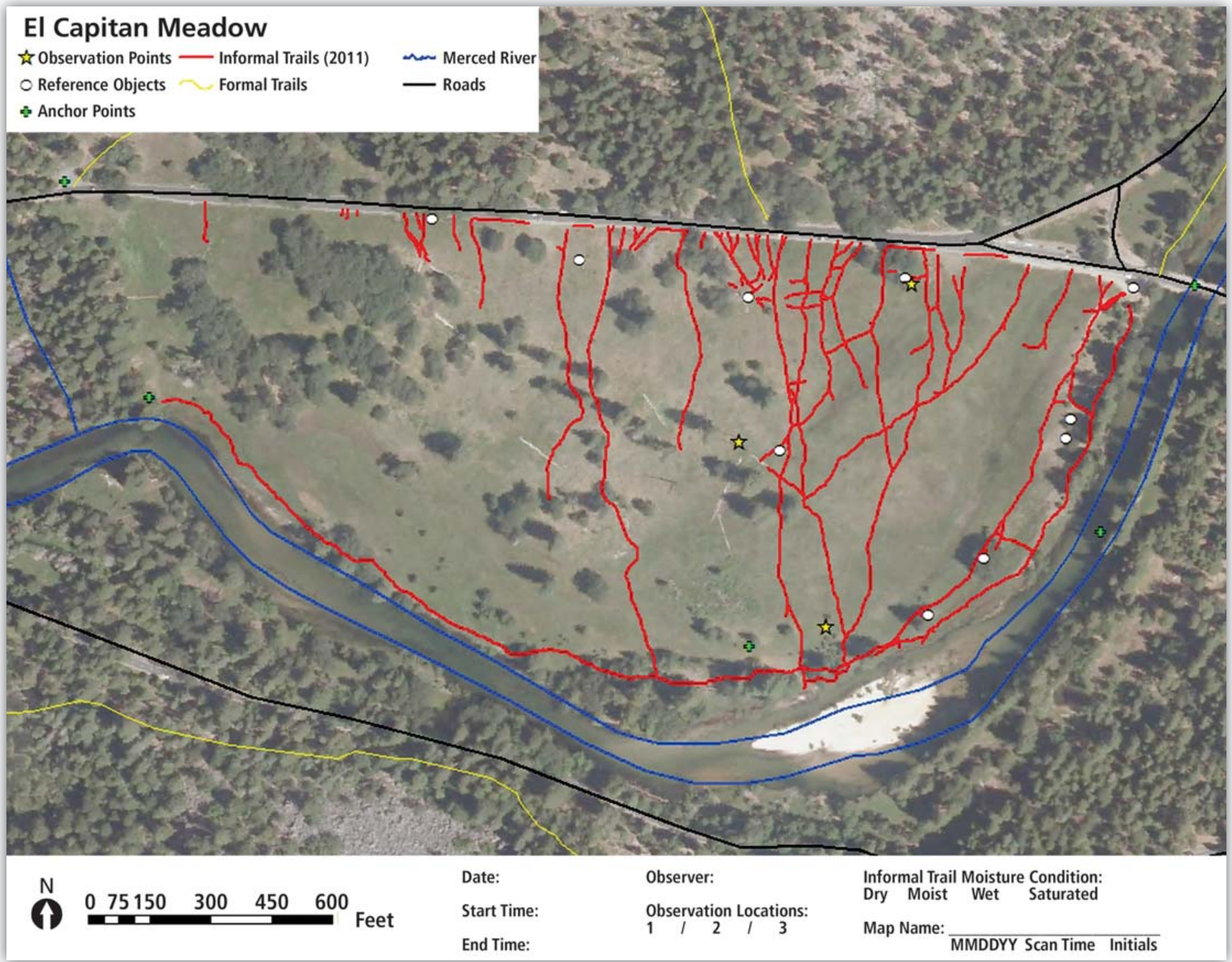

Figure 5. Base map used for data collection in El Capitan Meadow.

during the pilot test by having a trained observer document a second researcher recording GPS waypoints in two of the three study meadows. Because of time and resource restrictions, the pilot test measured accuracy for only one observer. The observer spent 12 hours practicing the method, in addition to several weeks in the study meadows developing the instrument, prior to the assessment. The distance between 22 observed points and the corresponding GPS waypoints were calculated and averaged. The average margin of error was 11.32 m (37.14 ft) with a standard deviation of 7.22 m (23.69 ft).

We collected meadow use data on identical color maps loaded either on a touch-screen tablet computer running a mobile GIS software program or on letter-sized sheets of paper. Both tools were used to assess the benefits and limitations of each as they pertained to method accessibility and volunteer involvement.

Data collected on the tablet computer were in the form of shape files with drop-down menus for variable selection. For data collected on the paper map, a numbered point that corresponded to the same number in a data collection spreadsheet represented the location and attributes of each individual (fig. 6, next page).

Volunteer observers were recruited through the park's daily e-mail report and social media outlets. Prior to data collection, volunteers participated in a meadow orientation and training session. All volunteers collected data on paper maps that were later digitized using the GIS software package.

Findings and discussion

Though the purpose of this article is to discuss observation method development, we also want to highlight the utility of the data. The 18 sampling periods resulted in the creation of 108 maps

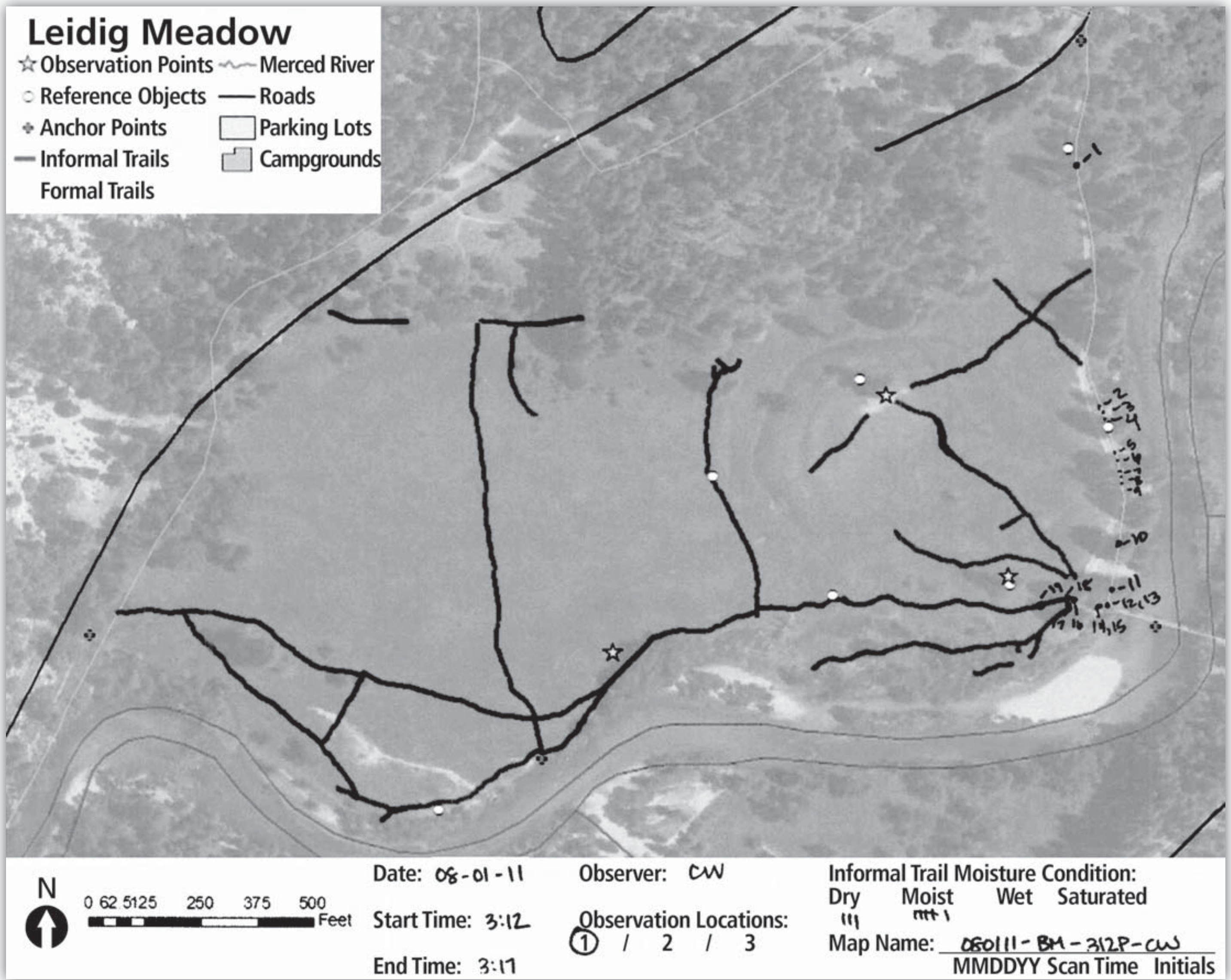

Figure 6. Completed behavior mapping session in Leidig Meadow using paper map.

(36 per meadow) and we summarize observed visitor demographics in table 2. Use numbers were relatively equal across all three meadows and a slight majority of visitors were male adults.

Observational point data generated through behavior mapping also produced maps indicating areas of concentrated use. For example, we used the average nearest neighbor tool to test the randomness of visitor distribution in meadows. For all three study meadows, visitor use was highly clustered and statistically significant. Some clustering in Cook's and Leidig Meadows can be attributed to the formal trails within the meadows. El Capitan Meadow did not have a formalized trail at the time of study. The GIS software enabled us to place three buffers (i.e., 5 m, 10 m, and 20 m [16.4 ft, 32.8 ft, and 65.6 ft]) around the formal trails in Cook's and Leidig Meadows to estimate the percentage of visitor use attributed to those trails. Buffers incorporated the margin of error and also addressed issues of map scale (i.e., approximately 1 cm [0.4 in] on the map represented 25 m [82 ft] of actual space). Of visitors documented during the study, a total of 68% in Cook's Meadow and 64% in Leidig Meadow were observed within 5 m (16.4 ft) of the formal trails. Though a majority of use was confined to formal trail corridors, more visitors in Leidig Meadow wandered from the formal trail, as illustrated by the percentage increase to 83% in Cook's Meadow and 69% in Leidig Meadow when the buffer extended to 10 m (32.8 ft).

Kernel density estimation (KDE) calculates the density of features within a specified search radius (O'Sullivan and Unwin 2010). In this study, KDE measured the spatial distribution of visitors to allow for exploration of areas of intense visitor use within a search

Table 2: Gender and age* of visitors observed by meadow			
	El Capitan	Leidig	Cook's
Male adult	225	275	274
Female adult	153	260	248
Male youth	16	30	30
Female youth	11	28	27
Total observed	405	593	579

*Youth is age 10 and younger.

radius of 50 m (164 ft). Figure 7 compares the KDE of active (e.g., walking, running) and stationary (e.g., photography, sitting) visitor use in El Capitan Meadow.

Behavior mapping data can also use the spatial distribution of visitors to examine patterns of dispersal or level of physical activity. Dispersal patterns may help guide the placement of signage. Additionally, use pattern data can serve as a guide for restoration planning and site design. For example, visitor concentrations in El Capitan Meadow may help support the addition and location of a formal trail. Although it is beyond the scope of this article, future analysis of the meadow use data collected in Yosemite will be spatially linked to informal trail and biophysical GIS data layers to examine relationships among use, informal trail, and biophysical variables.

