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PARKScience

Integrating Research and Resource Management in the National Parks

National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science
Office of Education and Outreach

CLIMATE-BASED HABITAT MODELING IN ZION

Mapping potentially suitable habitat for desert tortoise, American pika, and Shivwits milk-vetch

ALSO IN THIS ISSUE

- Fuel efficiency of oversnow vehicles in Yellowstone
- Speedy alternatives for recreational water quality analysis
- Solar energy development in the Southwest: Landscape-scale resource assessment
- An assessment of night resources and nighttime recreation in national parks

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Park Science is a research and resource management journal 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 or subject-matter experts review content for clarity, completeness, usefulness, scientific and technical soundness, and relevance to NPS policy.

From the Editor

Rummaging through the attic

I recently completed a project that had been on my to-do list for about 10 years: create and annotate digital versions (PDFs) of the entire catalog of *Park Science* articles and make them available online. Working from an index produced by National Park Service (NPS) library staff, I had begun the project years earlier, only to realize the goal was out of reach without a major time commitment. I was reinvigorated by a request to incorporate the index and PDFs into IRMA, the Integration of Resource Management Applications, which facilitates searching multiple NPS databases from a single Web portal. After nearly three months of work the project is done. The PDFs—3,608 of them—have been described with metadata, and the data records are being logged in IRMA. The collection will soon be available through the Data Store at http://irma.nps.gov/App/Portal. Later this year I plan to revamp the *Park Science* Web site search feature for use with this new collection.

Poring over the digital "stacks of paper" to create the collection was an exacting but enriching experience. I rediscovered many fine examples of exposition, analysis, wit, and wisdom that trace three decades of change and growth in the National Park Service with respect to research and resource management capabilities. The needs to professionalize resource management, communicate science findings effectively, and awaken NPS leaders to the full value of science for park understanding and management are argued persuasively and earnestly. Further strides are evident in the increase in resource management staffing levels, expertise sharing as a model for the inventory and monitoring networks, better access to scientific information, and broadening of park management approaches to ecosystems and consideration of landscape-level influences. Many of the changes were to the NPS organization, which has helped with consistency and integration of resource management programs. Individuals also stand out as articulate spokespersons for shaping the culture in which NPS staff can best understand, protect, and share park resources and their values.

In integrating research findings into park management, resource management strives to ensure the future of park resources. In publishing articles about this process *Park Science* aims to enhance this relationship. The recent development of the article catalog will give readers better access to this important source of knowledge and a historical look at our progress.

—*Jeff Selleck, Editor*

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

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

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

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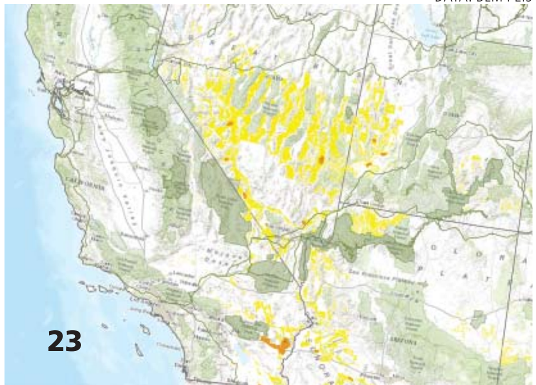

NPS/CHRISTINA MILLS

DEPARTMENTS

ON THE COVER

Rugged terrain marked by nearly 4,000 feet of relief makes Zion Canyon a complex laboratory for the study of climate change. Sensitive species must adapt or perish as temperature and moisture shift, but by how much and where? Beginning on page 14, scientists describe their work combining analytical techniques to map potentially suitable habitat in the future.

NPS/DAVID THOMA

STATE OF SCIENCE

CASE STUDIES

JESSE WHEELER

NPS/GEORGE SU

NPS/WOLF TRAP NATIONAL PARK FOR THE PERFORMING ARTS

UPCOMING ISSUES

Spring 2013
Seasonal issue. June release.
Contributor's deadline: 15 April

Fall 2013
Seasonal issue. December release.
Contributor's deadline: 15 October

Winter 2013–2014
Theme issue: Biodiversity discovery in the national parks. February 2014 release.
Contributor's deadline: 15 November.

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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RESEARCH REPORTS

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NATIONAL PARK AREAS DISCUSSED IN THIS ISSUE

Abbreviations

NHS	National Historic Site
NL	National Lakeshore
NP	National Park
NRA	National Recreation Area
NS	National Seashore

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State of Science

New recreational water testing alternatives

By Kurt Kesteloot, Azliyati Azizan, Richard Whitman, and Meredith Nevers

USGS/MEREDITH NEVERS

A technician samples water from a swimming area adjacent to Indiana Dunes National Lakeshore. New analytical methods allow for near–real time test results of water quality and better protection of public health.

ELEVATED LEVELS OF FECAL INDICAtor bacteria (FIB) such as *Escherichia coli* (*E. coli*) and enterococci can indicate the presence of pathogenic microorganisms, leading to health risk concerns for recreational areas along lakes, rivers, and oceans. These pathogens can cause a variety of illnesses in humans, including gastrointestinal illnesses, rashes, and eye infections. The U.S. Environmental Protection Agency (EPA) regulations provide standards for FIB levels in recreational waters that guide health advisory decisions. Until they were revised in November 2012, EPA-approved methodologies for monitoring FIB were relatively slow in providing results to health officials and recreational water users, typically 18–24 hours after sampling (Brady et al. 2009). According to the USEPA (2012), there is no scientific evidence supporting beach water quality determinations based on, at best, day-old (culture-based) data. Thus, health advisories or beach closures are usually issued many hours after visitors may have been exposed to potential pathogens and have since left the area.

Since the EPA recreational water FIB limits were established in 1986, faster methods have been developed; however, until recently, they were prohibitively expensive, complicated, unproven, and pending approval for protecting public health (USEPA Office of Water 2003; USEPA 2006). The National Park Service (NPS) monitors recreational water quality according to the EPA standards and for more than a decade, along with federal and other scientists and public health officials, has raised concerns that the lag time of standard reporting methods places water recreators at unacceptable levels of risk for waterborne disease outbreaks. However, in November 2012 the EPA revised its recreation water quality testing standards, allowing park and recreation area managers to begin to incorporate some of the newer, more effective testing methods that we review in this article into their operations.

Background

Congress enacted the BEACH (Beaches Environmental Assessment and Coastal

Abstract

Each year recreational water users descend on national parks by the millions. U.S. Environmental Protection Agency (EPA) regulations require monitoring waters for fecal indicator bacteria in order to safeguard human health, and obtaining results using the culturing method takes 18 hours or more of analytical time. Thus, under this surveillance regime swimmers can be exposed to waterborne disease organisms before health advisories can be issued. To address the need for timelier notification of recreational water quality, the EPA has evaluated and approved new and faster testing methods as of November 2012. This article discusses new recreational water testing methodologies such as qPCR, empirical predictive modeling, rainfall threshold levels, and advanced notification options for park managers to consider and tailor to their needs.

Key words

advanced notification, empirical predictive modeling, qPCR, rainfall threshold levels, recreational water testing, water-quality testing

Health) Act in 2000, amending and strengthening the Clean Water Act with respect to recreational water quality. Section 304 stated that within five years of the BEACH Act enactment, new or revised water quality standards for pathogens and pathogen indicators should be developed to better protect human health in coastal recreational waters. It also stipulated that within three years of revision to Clean Water Act section 304, states and tribes with coastal waters must adopt new or revised water quality standards applicable to changes in section 304 pathogen reporting. It further encouraged the continuing development of accurate, timely, and cost-effective methods for modeling and analyzing recreational water for pathogens harmful to human health (USEPA Office of Water and Office of Research and Development 2007).

Prompted by BEACH Act provisions, the EPA, Centers for Disease Control, local health departments, and many others collaborated on the National Epidemiological and Environmental Assessment of Recreational Water (NEEAR) and other studies to evaluate real-time recreational water testing techniques. Microbiological methods were tested for enterococci, *Bacteroides*, and alternate fecal indicator organisms. The methods were further assessed for specificity and sensitivity, their ability to reduce detection levels below the 1986 EPA enterococci limit, and the validity of data derived from samples that have endured long holding times. Alternate monitoring approaches were also explored, such as determining which hydrometeorological or chemical factors could predict FIB concentrations in swimming water. Among these, empirical predictive models (statistical models) were identified as especially promising (USEPA Office of Water 2011).

This article highlights the current developments and needs for a cost-effective, timely monitoring technique to protect swimmers' health in coastal waters. We review the recently revised federal criteria for safe swimming and discuss approaches the beach manager can use to combine or adapt methods for more accurate, site-specific application. We analyze and summarize four methodologies (see table 1, next page) because they appear to be the most viable options that are now available for testing recreational water in a timelier fashion.

New methodologies

The qPCR Method

Quantitative polymerase chain reaction (qPCR) is used in recreational water applications to detect *Bacteroides* or enterococci in water samples by identifying a particular signature genetic marker. When testing for enterococci, qPCR is more than 85% accurate in correctly identifying EPA-approved FIB levels (SCCWRP 2010). Figure 1 (next page) illustrates the correlation between incidences of reported swimming-related gastrointestinal illnesses and the average daily enterococcus values as measured using qPCR. Results of analyses for enterococci using qPCR do not typically match culturable bacteria counts: qPCR enumerates both live and dead bacteria. Studies have shown high correlations between qPCR and culturable counts, however, and studies in both marine and freshwater have revealed that public health protection decisions would be similar if time were not a factor (SCCWRP 2010; Whitman et al. 2010). However, the largest difference between the analytical techniques is that qPCR results can be obtained in just three to four hours, making it far timelier than culturable counts. In extensive epidemiological studies conducted by the EPA (NEEAR study) to test the use of qPCR for predicting illness of swimmers potentially exposed to point sources such as wastewater effluent, there was a significant correlation between incidences of gastrointestinal illnesses in swimmers and enterococcus levels as identified through the qPCR testing method. One study location at Indiana Dunes National Lakeshore (West Beach) showed a significant relationship between qPCR and the number of illnesses contracted by visitors (USEPA Office of Water 2010a).