Method benefits and limitations

We succeeded in developing an accessible method for visitor use monitoring in open landscapes; however, further research and analysis are needed to improve its accuracy, reliability, and efficiency. We tested accuracy of only one observer and found it to be 11.32 m (37.14 ft).[1] We recognize volunteers may not have the level of familiarity with study sites, and additional testing is necessary to better address accuracy levels. The 11.32 m (37.14 ft) measured in this study is in comparison to mapping-grade GPS units that can obtain positions within 2–5 m (6.6–16.4 ft) of true position and consumer-grade GPS units that can obtain results between 5 m and 10 m (16.4 ft and 32.8 ft) of true position, depending on satellite availability and canopy conditions (Wing et al. 2005). The accuracy level may be acceptable for visitor management purposes; however, consideration is warranted for integration with biophysical or other more precisely measured data (e.g., soil composition). Accuracy may also be an issue in areas with very dense trail networks (i.e., informal trail segments 20 m [65.6 ft] apart), in which case a complementary method applied conjointly or a different method applied independently should be considered.

1 Prior to this accuracy test, we conducted a preliminary assessment after the observer had spent minimal time in the meadow. Initial accuracy estimates prompted relocation of several observation locations to areas with improved sight lines and inclusion of additional reference features. Results from the reported accuracy test occurred after the observer spent several weeks working in the study meadows mapping informal trails and developing the behavior mapping instruments.

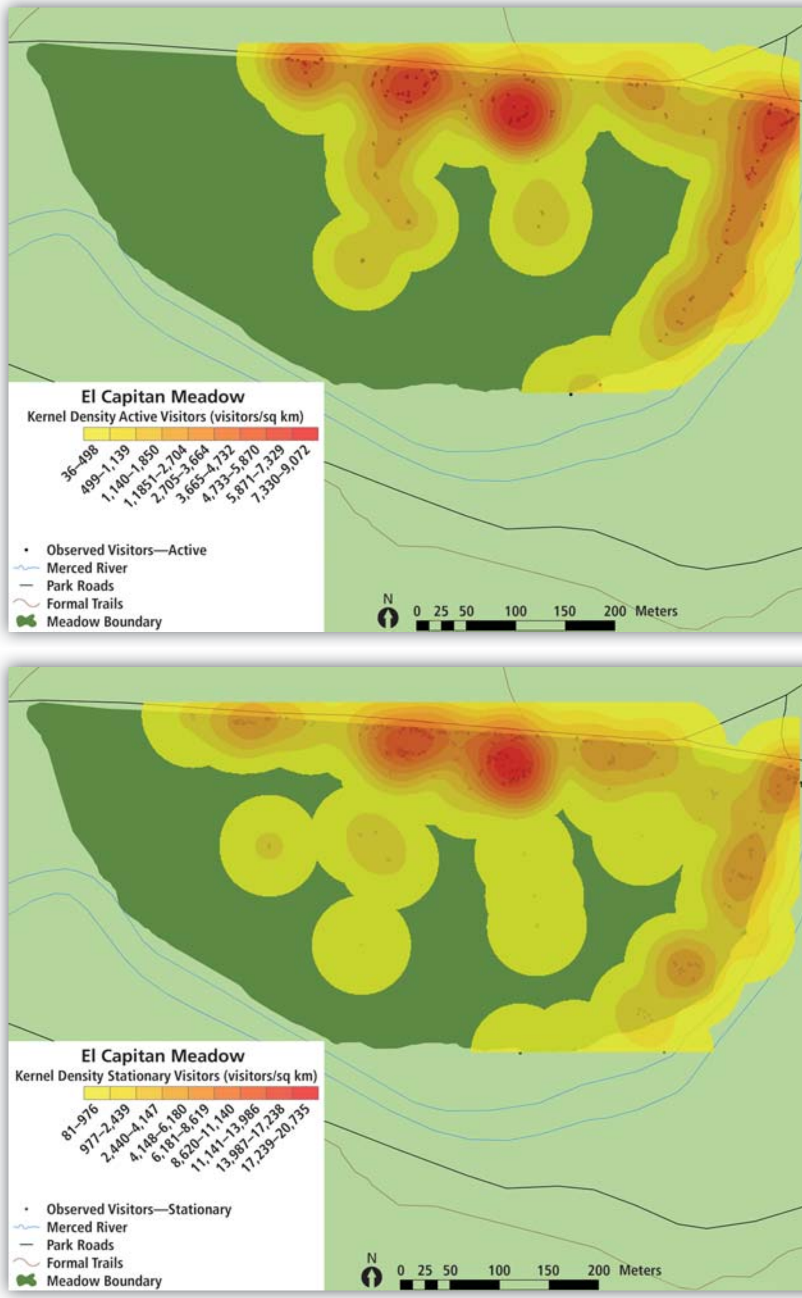

Figure 7. Kernel density estimation of (top) active (e.g., walking, running) and (bottom) stationary (e.g., photography, sitting) activities in El Capitan Meadow.

The large size of the meadows and height of the vegetation during late summer months may have affected observer accuracy. To lessen the potential for errors introduced by subdividing the meadows (i.e., double counts if observers are unsure as to whether the visitor is within their target area or an adjacent subdivision being observed by another volunteer), we sacrificed some accuracy for greater accessibility and so that visitors could experience the meadows without influence from the researcher. Future applications may explore the feasibility of subdividing target areas and the effect it has on accuracy. Smaller target areas may, in some locations, increase accuracy but potentially render observers more conspicuous. Although no visitors approached observers during the course of this study, interaction is still possible.

One key design consideration of this monitoring method that warranted its use in this context is its accessibility to a wide variety of users, including not only researchers and park staff but also local community and other park volunteers. Volunteers support longitudinal data collection efforts to explore seasonal variations of use. The paper-based mapping tool allows volunteers to collect data after a short training and orientation session at minimal supply cost. The only supplies required are paper maps, data collection spreadsheets, writing implements, timers, and binoculars. Thus paper maps were cost-effective and require little preparation time aside from creating the map itself. However, additional time was needed to digitize the paper maps, and observers were more prone to make errors during the data collection process (e.g., multiple persons numbered 12 on the same map or forgot to collect descriptive data). Additionally, navigating from the paper map to a separate spreadsheet to record demographic data was cumbersome and vulnerable to inclement weather conditions. The tablet computer, equipped with a touch screen and the required drop-down lists, eliminated a majority of the data entry errors during the data collection and digitization process. The tablet was also efficient to use in the field because it eliminated the need to switch between the map and demographic collection spreadsheet. Nevertheless, the tablet required creating a template shape file to house the drop-down menus prior to data collection and the observer needed basic familiarity with the software to collect data. Though the tablet computer helps minimize the time spent processing raw data and eliminates some field collection errors, it does increase material costs and training time. Open source GIS applications developed for mobile devices may be an option in the future to reduce both costs and data processing time.

Lessons learned

The incorporation of volunteers and the lessons learned from this experience can inform future work in other parks and protected areas. First, we included a more detailed meadow orientation with a training session to help the volunteer observers increase their familiarity with the study site and to practice the data collection procedures. Second, it is imperative not to inundate the study area with observers and therefore affect visitor experience. Volunteers make it possible to have recorders at multiple observation locations to help increase survey accuracy, scanning rate, and sampling periods to gain a more robust picture of overall visitor use patterns. However, meadow size and observation site options dictate how many volunteers can be placed at each observation point. Third, when using paper maps, observers should work in pairs with one individual mapping and the other recording demographic data. This makes the scans more efficient and allows for the mapper to focus solely on the location of the visitor and less on switching from the map to the data spreadsheet. Furthermore, a pair of volunteers affords the opportunity to replicate the data and examine spatial accuracy and measurement error.

The data resulting from this method can aid management in identifying areas of intense visitor use, planning trail maintenance or surface hardening, and planning for restoration. For example, the data from this study were provided to the park staff for consideration as they develop management and restoration plans for the three meadows observed. Specifically, the data assist managers in understanding how visitors use these locations and at what intensities. When considering specific restoration treatments, such as boardwalks and informal trail removal, the data yielded from behavior mapping will help inform the process of both design and restoration.

Although we tested this methodology on the meadows of Yosemite Valley, other high-use and ecologically significant open landscapes are candidates for future applications. Indeed, a major benefit of behavior mapping is the adaptability of the method, which can be tailored to different locations, or even to include wildlife. For instance, beaches, dunes, and tundra are areas in which behavior mapping may serve as a useful method for monitoring use patterns and could be integrated with resource condition data. It is important to note that each site may necessitate adaptation of the method to account for area size, topography, vegetation, and use levels. Further adaptation of the method, like subdivision of the study area or use of pin flags as reference points, may be required to ensure adequate accuracy in these more uniform landscapes. The data generated from modified behavior mapping, even if tailored to a new environment or species, can yield important descriptive and spatial data on use patterns to inform sustainable management of valued resources.

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Understanding endangered plant species population changes at Eureka Dunes, Death Valley National Park

By Jane Cipra and Kelly Fuhrmann

Figure 1. Eureka Dunes, Death Valley National Park.

Abstract

Eureka Valley dune grass (*Swallenia alexandrae* [Swallen]) and the Eureka Valley evening primrose (*Oenothera californica* ssp. *eurekensis* [Munz & Roos]) are both federally listed endangered species (43 FR 17910-17916, 26 April 1978) found only on three disjunct dune areas in the Eureka Valley of Death Valley National Park, California. Though these species have been monitored sporadically since the 1970s, habitat-wide surveys were impossible in the past without modern GPS equipment. Direct quantitative analysis of population trends over time is also problematic due to the shifting dune habitat. The last four years of monitoring have not revealed any positive or negative trends; however, comparison of photo points at Marble Canyon and on the Main Dune shows dramatic declines over the last 25 and 35 years, respectively. Factors such as climate change, visitor impacts, competition from invasive species, and plant-animal interactions may be contributing to the population declines and warrant further study.

Key words

endangered species, Eureka Valley, monitoring, *Oenothera*, rare endemic, *Swallenia*, vegetation mapping

EUREKA VALLEY IN DEATH VALLEY NATIONAL PARK, California, contains a dune system between 900 and 1,300 meters (2,953–4,265 ft) in elevation that is split into three dune areas: the Main Dune, the Saline Spur, and Marble Canyon (figs. 1 and 2). This dune complex is the entire range of two endemic species: the Eureka Valley dune grass (*Swallenia alexandrae* [Swallen]) and the Eureka Valley evening primrose (*Oenothera californica* ssp. *eurekensis* [Munz & Roos]), which are both federally listed as endangered species (43 FR 17910-17916, 26 April 1978).

Swallenia alexandrae is a perennial grass that forms stable hummocks approximately 1–3 m in diameter (3–10 ft), found primarily on the mobile sand that forms the steep slopes of the dunes (Pavlik 1979). The grass stems ascend up to 1 m high and are often branched. Although drifts of sand frequently bury *Swallenia* hummocks, giving the branching stems the appearance of multiple individuals emerging from the sand, *Swallenia* does not reproduce asexually through true rhizomes or stolons (Pavlik and Barbour 1985). Instead, *Swallenia* reproduction occurs solely by seed and appears to be dependent on warm-season rains in late summer and early fall (Pavlik and Barbour 1988).