The initial cost of a qPCR system is \$30,000–\$50,000, and the cost of each individual test ranges from \$8 to \$15. Use of qPCR also requires training for lab

Table 1. Characteristics of emerging testing methodologies for fecal indicator bacteria

qPCR	Empirical Predictive Models	Rainfall Threshold Levels	Advanced Notification
A rapid gene probe method used to quantify FIB levels; Cepheid Smart Cycler is an example of a device that provides means to speed up reactions. Significant setup cost Nominal single-test costs Need for skilled staff with training FIB levels determined in 3 hours or less Applicable to many sites Accepted by EPA with evidence of statistical significance for health effects	Tests various water and weather characteristics and develops relationships to FIB levels Resource managers select most cost-effective and statistically representative hydrometeorological characteristic that relates to FIB levels Potential significant development cost Minimal cost for individual tests Need for skilled staff with limited training FIB levels in minutes to hours Typically site-specific Accepted by EPA with evidence of statistical significance	Compares rainfall levels over specified durations from different floodplains that drain into recreational waters under investigation Relates FIB levels to rainfall Significant cost to develop thresholds Little to no cost for individual tests Staff with little to no training FIB levels in minutes to hours Site-specific Accepted by EPA with evidence of statistical significance	Analyzes statistical models, rainfall threshold values, weather predictions, and other data Extrapolates FIB levels for future by combining model results Significant development costs for models and correlations Nominal to marginal cost for individual tests Need for skilled staff with limited training Predictive FIB levels Typically site-specific Accepted by EPA with evidence of statistical significance

personnel to process and analyze results. Expensive initially, use of qPCR testing becomes more cost-effective as more tests are performed. The EPA has developed and validated a molecular testing method with qPCR, which is a rapid analytical technique for the detection of enterococci in recreational water (EPA Method 1611). Accordingly, it encourages federal and state agencies responsible for water quality monitoring to perform site-specific condition assessments before adopting statewide standards for FIB recreational water quality monitoring via qPCR. Agencies interested in developing site-specific water quality standards using qPCR will find a detailed discussion of EPA recommendations at http://water.epa.gov/scitech/swguidance/standards/criteria/health/recreation/upload/factsheet2012.pdf.

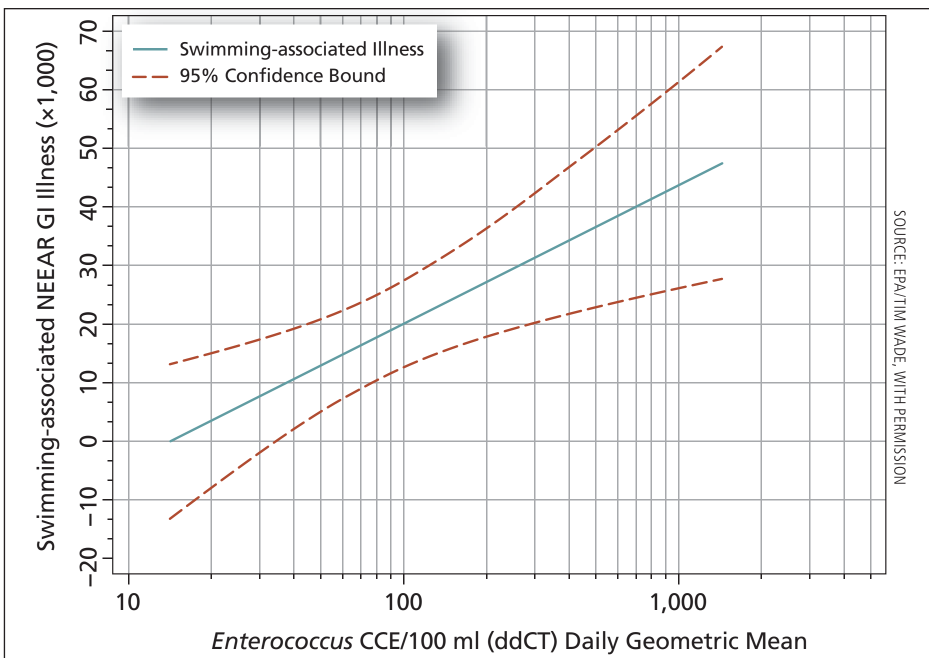
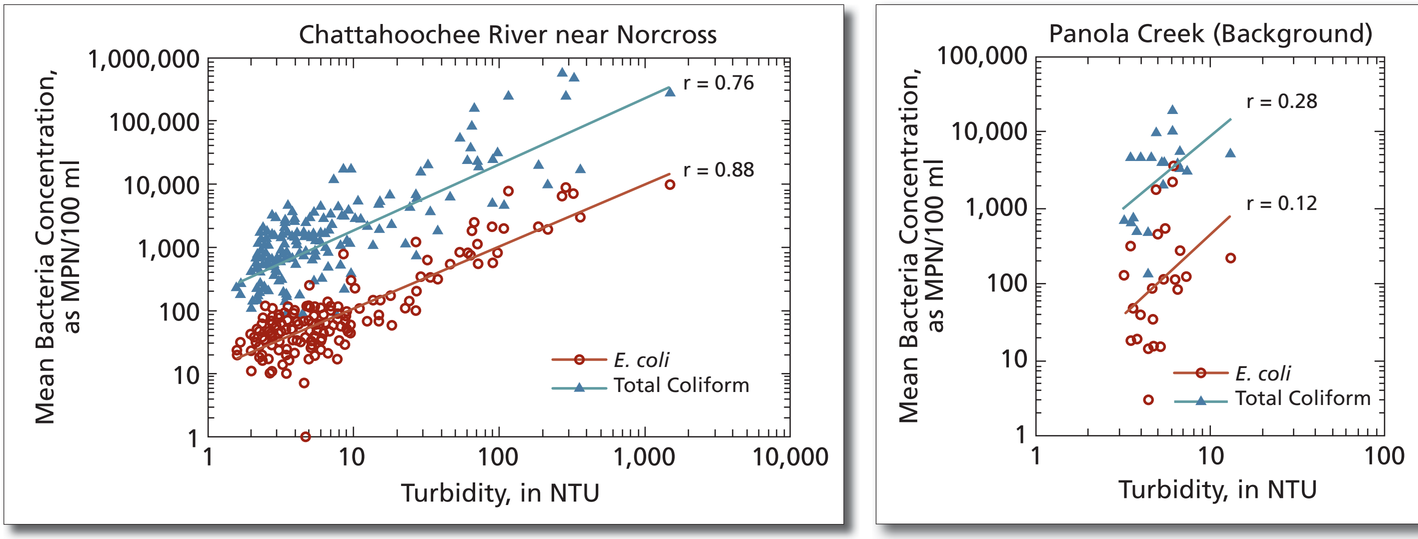


Figure 1. This graph relates the number of swimming-related gastrointestinal illnesses as defined by the National Epidemiological and Environmental Assessment of Recreational Water (NEEAR) study program to the average daily enterococcus qPCR calibrator cell equivalents (USEPA 2012), one of the promising new surveillance methods we review in this article.

Empirical predictive models

Commonly referred to as statistical models, empirical models can offer accurate and timely determinations of FIB levels in recreational waters. Physical, chemical, and meteorological conditions are commonly analyzed for statistical correlation with FIB and often include wind speed and direction, current magnitude and direction, tide or moon phase, river flow and stage, lake stage, groundwater levels, and physical location of the recreational area (USEPA Office of Water 2010b). Turbidity is a commonly used physical characteristic for approximating FIB, and can be measured instantaneously with a sensing probe. If an analysis of turbidity and bacteria levels reveals a statistically significant correlation between the two, then a single turbidity sensor reading can be used to signal unhealthy recreational water conditions. These empirical predictive models

SOURCE: USGS 2002/STEVE LAWRENCE WITH PERMISSION



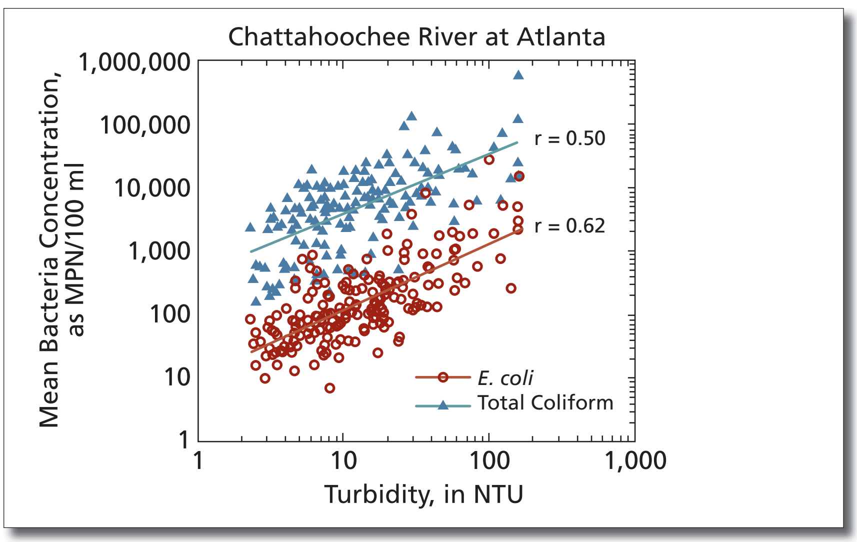


Figure 2. The graphs correlate bacterial counts of *E. coli* and total coliform at three sites in or near Chattahoochee River National Recreation Area, Georgia, with turbidity levels.

can be developed using single or multiple parameters, providing a robust prediction of real-time water quality (Nevers and Whitman 2005). Hydrodynamic models have been developed, but use and validation are trailing the traditional multiple linear regression models currently in use.

Since 2002 the National Park Service has based its health advisories for the Chattahoochee River National Recreation Area (NRA), Georgia, on empirical predictive models that correlate turbidity with *E. coli* and total coliform counts (USGS 2002). As shown in figure 2, some locations have a stronger correlation (*r* value) of turbidity to bacteria than others. At Chattahoochee River NRA, the *r* value between turbidity and *E. coli* ranged from 0.12 to 0.88, while the *r* value between turbidity and total coliform ranged from 0.28 to 0.76. An *r* value nearing 1.0 indicates a strong relationship between the data, while a value at or near 0.0 indicates little or no relationship between the sets of data compared. Therefore, in some locations at Chattahoochee NRA, turbidity levels provide a better indication of the amount of *E. coli* in the water than does total coliform.

Cuyahoga Valley National Park (Ohio) has also evaluated a similar model comparing turbidity and *E. coli* levels in the water. The model delivered promising results in 2009 at the Jaite site on the Cuyahoga River by correctly identifying unsafe levels of *E. coli* 81% of the time compared with traditional culture-based EPA testing methods. At a nearby river location called Independence, this same model also correctly identified unsafe *E. coli* levels 91% of the time, as opposed to 88% using the traditional method. However, results for other locations were not as accurate, with percentages in the low 70s for the model and low 80s for traditional methods (Brady et al. 2009). In 2011, one application of the turbidity-based model deemed the water safe when actually it tested poor using traditional methods (USGS Ohio Water Science Center 2011). The big advantage of the

The use of water quality standards specific to a location, combined with empirical predictive models, resulted in the greatest beach access without compromising health protection.

turbidity-based model, of course, is that it provided results within one hour, making it timelier than traditional monitoring methods. The EPA looks at empirical predictive models as a support tool for notifying recreational water users, thus there is no official r, R^2, or percentage comparison that is accepted that allows sole use of an empirical model for notifying and legally monitoring recreational waters.