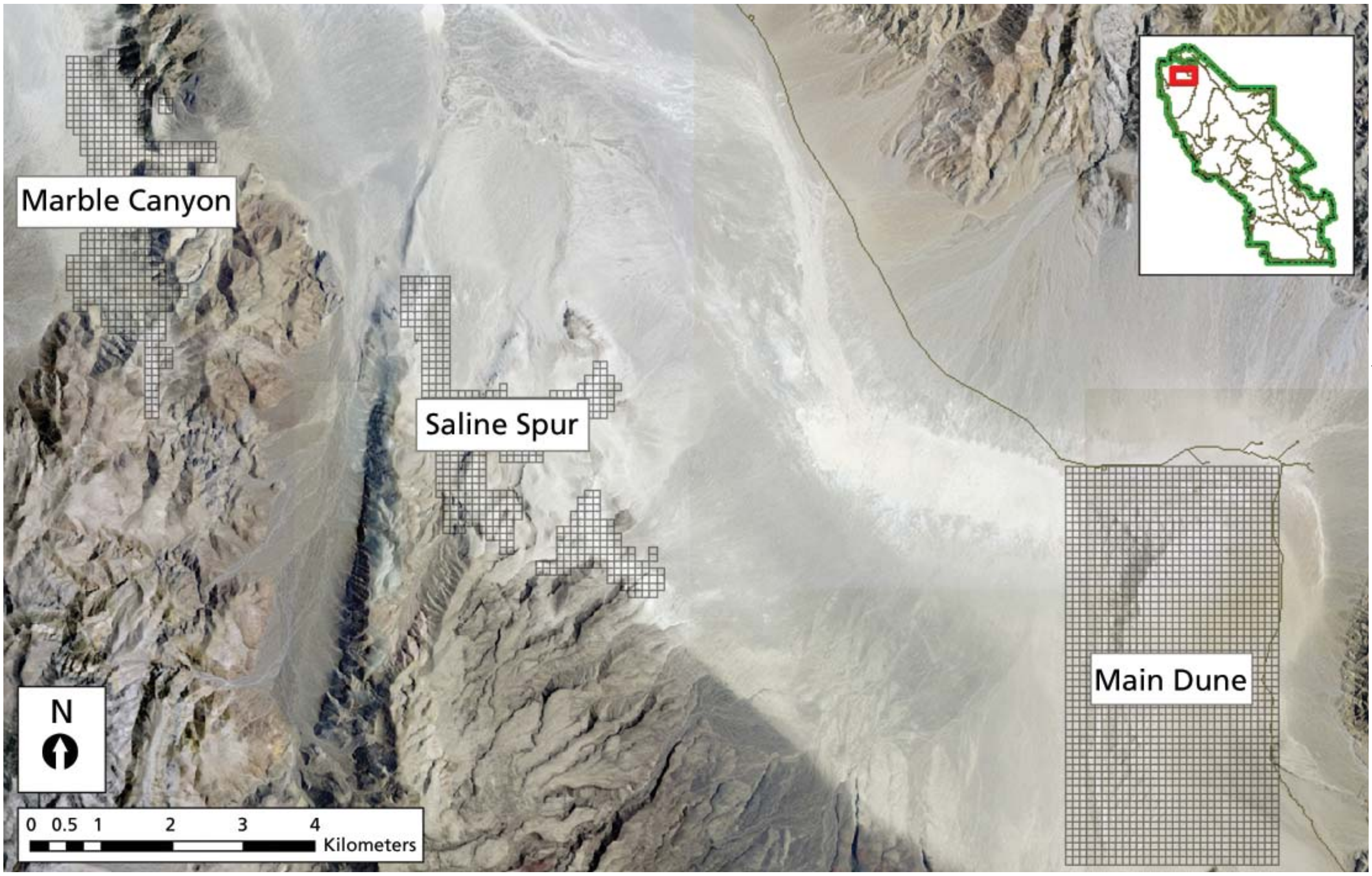

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Figure 2. Map of the Eureka Dunes Complex, including the Marble Canyon Dunes, the Saline Spur, and the Main Dune.

Oenothera californica ssp. *eurekensis* is an herbacious perennial primrose that dies back to the roots and remains dormant in the subsurface in dry years. This subspecies of *Oenothera* differs from others in that it is capable of forming new vegetative rosettes at the ends of buried branches (Pavlik 1979). *Oenothera* also reproduces by seed and is pollinated by hawkmoths (*Hyles lineata*) (Gregory 1963).

Because of the popularity of the Eureka Valley for off-road vehicle (ORV) recreation in the 1970s, *O. californica* ssp. *eurekensis* and *S. alexandrae* were both listed as endangered species in 1978, with ORV recreation cited as the threat to their populations. The Eureka Dunes were officially closed to ORV use by the Bureau of Land Management (BLM) in 1976 when *Swallenia* and *Oenothera* were proposed for listing (Noell 1994); however, enforcement of this closure was not fully implemented until 1980 (USFWS 1982). Occasional ORV trespass still occurs at the Main Dune (Death Valley National Park patrol logs).

Mapping and monitoring history

Since the listing of *Oenothera* and *Swallenia*, several attempts have been made to establish permanent plots and map the full extents of both species. A variety of mapping methods and technologies have been used over the last 40 years, which presents difficulties in measuring population trends. The biology of both *Oenothera* and *Swallenia* presents additional difficulties in estimating population densities. Both species can branch underground or become partially buried by drifting sand, obscuring the boundaries of individual plants or hummocks. In addition, *Oenothera* dies back to the roots every year, disappearing completely from the sand surface, and may not reappear for many years. Despite these obscurities, changes in population extent since 1976 have been large enough to be visible in both maps and photos.

The first known maps of the rare Eureka endemics were published in a 1976 Environmental Analysis produced by the BLM. Although these maps are extremely detailed, the methods are described simply as “field survey conducted by BLM personnel Spring 1976.” A second map produced in 1979 by Mary DeDecker and later published in a 1982 report by P. G. Rowlands indicates very generalized population extents at the three dune areas, but of particular note is a wide expanse of *Oenothera* habitat on the east side of the Main Dune.

Although the maps produced in 1976 and 1979 are very different in detail, there is one key similarity: the large population of *Oenothera* in the flat area east of the Main Dune described as a "heavy" concentration in 1976. In addition to these maps, the literature contains a verbal description of this area: "On the eastern side of the dune the primrose occupies the lower, gentle slopes and flats where it interfingers with an extensive stand of *Oryzopsis [Stipa] hymenoides*. It is in this area that the population is most concentrated, although in years of low rainfall it may seem quite scarce" (Pavlik 1979).

From 1974 to 1979, Mary Ann Henry established a series of transects and photo points to assess the potential impact of off-road vehicles (unpublished data). In 1985 Mark Bagley established an additional set of transects, permanent plots, and photo points along the north side of the Main Dune for baseline monitoring (Bagley 1986). In 2007 and 2008 the park botanist Michèle Slaton was able to relocate and resurvey all transects and photo points from the 1970s and 1980s and found reductions in *Swallenia* from 96% to 99% (Slaton 2008). She also found *Oenothera* to be reduced from 1979 to 2008, but there was considerably more fluctuation in population levels from year to year.

Slaton developed a geographic information system– (GIS) based monitoring approach by creating a virtual grid over 2,600 hectares (6,425 ac) covering all the suitable habitat at the Main Dune, Saline Spur, and Marble Canyon. In 2007 Slaton surveyed the Main Dune and in 2008 Marble Canyon and Saline Spur, and recorded presence/absence of *Swallenia* and *Oenothera* within each hectare grid.

Survey methods

In 2011 the park botanist and a team of four biological technicians accomplished a habitat-wide survey of all three dune systems in the same season for the first time. We covered all 2,658 hectares (6,568 ac) of suitable dune habitat from 15 March to 11 April. In habitat with relatively dense vegetation, two people walked straight lines through the hectare approximately 50 m apart. In habitat that was relatively sparse with sheets of bare sand, one person surveyed the hectare alone, using binoculars when necessary, to verify plant identification. We collected data on 3- by 4-foot paper maps with survey grids superimposed on National Agriculture Imagery Program (NAIP) aerial imagery. We used Trimble Juno™ GPS devices loaded with the same imagery and grids in the field for location and orientation. We recorded the presence of *Swallenia* and *Oenothera* with relative densities of low, medium, and high: "low" = 1–10 individuals, "medium" = 11–60 individuals, and "high" > 60 individuals per hectare.

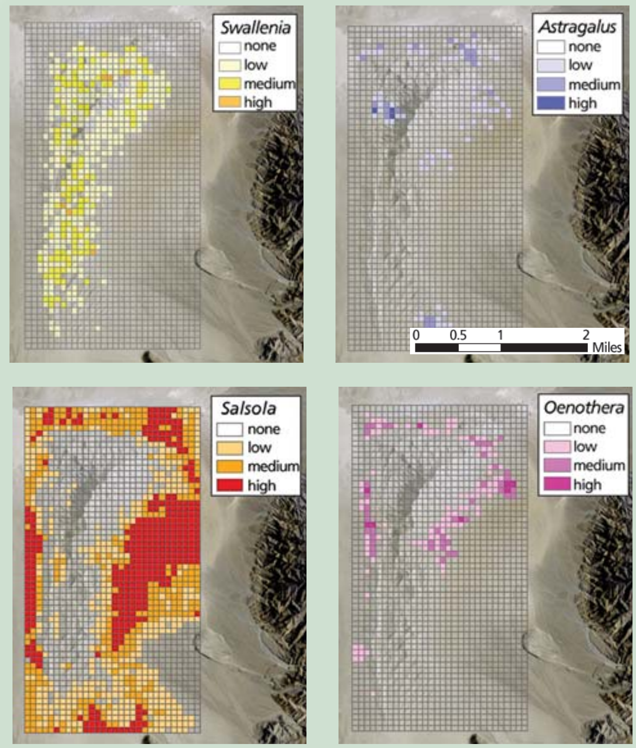

Figure 3. Abundance of rare plant and *Salsola* from surveys on the Main Dune in 2011. (Scale applies to all plates.)

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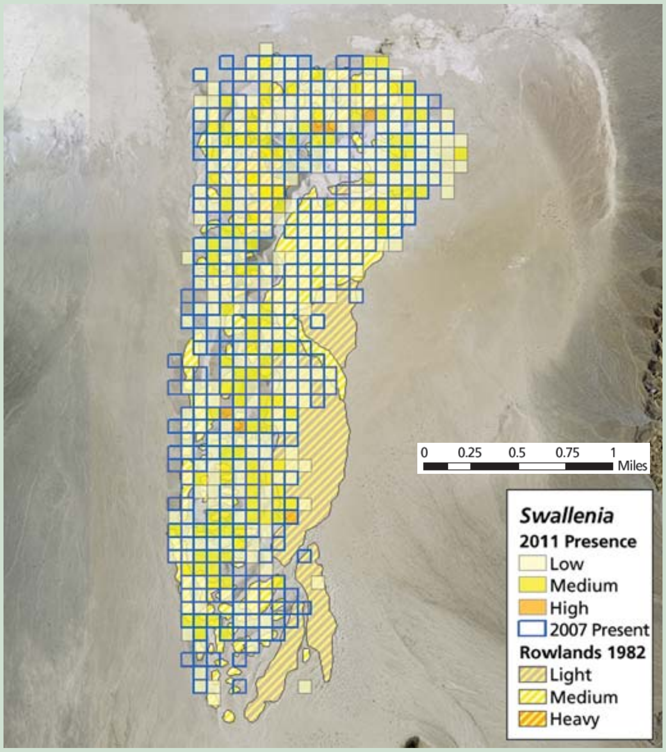
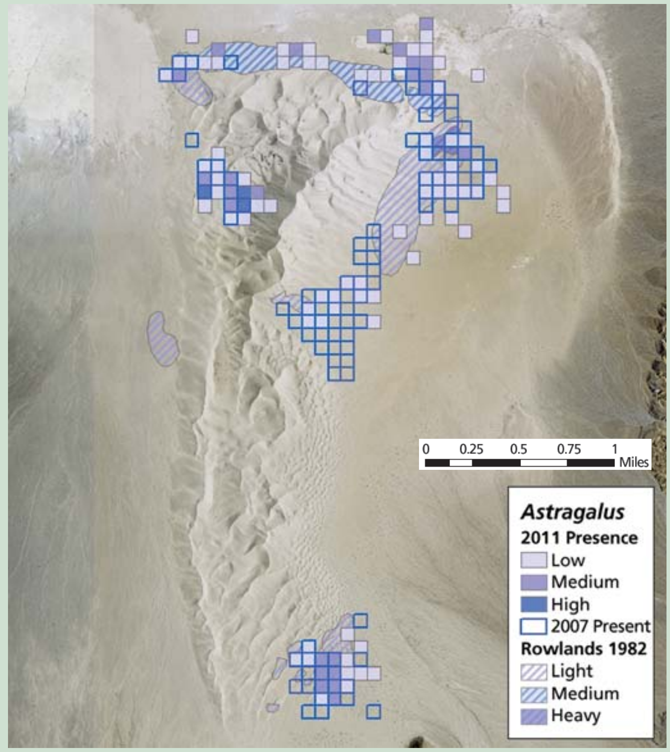
In addition to the rare plant species, we mapped Russian thistle (*Salsola gobicola* [Iljin]) in the 2011 survey. The *Salsola* biomass that was counted was almost entirely senesced and rooted plants from the previous year. Very little new *Salsola* germinated in 2011. The *Salsola* species in the Eureka Valley appears to be a hybrid of *S. paulsenii* and *S. tragus* known as *S. gobicola* (Hrusa and Gaskin 2008). It has been referred to in past literature as *Salsola paulsenii* but is referred to here by the generic epithet. Because of the large numbers of *Salsola* plants, relative densities were estimated as percent cover: "low"= 1–3%, "medium" = 4–10%, and "high" > 10% cover.

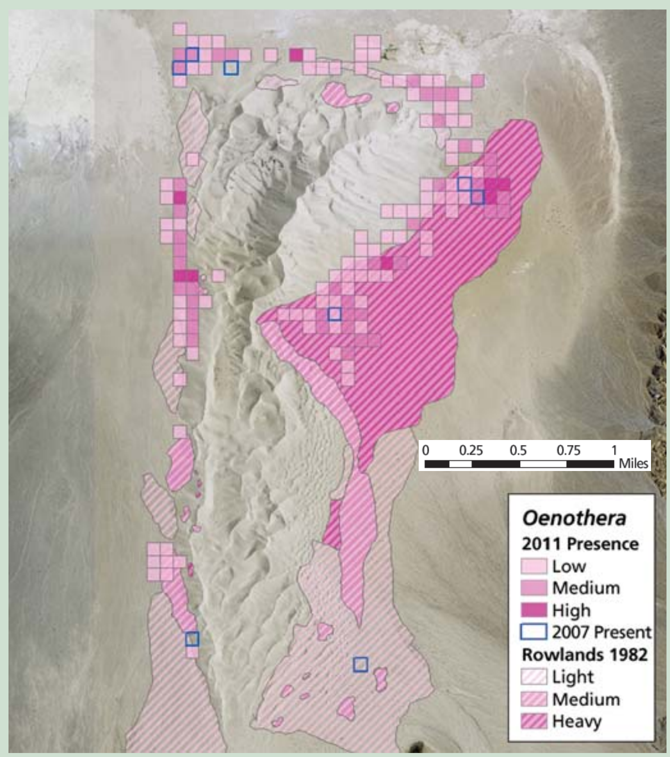
Results

The population extents and relative densities of *Swallenia*, *Oenothera*, and *Salsola* on the Main Dune in 2011 are shown in figure 3. All surveys we conducted found large amounts of *Salsola* in comparison with the rare endemic species.





Figures 4–6. Change in population extents of *Swallenia* (figure 4, above), *Astragalus* (figure 5, above right), and *Oenothera* (figure 6, below right) on the Main Dune from 1982, 2007, and 2011.



In order to quantify change over the last four years, we counted hectares that have gained or lost rare plant presence and compared across years. When comparing 2007 and 2008 surveys with that of 2011, an almost equal number of hectares lost species presence as gained it (figs. 4 and 5), with the notable exception of *Oenothera* at the Main Dune, which increased from 8 hectares (20 ac) in 2007 to 151 hectares in 2011 (fig. 6). This is an indicator of the extreme annual variability of germination and aboveground growth in *Oenothera* rather than an expansion of range over the last four years.

Although the last four years of surveys and monitoring have not shown measurable positive or negative change, there is evidence of substantial loss of *Swallenia* since the 1970s and 1980s, as can be seen from repeat photography. The photo points that illustrate the most dramatic change were taken at Marble Canyon in 1985 by Mark Bagley (fig. 7, next page). Photo points established at the Main Dune also show a substantial loss of *Swallenia* cover and density, although the trace amounts of *Swallenia* remaining have preserved the overall population extents since the 1970s (fig. 8, next page). *Oenothera* also appears to have declined based on comparisons with mapped population extents from the 1970s. However, *Oenothera* is only detectable aboveground with substantial winter rainfall and may still be present belowground in its historical habitats. Complete

Figure 7. Photo point record from Marble Canyon showing substantial and widespread loss of *Swallenia* cover from July 1985 (top) to April 2011 (bottom).

Figure 8. Photo point comparison from the Main Dune showing substantial loss of *Swallenia* on the dune slopes from June 1985 (top) to May 2011 (bottom).

surveys after a wet winter will be necessary to determine *Oenothera*'s real population status.

Discussion

There have been three periods of observation at the Eureka Dunes: the 1970s, the 1980s, and the last four years. The differences observed among these periods could represent a trend of dramatic decline or may simply be the result of variability in precipitation. A 30-year cycle of drought has been observed in precipitation throughout the desert region and is significantly correlated with temperature shifts in the North Pacific Ocean known as the Pacific Decadal Oscillation (Hereford et al. 2006).

The Eureka Dunes endemic plants may now be at a low ebb and will return in coming decades when this cycle of drought ends. Long-term monitoring of vegetation plots at the Nevada Test Site has revealed that desert vegetation is extremely dependent on precipitation (Webb et al. 2003), although overall cover and biomass at the Nevada Test Site have increased over the last 50 years.

Climate change can also have indirect effects by causing the loss or mistiming of *Oenothera* pollinator phenology or increased predation pressure by insects, lizards, and rodents on perennial plants in the absence of annual plant forage.

Swallenia populations have been reduced from 95% to 99% over 25 years as measured in long-term transects (Slaton 2008) and estimated from repeat photography. With additional environmental stressors, it is possible the species will not survive until the next upswing in precipitation. Additionally, climate models predict a continuing drying trend throughout the Southwest (Lenart 2007), which could mean *Swallenia* is in real danger of extinction within the next 30 years. Additional environmental stressors that could

The Eureka Dunes endemic plants may now be at a low ebb and will return in coming decades when this cycle of drought ends.

influence long-term population trends are visitor impact and invasive species.

Visitor impact

Visitor impact in the form of off-road vehicles was the original reason for listing these species as endangered in 1978. Although enforcement has not always been at ideal levels, ORV use at Eureka Dunes has gradually declined over the decades to isolated incidents at the Main Dune. The majority of visitors to Eureka Valley now concentrate their use in the form of foot traffic at the north end of the Main Dune. Widespread loss of *Swallenia* across the Eureka Valley, including remote areas, suggests that visitor impact is not the underlying cause of adult plant mortality. However, foot traffic could have severe impacts on the survival of delicate grass seedlings during rare germination events.

Invasive species competition

The most surprising result of the 2011 surveys was the extent of *Salsola* invasion in the Eureka Valley. *Salsola* has colonized and dominates almost all of the semistabilized sand that is favored by *Oenothera*. The only habitats where *Salsola* is not found are the actively mobile sands and the desert pavement surrounding the dunes. The maps and written accounts of *Oenothera* populations in the 1970s indicate that more than 100 hectares (247 acres) of a "heavy" *Oenothera* population on the east side of the Main Dune have been converted to a *Salsola* monoculture (fig. 3). *Salsola* could also be negatively affecting *Swallenia*. Although standing *Salsola* does not overlap heavily with *Swallenia* habitat, *Swallenia* hummocks do provide a semistabilized microhabitat that is capable of colonization by *Salsola*. Both *Swallenia* and *Salsola* are warm-season plants that share C_4 photophysiology, which may cause them to compete for water and nutrients during the same time of year (Noell 1994).

As early as 1979, Pavlik noted that "*Salsola paulsenii* is the only introduced plant commonly found on the dune." In 1988, Mary DeDecker, a prominent local botanist, wrote a letter to the Ridgecrest Bureau of Land Management office stating her concern over Russian thistle:

> I was shocked to see that the large stand of Indian rice grass had been taken over by a solid field of Russian thistle. It had been perhaps 40 acres of almost pure rice grass (*Oryzopsis [Stipa] hymenoides*) with some apricot mallow (*Sphaeralcea ambigua*) . . . There is also the likely possibility that the Russian thistle will move on and take over the large area of the endemic evening primrose nearby, a bit to the south.

Unfortunately the *Salsola* observed in 1988 has since spread throughout the Eureka Valley and is now found even in the most remote and isolated patches of sand in Marble Canyon and the Saline Spur. *Salsola* has spread far beyond the bounds where chemical or mechanical control might be effective. The only possibility for control of *Salsola* in the Eureka Valley would be the introduction of a biological control agent. An eriophid mite, *Aceria salsolae*, has been identified (Smith et al. 2009) as specific to *Salsola* species, but further testing to ensure effective control of the *S. gobicola* present in the Eureka Valley will be necessary before it can be considered for use. Direct competitive effects between *Salsola* and *Oenothera* or *Swallenia* should also be proven beyond the circumstantial evidence of shared habitat before the ecosystem is permanently altered with the introduction of biological control.

Future plans

The Eureka Dune endemics will continue to be monitored with a habitat-wide survey repeated every three to five years, and a survey of the Main Dune annually. Line distance transects to measure *Oenothera* densities were initiated in 2010 and will be monitored annually as a cooperative USGS and NPS study.

In addition to regular NPS monitoring, two USGS studies will be initiated in 2012. One study will examine how precipitation and hydrology in the Eureka Valley influence soil moisture, seed germination, plant growth, and soil mobility and whether changes observed in growth and reproduction are most related to changes in local climate, groundwater, current visitor use, or some combination of these factors.

A second USGS study will evaluate the relative importance of competition and herbivory in limiting populations of *Oenothera*. Field surveys will estimate *Oenothera* and *Salsola* density, lagomorph (i.e., rabbit) density, and patterns of mortality and reproduction. Field experiments will also evaluate competition between *Oenothera* and *Salsola* and the hypothesis that *Salsola* could confer protection against herbivory.

Additional areas for research include an analysis of Eureka Valley–specific data from radar archives to understand the role precipitation plays in the multidecadal trends of *Swallenia* recruitment. Remote sensing using improved aerial and satellite imagery could also provide precise population measurements without labor-intensive and potentially injurious ground surveys.

The U.S. Department of Agriculture is continuing research on potential biological controls for *Salsola*. If a safe and effective control is identified, consultation with the U.S. Fish and Wildlife Service (USFWS) will help determine if biological control is a suitable method to preserve the rare Eureka Dunes endemic plant species.