Likewise, Indiana Dunes National Lakeshore uses predictive models developed by the U.S. Geological Survey (USGS) that assist with determining FIB levels at West Beach in the park and nearby Burns Ditch (Olyphant and Whitman 2004; Nevers and Whitman 2005). Based on the research of Nevers and Whitman (2011), the use of water quality standards specific to a location, combined with empirical predictive models, resulted in the greatest beach access without compromising health protection. However, they found that beach-specific models often incur greater costs than regional models that incorporate multiple beaches (Nevers and Whitman 2008). USGS scientists refined their model by including turbidity results along with many other hydrometeorological variables, such as rainfall, wind speed and direction, wave height, lake stage, air and water temperature, nearby stream discharge, and *E. coli* loading from nearby streams (Nevers and Whitman 2005). They also correlated their results with qPCR analyses of enterococci levels and found that the revised model more accurately closed beaches than the traditional method, with 95% accuracy in correctly issuing beach advisories. In areas where turbidity models do not work well, qPCR and those models linked to other water quality characteristics or hydrometeorological variables may prove timelier and more cost-effective. Current models for Portage Lakefront Beach, Indiana Dunes National Lakeshore, yielded highly reliable results (R^2 of 0.7) as opposed to an R^2 of 0.1 using culturing techniques. One of the most current and sophisticated programs of public notification of beach conditions was developed by Nevers and Whitman in collaboration with the Chicago Park District. Three weather stations and seven water quality monitoring buoys gather data and predict swimming conditions continuously, feeding the information to the Internet, smartphones, and managers, keeping everyone abreast of swimming conditions in real time (Hazlett 2011).

The chief disadvantage of modeling is the degree of expertise in modern statistics needed to develop and optimize the performance. To address this problem, the EPA developed software that is highly user-friendly. Virtual Beach 2.0 is a computer program that develops, tests, and ranks multiple linear regression models based on user-specified selection criteria. This allows users to settle on the best model for their application. More information about the program can be found in Zepp et al. 2010 and at http://www.epa.gov/ceampubl/swater/vb2/.

Rain threshold levels

Runoff from rainfall often contains harmful pollutants that may include elevated levels of fecal indicator bacteria. Rainfall thresholds, for example inches of rain in a 24-hour period, are useful indicators of FIB levels at beaches impacted by a river or stream outfall; thresholds can serve as the primary method for identifying when FIB levels are likely to exceed recreational water quality standards. Rain threshold levels are a form of empirical predictive model. The rainfall threshold level is related to the amount and intensity of a rainfall event in a watershed that drains to a specific recreational water area under monitoring. Thresholds are relatively easily determined by analysis of a statistical association between FIB and rainfall levels. California, Delaware, Hawaii, New Jersey, Wisconsin, New York, and Scotland are a few locations that use rainfall thresholds to determine when to post beach advisories (reviewed in USEPA Office of Water 2010b). These alerts often need to remain in effect for 24 hours after the rain event to ensure that water quality returns to acceptable levels for water recreation. The rainfall threshold advisory method has proven effective when rainfall occurs during periods of normal weather or drought, as contaminants build up on land. It is highlighted separately here because it is a cost-effective method for national park units to consider. However, beaches and recreational areas cannot rely solely on this method.

Advanced notification and emerging technologies

The National Oceanic and Atmospheric Administration (NOAA) maintains forecasting models, such as Nowcast, that aid in predicting recreational water quality up to 120 hours in advance. The Nowcast cycle uses surface meteorological data gathered from the National Ocean Service (NOS) Operation Data Acquisition and Archive System (ODAAS). The National Weather Service (NWS), National Centers for Environmental Prediction (NCEP), and National Coastal Ocean Program (NCOP) provide meteorological data to ODAAS from the NCEP's central computer system two times per hour to assist in developing forecasting models (Kelley et al. 2007). Based on models, NOAA's Great Lakes Environmental Research Laboratory has been working to develop specific forecasting methods for Grand River, Michigan (near Grand Rapids), and Burns Ditch, adjacent to Indiana Dunes National Lakeshore. More information on these techniques can be found at http://www.glerl.noaa.gov/res/glcfs/gh/, http://www.glerl.noaa.gov/pubs/fulltext/2007/2007tmNOS_CS8.pdf, and http://www.glerl.noaa.gov/res/glcfs/bd/ (USEPA Office of Water 2010b).

The NOAA Human Health Initiative is developing prototypic beach-closure forecasting models. NOAA is attempting to forecast *E. coli* and enterococci concentrations throughout the Great Lakes using three-dimensional hydrodynamic modeling. Staff compares model results with field data and evaluates the ecological consequences of model simulations under varied weather and FIB loading conditions (NOAA CEGLHH 2012). Development of predictive and empirical predictive models along with rainfall threshold levels will help provide for minimal to low-risk recreational water access, and combinations of various types of testing will aid further in the development of real-time, cost-effective notification for recreational water users.

Summary

Development of real-time water quality testing methodologies is an important step toward decreasing health risks for water recreators. The culture-based EPA recreational water testing methodologies in place from 1986 to 2012 determined FIB levels in 18 hours or more, whereas the new FIB testing methods, released by the EPA in November 2012, return results in three hours or less and result in fewer beach closures than traditional methods, without increasing health risks. These new methods and models incur significant start-up costs and greater complexity but provide a means to notify recreators of the public health risks associated with recreational water activities in near–real time, which in itself provides economic benefits as well as health advantages (Rabinovici et al. 2004; USEPA Office of Water 2012). They also give managers more flexibility to tailor their recreational water quality monitoring to best meet their needs.