The USFWS had identified *Swallenia alexandrae* and *Oenothera californica* ssp. *eurekensis* as spotlight species for delisting after review of the status of recovery of the plants since listing in 1978. However, the available qualitative data demonstrate a further decline of these species. Further quantitative data collection is needed to determine population density trends of these endangered species at Eureka Dunes.

Acknowledgments
This survey would not have been possible without the dedicated work of Tim Szewczyk, Amanda Schwantes, Drew Kaiser, and Steven DelFavero, who together surveyed over 2,600 hectares (6,425 ac) and hiked over 400 miles (644 km) on sand in every kind of weather in the space of three weeks.

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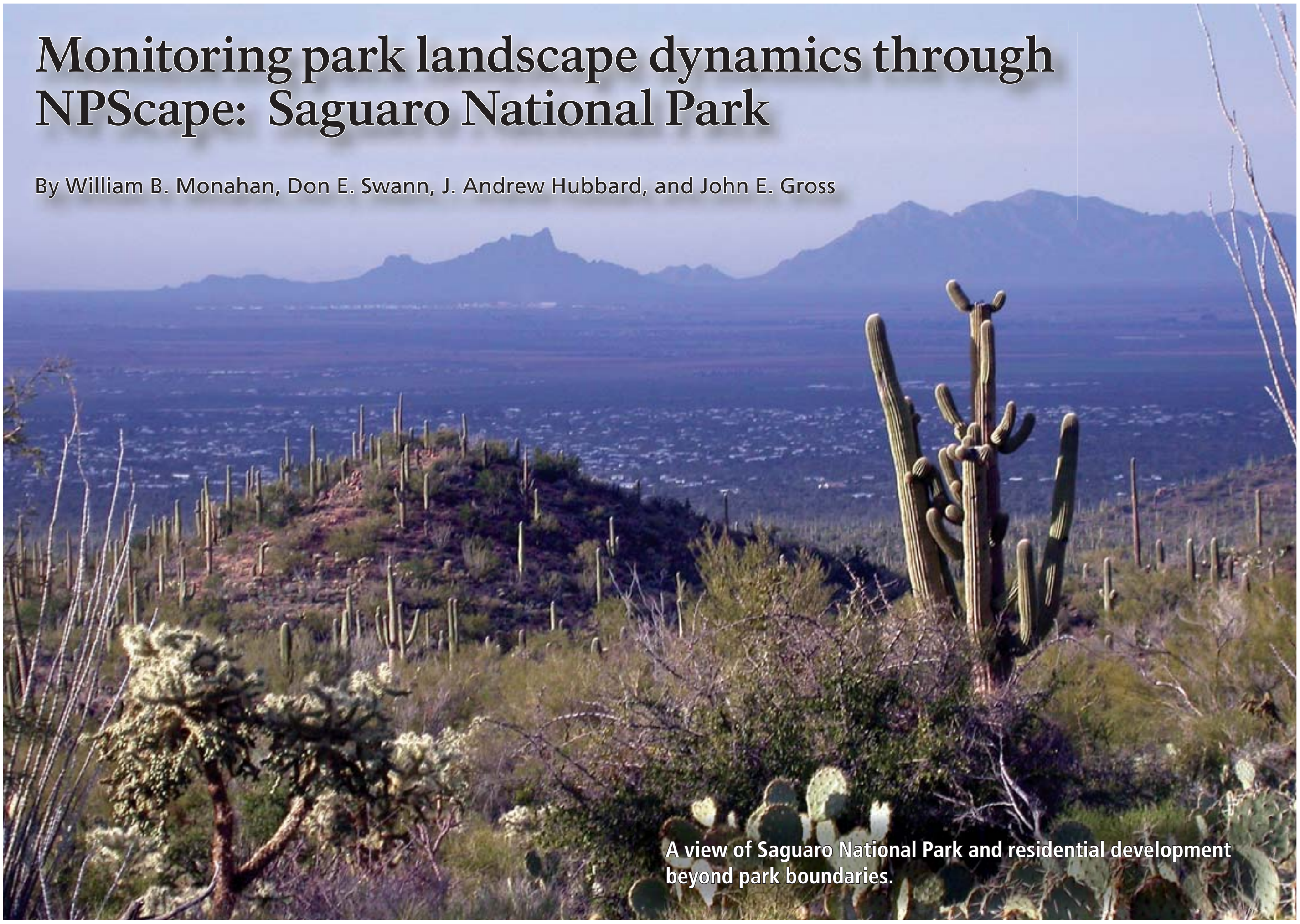
Case Studies

Monitoring park landscape dynamics through NPScape: Saguaro National Park

By William B. Monahan, Don E. Swann, J. Andrew Hubbard, and John E. Gross



NPS PHOTO ARCHIVE

A view of Saguaro National Park and residential development beyond park boundaries.

Abstract

Changes in the composition and configuration of different land cover types within and adjacent to national parks can affect a multitude of biological and physical processes, including habitat availability, animal movements, potential for invasion by exotic plants, water quality, and in-stream habitat for fish and other aquatic organisms. Information about the status and trends of landscape-scale indicators in and around parks can help park staffs anticipate, interpret, plan for, and manage associated effects on park resources. NPScape is a landscape dynamics monitoring project that produces and delivers to parks a suite of landscape-scale data sets, maps, reports, and other products to inform resource management, planning, and interpretation at local, regional, and national scales. The target audience for NPScape spans the range from GIS specialists who will benefit from the geospatial data and tools, to network ecologists and park resource management specialists who will be interested in general landscape metrics presented in a local and regional context, to park superintendents who can incorporate the maps and graphics into reports or briefings. Here, we present an overview of NPScape and describe its uses at Saguaro National Park.

PARKS AND OTHER PROTECTED AREAS ARE IMPORTANT sources of highly valued ecosystem services that include preservation of biodiversity, provision of freshwater, detoxification of pollutants, recreation, and scenic enjoyment. When the National Park Service (NPS) was established in 1916, the prevailing thought was that these resources would be retained by simply "building a bigger fence"—that is, by isolating parks from threats and insults that originated outside park boundaries.

We now know that land use changes outside parks have profoundly affected virtually all U.S. national park units, and they will continue to do so in the future (U.S. General Accounting Office 1994; Radeloff et al. 2010; Davis and Hansen 2011; Monahan and Gross 2012). Furthermore, recent land use intensification has occurred at a disproportionately rapid rate near the boundaries of protected areas (Wittemyer et al. 2008; Wade and Theobald 2010). If this trend continues, projections are for an additional 17 million housing units to be constructed within 50 km (31 mi) of protected areas in the United States, with more than 1 million units within 1 km (0.6 mi) (Radeloff et al. 2010). Impacts of external threats on

Key words

conservation context, conservation status, GIS, housing, human drivers, human population, inventory and monitoring, land cover, landscape dynamics, landscape pattern, natural systems, NPScape, resource management, roads, Saguaro National Park

parks are already so prevalent that well-considered essays have questioned the ability of the National Park Service to retain even large wilderness parks in an "unimpaired" condition (Cole et al. 2008; chapters in Cole and Yung 2010).

Our appreciation for the importance of broad-scale influences on park resources has grown more rapidly than our ability to identify and assess the specific locations and magnitudes of risk posed by these factors. Most protected areas are threatened by invasive species, climate-driven changes, habitat conversion, and loss of connectivity. Recognition that the effective scale of these critical threats is much broader than individual management units has motivated actions at local to national scales to form new partnerships, and has stimulated the establishment of the emerging Department of the Interior (DOI) Landscape Conservation Cooperatives and regional Climate Science Centers (DOI Secretarial Order 3289). In concert with these higher-level activities, DOI bureaus are conducting assessments at watershed to ecoregional scales. The broad geographical scope of these assessments is consistent with our current ecological thinking, but it is well beyond the area traditionally addressed in park-based natural resource studies and it far exceeds the data holdings and analytical capabilities of most U.S. land management units administered by the National Park Service or any other U.S. bureau.

NPScape: Landscape dynamics monitoring of national parks

NPScape is an NPS landscape dynamics monitoring project designed to help parks better understand the landscape-level opportunities and challenges they face in protecting park natural resources. To support these needs, NPScape produces and delivers landscape-level data, maps, analyses, and interpretations to inform natural resource management and planning over a range of park-relevant scales. Key NPScape objectives are to provide

- a coherent conceptual and analytical framework for conducting landscape-scale analyses and evaluations that can inform decisions
- useful geographic information system (GIS) data and maps at broad scales not typically available to individual parks
- well-documented methods founded on strong science, and readily repeatable and extensible with local data
- assistance to parks in interpreting results

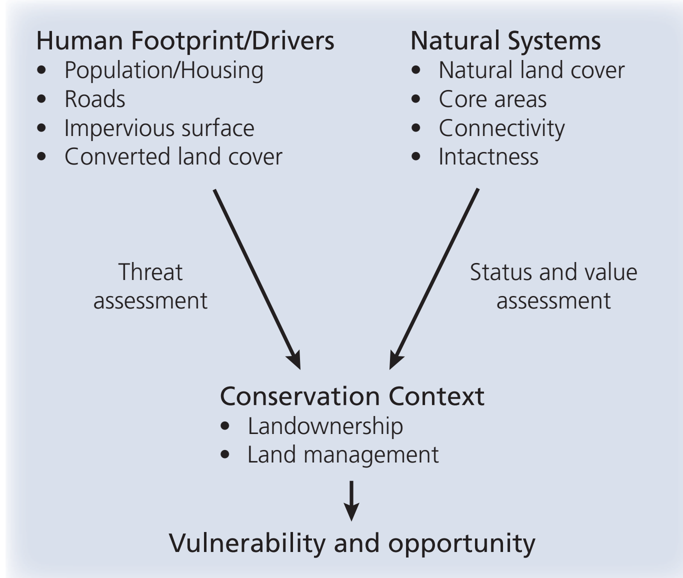


Figure 1. Broad categories of measures evaluated by NPScape and how they contribute to understanding the landscape context of parks and park resources.

These objectives are well aligned with needs common to most natural area managers and current DOI directives that address some of the most pressing environmental issues of our time.

NPScape data and analyses are developed from a conceptual framework that links measurable attributes of landscapes to natural resources within parks (fig. 1). This framework articulates key attributes of the greater park environment and relates these attributes to landscape condition and the ecological context of parks. At its core, NPScape is designed to support and enhance conservation of park resources that may be vulnerable to or benefit from landscape-level changes and management. The framework focuses on attributes of (1) the natural systems, (2) human drivers of landscape change, and (3) conservation context of surrounding areas. This framework is derived from and founded on more comprehensive analyses of the mechanisms that link land use intensification outside protected areas to the resources within those areas (Hansen and DeFries 2007).