The array of techniques now available for recreational water quality analysis are a boon to public health safety, but evaluating the trade-offs in cost and other factors creates challenging decisions. Managers may need guidance from scientists and experienced regulators to help choose and implement appropriate management and monitoring strategies. Fortunately, veteran scientists and public health professionals at the Department of the Interior, the EPA, the state level, and universities can provide managers with good information to optimize solutions that protect swimmers and park resources alike and address programmatic feasibility. Organizations such as the Great Lakes Beach Association are another great resource for further information.

The field of recreational water quality monitoring technology has been evolving rapidly, and here we have covered only a few techniques recommended by the EPA. However, several additional methods are now in development and will continue to advance the state of the art. For example, new in situ devices that measure pathogens directly, the use of anthropogenic chemical tracers, molecular markers and arrays, sophisticated computer modeling, dynamic modeling, and longer-scale forecasting are emerging techniques that hold promise. The best news is that technology for evaluating recreational water quality is quickly improving, providing managers with the promise of higher confidence in making the best decisions for the safe, healthy enjoyment of recreational aquatic resources in the National Park System.

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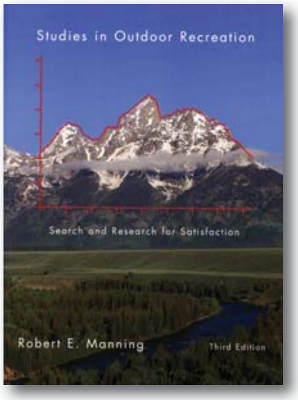
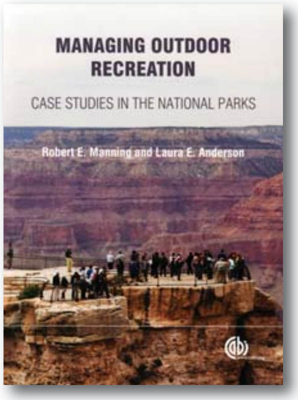
PS

Information Crossfile

BOOKS

Outdoor recreation management duo





SOCIAL SCIENTIST AND PROFESSOR OF RECREATION MANagement Robert Manning of the University of Vermont has published a couple of books in the past two years that park managers may find useful. The first, released in 2011, is the third edition of *Studies in Outdoor Recreation: Search and Research for Satisfaction*. For 25 years this work has served as an important reference for park and recreation managers and a standard text in college courses. It reviews social science research on outdoor recreation and synthesizes it into a body of knowledge that not only provides a historical perspective on the research but also further develops the practical management implications of this knowledge. This edition is fully revised to reflect current research and new field concerns. A new chapter examines the emerging issue of sense of place and its relationship to outdoor recreation. The book concludes with 20 principles to guide outdoor recreation management and research. An extensive bibliography of nearly 2,000 entries and a related appendix help guide readers to valuable primary source material. The book is published by Oregon State University Press in Corvallis.

The second work, written with Laura E. Anderson, a postdoctoral associate with the Rubenstien School of Environment and Natural Resources and Park Studies Laboratory at the University of Vermont, examines strategies for managing outdoor recreation in ways that protect the integrity of park resources and the quality of the visitor experience. Organized in three parts, the book is both theoretical and practical in its approach. Part I outlines potential impacts from outdoor recreation, describes the range of management strategies and practices that can be employed, and develops a series of matrices to help guide management choices. Part II analyzes 20 case studies of successful outdoor recreation management in the national parks. They exemplify a wide variety of contemporary issues from many parks: crowding, road congestion, visitor safety around wildlife, protecting water quality, trampling of vegetation and soil compaction, excessive noise, light pollution, and looting of cultural artifacts. The solutions offered cover a range of management tactics: the development of effective educational programs and informational materials; innovative design of trails, campsites, facilities, and services; use of rules, regulations, and zoning; and the equitable allocation of and access to particular kinds of activities. The final section discusses a set of best practices to guide management of outdoor recreation in the national parks and elsewhere. The book is published by CABI, Cambridge, Massachusetts.

▪ ▪ ▪

SOFTWARE

Rocky Mountain Wildflowers

THERE'S AN "APP" FOR THAT TOO. HIGH COUNTRY APPS has developed an inexpensive ($5) mobile field guide called "Colorado Rocky Mountain Wildflowers." Designed for the tablet, smartphone, or Kindle, the app functions without a phone signal and is well-suited to field use. Like a traditional field guide, it features color photos, drawings, descriptive information, range maps, and a key for identifying plants. It differs in the flexibility you have to construct your own plant lists or locate particular species, which you do by selecting parameters from a master list that includes size, habitat type, leaf shape, flower color, and status as a native, invasive, or noxious species, among many others. The resulting plant list changes as you modify your selections. To browse a plant list you tap a small photo of a species to reveal illustrations of that plant's features and a range map, or you can choose to view full descriptive information and related facts about the species. Another useful feature is the ability to alphabetize the lists by common or scientific name or by family group. Picture quality and variety are good and the information is based on botanical authorities. Other educational features are diagrams of flower parts and leaf characteristics, a glossary of botanical terms, a description of plant families, and user help. The app can be updated as new information becomes available. The developers have plans to increase the app's functionality for scientific field uses, including developing a field notes feature, a way to save user-built plant lists and log users' photos with GPS location information, and the ability to output data. All told, the application features photos of 530 species of wildflowers, ferns, shrubs, and trees with an additional 150 species described but not illustrated. Coverage is from the foothills to alpine life zones throughout the Rocky Mountains of Colorado, Wyoming, eastern Utah, and Montana. The developers have also released similar applications for wildflowers of the Yellowstone and Glacier National Parks regions and the Wasatch Mountains of Utah. They welcome feedback from users.