Landscape dynamics is one of the highest-priority "vital signs" identified by NPS Inventory and Monitoring (I&M) networks (Fancy et al. 2009; Fancy and Bennetts 2012). As part of landscape dynamics monitoring, NPScape focuses on a set of information-rich, landscape-scale metrics in six major categories: population, housing, roads, land cover, landscape pattern, and conservation status (table 1). These categories broadly address the human drivers, natural attributes, and conservation context of parks (fig. 1). NPScape data, methods, and results are designed to support decisions at the park level and focus on analyses that rely heavily on

Table 1. Core NPScape measures, metrics, and key data attributes

				Geographic coverage					
Measure	**Metric**	**Years**	**Resolution**	**Alaska**	**Lower 48**	**Pacific**	**Caribbean**	**Mexico**	**Canada**
Population	Current: total and density	1990, 2000, 2010	Census block groups	X	X	X	X		
	Historical: total and density	1790–1990, by decade	County		X				
	Projected: total and density	2010–2050, by decade	County	X	X				
Housing	Housing density	1970–2100, by decade	100 m cells		X				
Roads	Road density	Varies, up to 2005	Varies	X	X	X	X		X
	Distance from roads	Varies, up to 2005	Varies	X	X	X	X		X
	Area without roads	Varies, up to 2005	Varies	X	X	X	X		
Land cover	Natural vs. converted	Varies, 1996–2006	30 m or 250 m cells	X	X	X		X	X
	Anderson Level I & II	Varies, 1996–2006	30 m or 250 m cells	X	X	X		X	X
	Impervious surface	2001, 2006	30 m cells		X	X			
Pattern	Patch size	2001 or 2005	30 m or 250 m cells	X	X			X	X
	Morphology	2001 or 2005	30 m or 250 m cells	X	X			X	X
	Area density	2001 or 2005	30 m or 250 m cells	X	X			X	X
Conservation status	Area protected	Varies	Varies	X	X	X	X	X	X
	Ownership	Varies	Varies	X	X	X	X	X	X

Note: Where possible, metrics are provided with coverage extending into Canada and Mexico for the benefit of parks located near these international boundaries.

GIS. NPScape delivers the landscape metrics listed in table 1 for most parks using published, national-level source data, thereby facilitating use by parks that do not have in-house GIS capabilities or data. In addition to the landscape metrics computed for various areas around parks, NPScape provides a dynamic map viewer, which enables non-GIS specialists to quickly visualize results and save maps for use in reports or briefings (e.g., housing and road density maps, such as those shown on pages 74–75, could be produced by anyone using the NPScape map viewer).

NPScape products also include a series of methodological reports, or standard operating procedures (SOPs), and ArcGIS scripts and toolboxes that enable GIS users to quickly recompute NPScape metrics using other data sources and spatial extents.

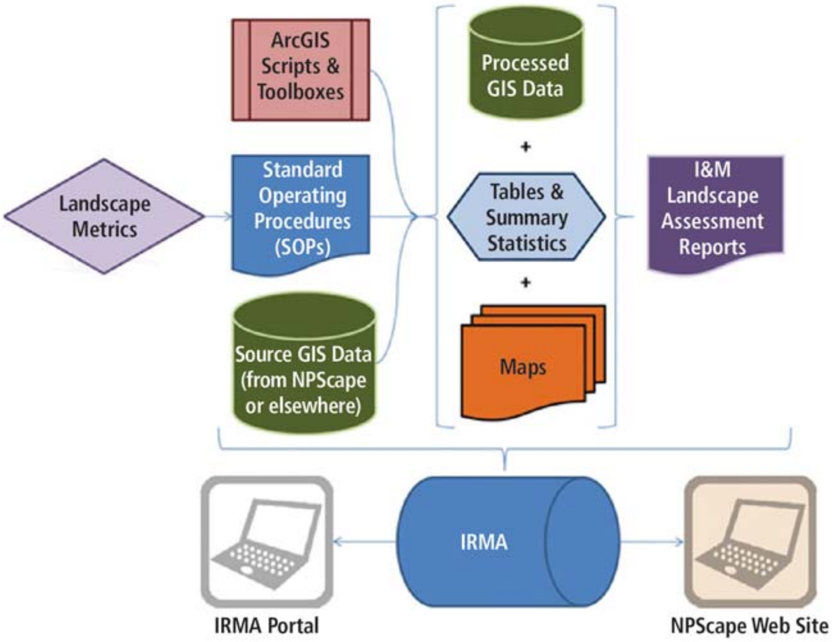


Figure 2. Overview of processing steps and products delivered by NPScape to I&M networks, parks, and others. We begin by defining a core set of landscape metrics that are of fundamental value to all or most parks (see table 1). We then document in great detail the GIS methods (SOPs) needed to quantify the landscape metrics, including the source GIS data inputs and ArcGIS scripts and toolboxes to assist with computations. Importantly, these methods enable others to recompute the landscape metrics using local source data, where available. Primary outputs from our methods include processed GIS data, tables with summary statistics, and maps to assist visualization by non-GIS audiences. These outputs are then used to generate I&M assessments and reports. All NPScape products are managed through the Integrated Resource Management Applications (IRMA) system and are available for public viewing and download through either the IRMA portal or the NPScape Web site (see sidebar).

Finding and acquiring NPScape products

Main NPScape Web site for overview of project and access to products: http://science.nature.nps.gov/im/monitor/npscape/

NPScape map viewer for exploring land-scape data and creating custom maps: http://science.nature.nps.gov/im/monitor/npscape/viewer/

NPScape guidance for conceptualizing and interpreting landscape-level analyses: http://science.nature.nps.gov/im/monitor/npscape/interpguide.cfm

NPScape methods for conducting land-scape-level analyses: http://science.nature.nps.gov/im/monitor/npscape/methods.cfm

NPScape GIS data and results: http://science.nature.nps.gov/im/monitor/npscape/gis_data.cfm

Direct access to NPScape products through the IRMA portal: https://irma.nps.gov/App/Reference/Profile/2183558

For example, NPScape relies on relatively coarse-scale GIS data because these are the only suitable data available at regional to national extents. But some parks have access to finer-resolution data that may only be available (and consistent) at county to state extents, and they generally want to use these data in a decision-making process. Using standardized NPScape methods (i.e., SOPs and GIS toolboxes), GIS specialists can easily and quickly recompute NPScape metrics using, for example, a higher-resolution land cover data set or a customized park planning region. These unusually well-documented SOPs and GIS processing tools are powerful resources to help parks calculate landscape metrics on local data using expert knowledge.

NPScape provides a rich and varied source of basic data as well as a large and sophisticated set of analyses. Few parks, I&M networks, or regional offices have staffs with the expertise to interpret this broad range of results. To help educate users, we developed a guide on how to interpret NPScape data and analyses in relation to park natural resources (Monahan et al. 2012). The NPScape interpretive guide furnishes examples of landscape metrics for particular parks, describes the ecological basis of the metrics, and summarizes scientific literature for how each may influence key resources such as biodiversity, watershed condition, and habitat connectivity. The interpretive guide is intended to help parks and networks use landscape-level data and results to address questions that often arise with little warning. Additional examples of park applications of NPScape include analyses of park upstream watersheds (Monahan and Gross 2012), geospatial analyses of BLM-proposed solar energy program lands (National Park Service 2012), natural resource condition assessments (Stark et al. 2011), and park-focused landscape dynamics reports (McIntyre and Ellis 2011).

Accessing and integrating NPScape products

NPScape products are available for public download through the DataStore of the Integrated Resource Management Applications (IRMA) portal and the NPScape Web site (fig. 2; see sidebar). IRMA is essentially a one-stop shop for park data, and by distributing NPScape products via IRMA they are discoverable using standardized search tools that will also identify other types of park-based information in the form of reports, publications, park species lists, and links to other data sources. Additionally, IRMA DataStore references provide, serve, and archive detailed metadata on the compilation and derivation of NPScape products. The NPScape project Web site provides basic background information and streamlines access via direct links to products in the IRMA DataStore.

Landscape-scale resource management means working with partners, which dramatically increases the need for effective information sharing and integration. IRMA provides basic means to relate NPScape products to other landscape projects, but NPScape goes a step further by sharing its data via Internet map services that may be readily integrated into other GIS-based landscape projects and Web sites. Four other groups and projects that NPScape has been working with in this regard are

- Park Analysis and Landscape Monitoring Support (PALMS, http://science.nature.nps.gov/im/monitor/lulc/palms/index.cfm, Gross et al. 2011), which includes products from NASA Ames' Terrestrial Observation and Prediction System (TOPS, Nemani et al. 2009, http://ecocast.arc.nasa.gov/)
- USGS Gap Analysis Program (http://gapanalysis.usgs.gov/)
- Assessing Socioeconomic Planning Needs, a joint USGS/NPS socioeconomic analysis decision support tool under development (Koontz et al. 2011; Montag et al. 2012)
- Landscape Climate Change Vulnerability Project (LCC-VP), an NPS Inventory and Monitoring and NASA-funded project that seeks to develop and link climate change vulnerability assessments to management in two Landscape Conservation Cooperatives (Hansen et al. 2011, http://www.montana.edu/lccvp/index.html)

Our goal in forging these new connections is to help ensure that NPScape is increasingly able to deliver to parks the information needed to understand resource conservation in a landscape context.

The value of NPScape to Saguaro National Park

By way of introduction, consider the example of the desert tortoise (*Gopherus agassizii*) in Saguaro National Park, Arizona. Within the park, the attributes of the natural system that support tortoise populations are areas of suitable habitat, and integrity and connectedness of the habitats. The capacity of the natural system to maintain tortoise populations must be evaluated in the context of landscape changes and threats, including human population, housing, roads, and other land cover conversions. Tortoise populations in the park were historically connected to populations outside, but this connectivity is being disrupted by habitat loss because of urban development and barriers that include roads and residential developments (Edwards et al. 2004a, b; figs. 3 and 4, pages 74–75). The overall assessment and evaluation of conservation potential rely on the stewardship of the park and surrounding natural systems. Conservation potential depends on current land condition, landownership, level of protection, and the spatial (geographical) context of lands suitable for conservation. NPScape describes and illustrates these essential landscape elements and provides a framework and methods to quantify, analyze, and interpret results. In turn, these customized park products enhance planning and management of natural resources such as the desert tortoise.

Saguaro National Park, like many parks in the western United States, has experienced rapid urban growth outside its boundaries. When the park was first established as a national monument in 1933, the nearby city of Tucson had fewer than 40,000 residents, and the city was more than 20 miles (32 km) distant along poorly developed dirt roads. Today, Tucson has nearly 1 million residents, and according to state projections compiled by NPScape the population in Pima County is expected to increase to more than 1.4 million by the year 2030.

The park comprises two districts: the Rincon Mountain District, approximately 100 square miles (259 sq km) on the east side of Tucson, and the Tucson Mountain District, approximately 40 square miles (104 sq km) west of Tucson. Housing developments flank both districts and housing densities have rapidly increased in recent decades (fig. 3). In addition, a major commuter road (Picture Rocks Road, fig. 4) cuts through the Tucson Mountain District. These landscape-level changes have profoundly affected the park's resources, especially wildlife such as javelina, deer, coyote (McClure et al. 1996), and desert tortoise (Edwards et al. 2004a, b). An estimated 29,000 animals are killed annually by cars on the 76.6 miles (123.2 km) of roads that run through the park or along the park's boundary (Gerow et al. 2010). Park resources are also affected by nonnative species, particularly domestic dogs and buffelgrass. The city concentrates urban heat near the park, raises ozone and particulate pollution, profoundly alters night skies, and contributes sound pollution from increasing air traffic over the park's interior.

Landscape dynamics also affect visitation to the park. Seventy-eight percent of Saguaro is classified as wilderness (National Park Service 2007). The East and West Saguaro Wildernesses—along with the U.S. Forest Service Pusch Ridge Wilderness north of Tucson—anchor the larger network of protected areas in the region. Some areas, especially in the Rincon Mountain District, are quite remote, but others that were remote when the wilderness was

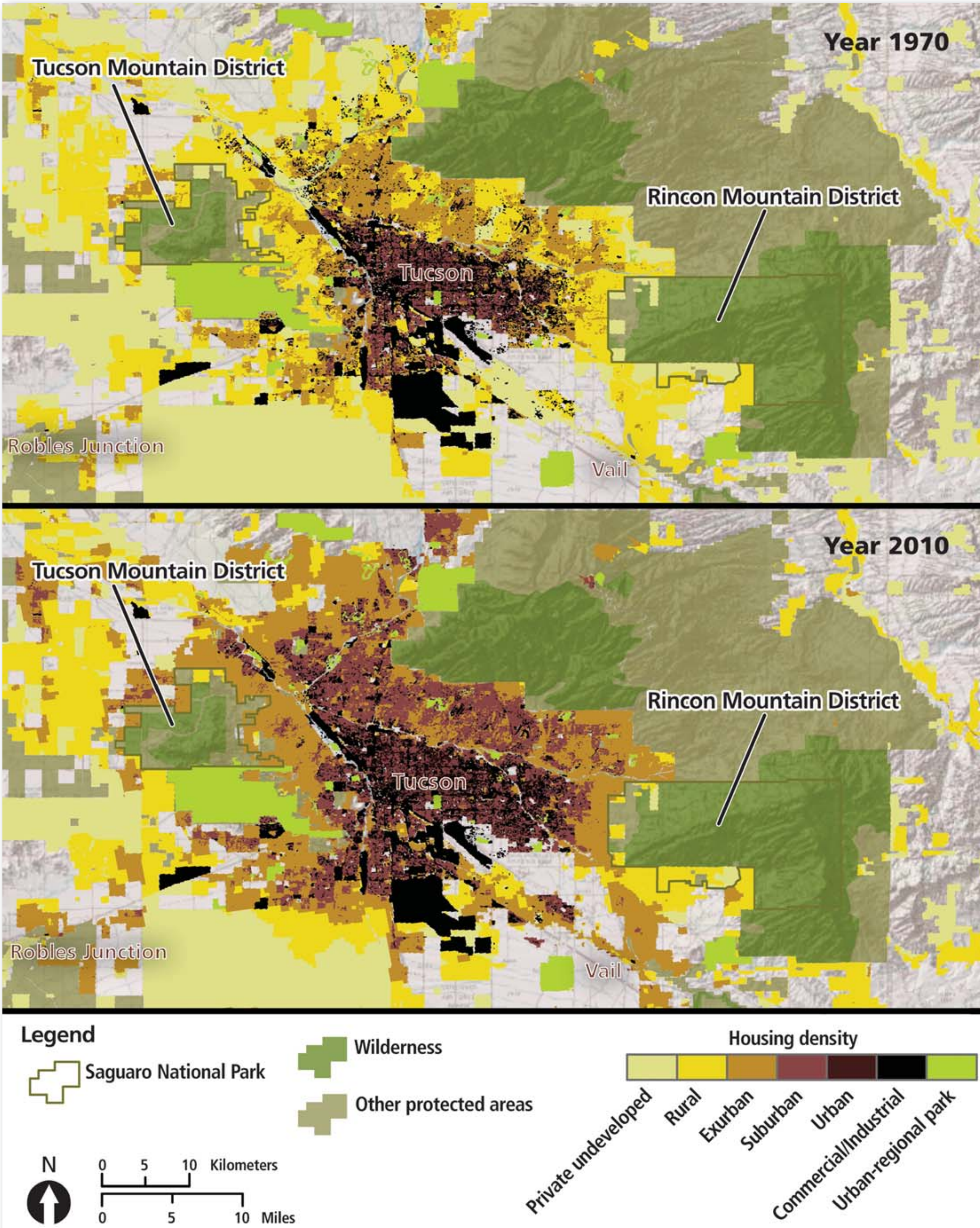


Figure 3. Housing density around Saguaro National Park in the recent past (1970, top map) and present (2010, bottom map). Housing density categories are defined by Theobald (2005): rural (< 0.0618 housing units/ha [< 0.1527 units/ac]), exurban (0.0618–1.47 units/ha [0.1527–3.63 units/ac]), suburban (1.47–10.0 units/ha [3.63–24.7 units/ac]), and urban (> 10.0 units/ha [> 24.7 units/ac]).

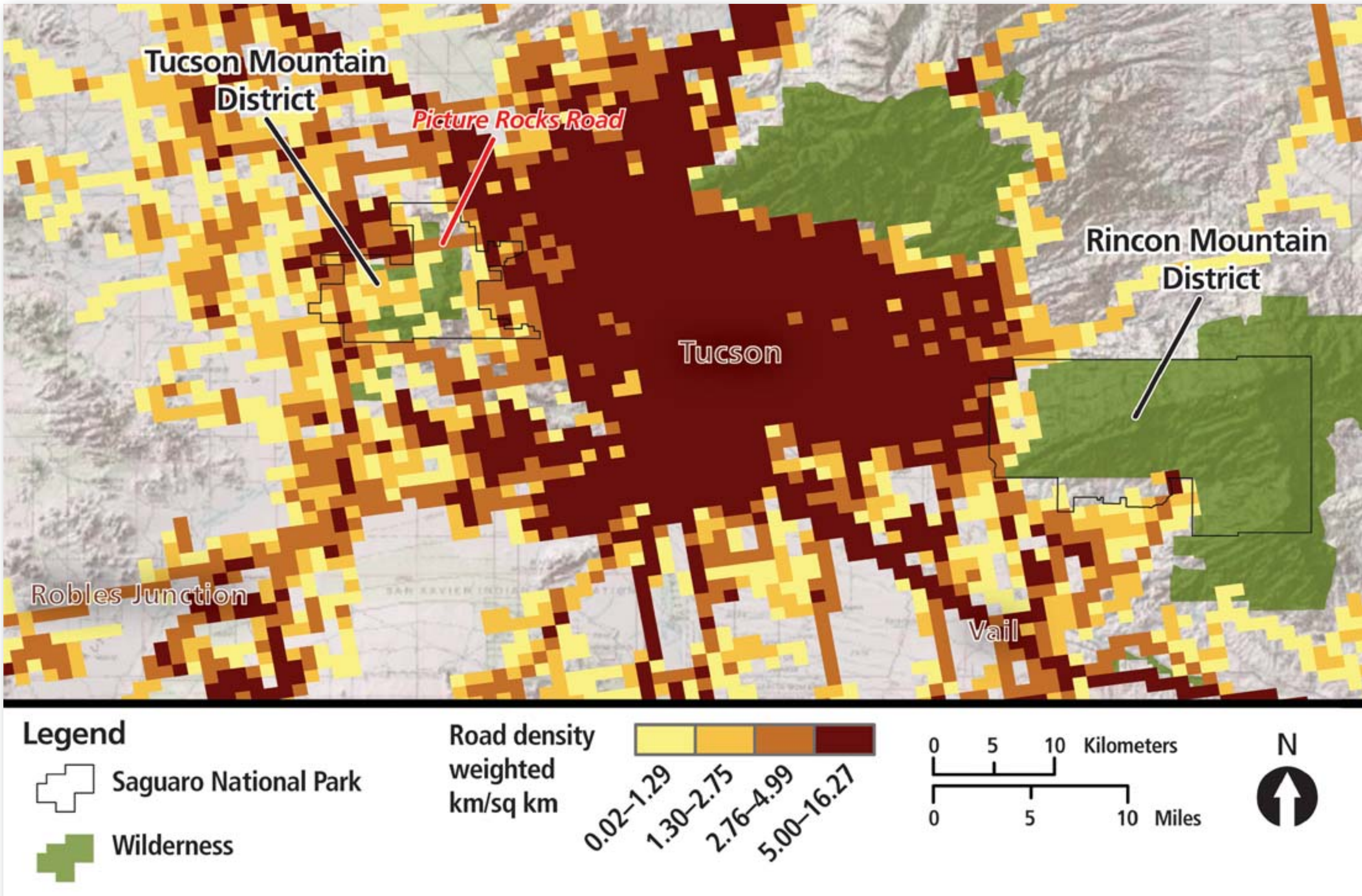


Figure 4. Weighted road density in the local area surrounding Saguaro National Park. Higher road densities are often associated with higher traffic volumes and larger areas of road clearings.

Changes in the landscape surrounding Saguaro National Park are now part of the park's story, no less than ecological changes in the saguaro forest.

designated are now adjacent to high-density housing (fig. 3) and roads with high traffic volume (fig. 4). Whereas visitation to the park once was primarily by out-of-town tourists, the vast majority of current visitors are local recreationists, with the number of bicycles now approaching the number of cars on the Rincon Mountain District's Cactus Forest Loop Road (Saguaro National Park, unpublished data).

NPScape products are of considerable value to Saguaro's managers, who have come to recognize that the park can no longer be managed in isolation from its neighbors. One simple but important application for landscape-level maps is to illustrate the significant changes the park is experiencing, and to interpret those changes for park staff, partners, and the public. NPScape maps of Tucson's explosive urban growth (fig. 3) tell the story of landscape change more profoundly than any words. They help explain the park's issues in protecting resources to partners, who can then help carry that message and work forward.

These maps also create opportunities for working with new partners. Saguaro is currently developing a wilderness management plan, and NPScape products have the potential to illustrate how landscape-level changes outside the park can influence aspects of wilderness character, especially visitor experience. For example, nighttime light pollution may be assessed in relation to viewsheds from key observation points inside the park (fig. 5, next page). Insights gained from these analyses may suggest ways to mitigate

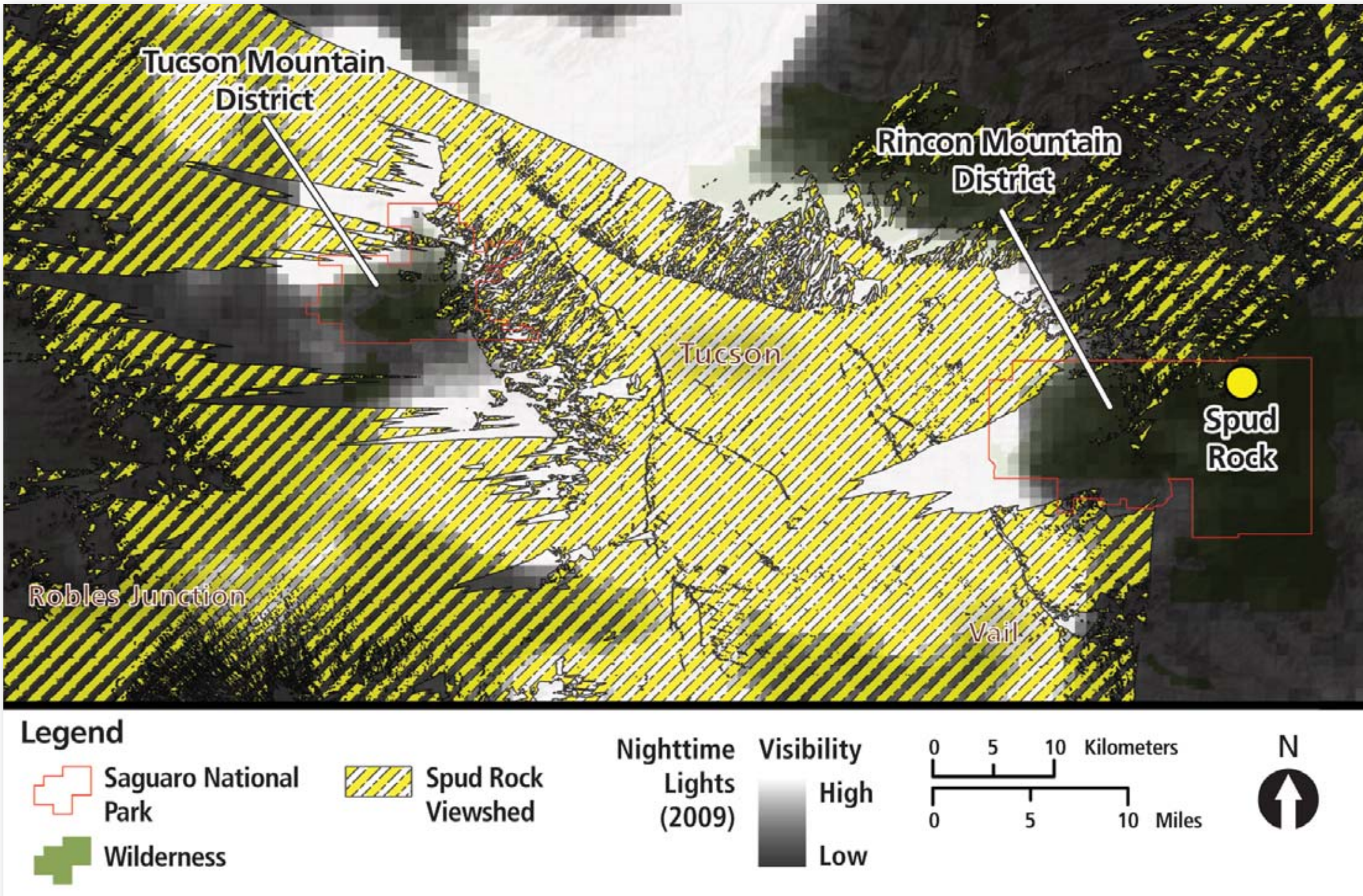


Figure 5. Viewshed from Spud Rock in the Saguaro Wilderness of Rincon Mountain District, considered in relation to nighttime light pollution (year 2009). Lighter areas (white and light gray) have more light pollution than dark areas (dark gray and black). Yellow hatching identifies all areas visible from Spud Rock; some of these areas are more challenged by nighttime lights than others. Saguaro is able to use maps such as this in wilderness planning.