—Jeff Selleck

Case Studies

Using landscape patterns, climate projections, and species distribution models to map future potential habitats for desert tortoise, Shivwits milk-vetch, and American pika in Zion National Park, Utah

By David Thoma and Henry Shovic

Abstract

Quantitative assessment of climate effects is needed to help understand the spatial distribution of change to species habitat and species distribution that may occur in the next 100 years. This can provide insight for developing mitigation and adaptation actions for species survival on a park-level basis. We modeled the potential impacts of projected temperature change on habitat suitability for desert tortoise, Shivwits milk-vetch, and American pika in and around Zion National Park, Utah. We used species distribution models with historical temperature data from weather stations and climate projections of temperature to determine the location and suitability of present-day potential habitat and potential habitat in the year 2100. Our analysis was not intended to predict habitat quality or how species might respond. Rather, it was intended to map the location of potential or suitable habitat in Zion. Results indicated suitable habitat may increase in area for Shivwits milk-vetch, increase in suitability for the desert tortoise, but decline in area for American pika. Based on these findings, we made interpretations that summarized species vulnerability and potential impacts on species habitat and on park management. This type of information can serve as a starting point for developing a practical adaptation framework that considers potential management options at different temporal and spatial scales.

Key words

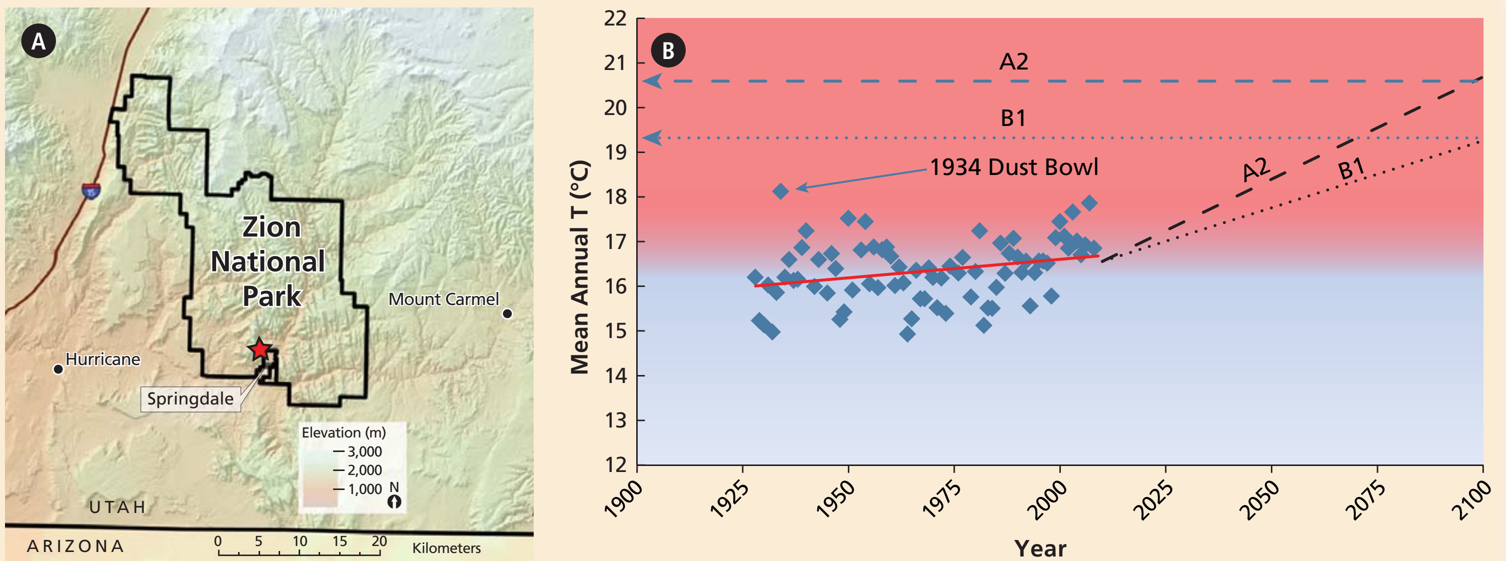
American pika, climate change, climate projections, desert tortoise, lapse rate , mapping habitat changes, Shivwits milk-vetch, species distribution model, vulnerability assessment

MEAN ANNUAL TEMPERATURE (MAT) at Zion National Park, Utah, has steadily increased since 1928 and will likely continue to increase as more carbon dioxide is added to the atmosphere (IPCC 2007a; Gonzalez et al. 2010) (fig. 1). Climate projections for Zion suggest that mean annual temperature by 2100 may be higher on average than in any year in the last century, including the 1934 Dust Bowl. Natural variability ensures that the temperature trend will not be as linear as shown by projections in figure 1, but at broad scales the upward direction and magnitude are very likely (>90% probability), according to the most credible and widely accepted projections (IPCC 2007b). Projected changes in precipitation are less certain, with some scenarios indicating increase and others decrease. What effect these changes in climate might have on species distributions if the new "normal" exceeds anything we have seen in the last 100 years is of great interest to park managers. We examine this question by explicitly mapping potential habitat under climate change scenarios 100 years from now for three species of concern in Zion by following established guidelines for vulnerability assessments (Glick et al. 2011). These maps and the associated data are a first step toward developing the credible scientific underpinnings for park-level planning under the constraints and opportunities of climate change.