such influences or work with partners who are grappling with similar issues.

While the focus on profound landscape-level changes (such as the increases in human population) is usually on the negative effects of these changes on park resources, NPScape also provides maps and analyses that can help parks achieve other goals. An important goal at Saguaro is to increase the park's relevance to the surrounding community, particularly among youth. NPScape has developed customized maps for the park that use U.S. Census data to identify such attributes as age and economic status in communities that are currently underserved by the park (fig. 6). For the NPS–National Geographic Society BioBlitz, Saguaro's major event in 2011, park staff connected schoolchildren with biological diversity and reached out to schools that have not traditionally visited the park. NPScape maps show where the two Saguaro districts are in relation to these opportunities, and provide educational materials for teaching how its natural resources—saguaro cacti, birds, water, and dark skies—both contribute to Tucson and are influenced by the actions of all who live nearby.

Changes in the landscape surrounding Saguaro National Park are now part of the park's story, no less than ecological changes in the saguaro forest (Swann et al. 2012). NPScape maps of human drivers changing over time—housing density, human population, road density—can be used to illustrate this story by interpretive staff. Ultimately, the data and maps can help to illustrate the story about the relationship between human society and the "natural" world, and the role of national parks within it.

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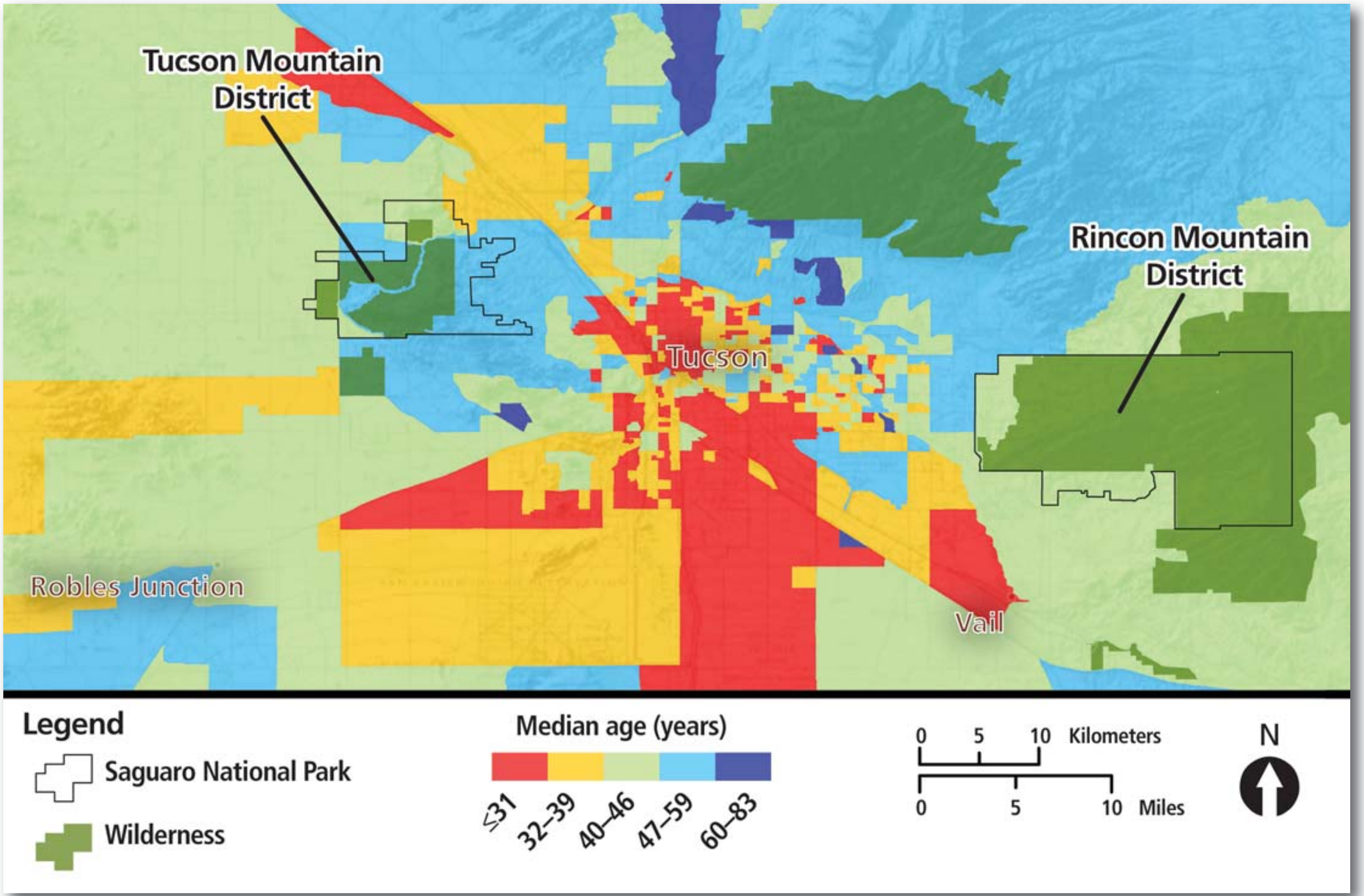

Figure 6. Median age of residents based on data from the 2010 U.S. Census for areas surrounding Saguaro National Park. Census-based demographic maps and analyses such as these provide important insights on where and how best to engage local communities as park recreational visitors. NPScape coordinates with the Social Science Branch of the Environmental Quality Division on the production and distribution of these metrics.

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PS

Information Crossfile

BOOK REVIEW

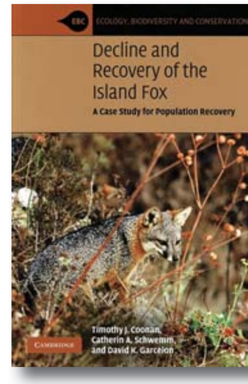
Decline and Recovery of the Island Fox

By the editor

Decline and Recovery of the Island Fox: A Case Study for Population Recovery

Timothy J. Coonan, Catherin A. Schwemm, and David K. Garcelon

2010
Cambridge University Press



THE STORY OF ECOLOGICAL RESTORATION OF THE CALIFORNIA Channel Islands, including Channel Islands National Park, is an inspiring one, and the plight of the diminutive but resilient island fox (*Urocyon littoralis* spp.), the top predator in this relatively simple ecosystem, is central to the tale. By 1995 ecological monitoring on San Miguel and Santa Cruz Islands in the national park had detected rapid and alarming declines in the populations of island foxes there; subsequent assessments on Santa Rosa and Santa Catalina Islands confirmed population declines there as well. These findings set in motion a decade-long series of emergency conservation measures aimed at understanding the declines, weighing options to prevent the foxes' extinction, and fostering recovery of the species. The incredibly effective work of more than 100 biologists, land managers, academics, veterinarians, and other endangered species experts is explained from start to finish in this detailed account by NPS wildlife biologist Tim Coonan, NPS ecologist Cathy Schwemm, president and founder of the nonprofit Institute for Wildlife Studies David Garcelon, and two other chapter authors Cheryl Asa and Linda Munson.

As part of the Ecology, Biodiversity, and Conservation series of Cambridge University Press, this book is a scientific treatise on the decline and recovery of four of the six subspecies of island fox. Though it is authoritative, its style is accessible and inclusive of nonscientists, describing specific topics in the context of the whole recovery effort and the social, political, economic, legal, and policy aspects of the management setting. It also does a marvelous job of relating this case study in population recovery to general ecological and restoration principles drawn from the literature. At many points the authors review conservation theory and then reason how it applies (or not) to the situation of the island fox, a most interesting leap of intellect that most readers will appreciate. I also value the manner in which the authors clarify jargon by interjecting stimulating alternative explanations that greatly improved my understanding of technical material.

Apart from the initial chapters that describe the life history and related biological facts of the island fox, I found the book to be very interesting and inspiring. In particular, when the story turned to the investigation of fox mortality, it read like a forensics mystery in which the protagonists gather and analyze evidence that challenges their assumptions, devise and test new hypotheses, and find meaningful leads. Eventually a picture emerges of unrelated yet contemporaneous causes of the declines: canine distemper virus (CDV) on Santa Catalina Island and predation by golden eagles on the other three islands. However, the story is more complex than this. Human influences on the islands were responsible for (1) the introduction of domestic dogs and the attraction of raccoons that may serve as hosts for distemper virus and (2) the introduction of pigs that became the primary food source of otherwise nonresident golden eagles that threatened northern Channel Islands foxes. Recovery of the island fox ultimately involved captive breeding programs for four subspecies of fox, eradication of feral pigs, relocation of golden eagles to the mainland, reintroduction of bald eagles that may help discourage golden eagle nesting, development and administration of a CDV vaccine for Catalina Island foxes, population modeling, federal listing as an endangered species, and the controversial reintroduction of captive-held or -born island foxes to the wild.

Throughout the text the authors acquire and integrate new information as they confront problems and work out solutions. They form workgroups, reach out for help, mount an educational campaign, revise conservation strategies, and contemplate actions. Their methods clearly improve over time. The process is not always smooth but they press on. They attribute their success partly to the ecological monitoring at the time, which detected the rapid decline. (Indeed the book makes a strong case for ecological monitoring even in the absence of any signs of trouble.) Not only did I get a good sense of the dedication and intelligence of the personnel behind the recovery work, but also I got to know the island fox and its ecological place on the islands, a pleasurable experience for me.

The book is substantial but not overwhelming. At 212 pages it has 15 chapters, 28 photos, 15 graphs or diagrams, and 14 tables. It will surely interest biologists involved with small mammal conservation or maintaining island biodiversity. It will also appeal to conservation-minded people for its uplifting story of successful intervention and recovery of this species and for the well-functioning team involved in these efforts. As the authors state in conclusion, "We suggest that with or without Endangered Species Act protection, species and habitat conservation will benefit most from productive and sincere human collaborations." I couldn't agree more.

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