Climate is the most important driver of species distributions at broad scales, but other factors like species interactions, dispersal, and physical factors such as soil type influence species distributions at the local or park scale. As climate changes, species will adapt, migrate, or perish in response to both direct and indirect effects, but which are the most likely outcomes? That depends on species life history traits, availability of habitat in the future, and a host of other factors that we cannot predict with accuracy. However, mapping the intersection of important landscape parameters in and near parks and climate in relation to species distributions provides clues to help predict where suitable habitat may exist in the future.

Habitat maps are integral to adaptation frameworks in order to plan courses of action that could include managing for resilience, resistance, and facilitated migration (Stephenson and Millar 2012). More immediate actions based on habitat maps could include negotiating land sales or conservation agreements to protect or link habitats. Collectively, these kinds of adaptation actions could provide time and space for species to adapt to new climates. Yet in spite of its importance for planning, predicting future habitat for specific organisms is an evolving science with considerable uncertainty.

The goal of this research was to use existing data, models, and information from subject-matter experts to map current and future potential habitat for selected species in Zion National Park as input to a vulnerability assessment. Our focus was on the potential future habitat of the threatened desert tortoise (*Xerobates* [*Gopherus*] *agassizii*), the endangered Shivwits milk-vetch (*Astragalus ampullarioides*), and the climate-sensitive American pika (*Ochotona princeps*) in and near Zion (fig. 1).



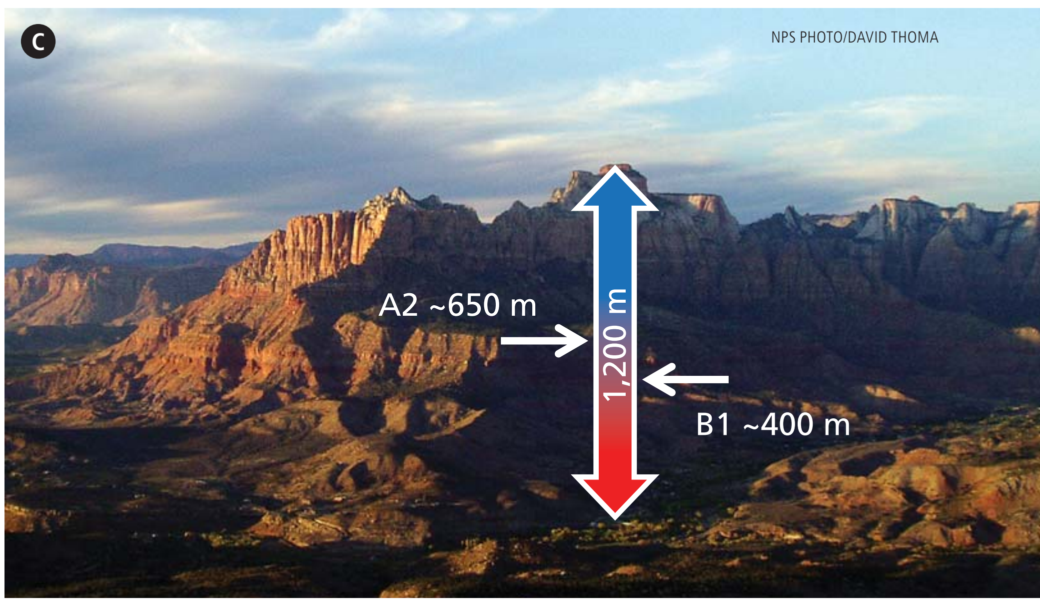


Figure 1. (A) Zion-centered study area with location of Zion National Park headquarters weather station (red star). **(B)** Historical and projected trends in mean annual temperature (MAT) for the 1928–2008 period. The red line is the linear trend in the historical MAT. The dashed and dotted lines are the most recent 30-year averages, 16.6°C (61.9°F) linearly modeled into the future under IPCC emission scenarios with MAT in 2100 projected to be 19.3°C (66.7°F) under B1 and 20.7°C (69.3°F) under A2 scenarios (projections made using IPCC 2007) (Gonzalez et al. 2010). **(C)** Zion Canyon and the town of Springdale, Utah, looking north across desert tortoise and Shivwits milk-vetch habitat. Potential pika habitat occurs in isolated areas on the highest plateaus. Large vertical arrow indicates relief between Zion Canyon and the summit of West Temple. Horizontal arrows indicate vertical shift in MAT that may affect habitat suitability and location under A2 and B1 emission scenarios by 2100.

Climate change and range shift

The net result of projected changes in temperature and precipitation over the next 100 years will most likely be upslope compensatory range shifts (retraction) for most species (Stephenson and Das 2011). The expectation of upslope range retraction in the next century is consistent with observed upslope retraction for small mammals in Yosemite National Park (California) since 1914 on the order of 500 m (1,641 ft) per century (Moritz et al. 2008) and observed vertical shifts of 145 m (476 ft) per decade for Great Basin region pika since 2000 (Beever et al. 2011).

We used mean annual temperature projections from the Intergovernmental Panel on Climate Change (IPCC 2007a) that were downscaled to our study area (Gonzalez et al. 2010). We selected 100-year climate scenarios B1, representing a low greenhouse gas emission scenario (using the lower value of the range, or a 3°C [5.4°F] increase), and A2, representing a high-emission scenario (using the upper value of the range, or a 4.6°C [8.3°F] increase). This gave us a wide range of possible MAT futures for modeling habitat shifts and changes in habitat suitability. For this study we used projected changes in MAT alone as the climate predictor because of the inherent variability of precipitation and the wide range in its projected changes, which include both increases and decreases for this region over the next 100 years (Gonzalez et al. 2010; IPCC 2007c).

Modeling habitat shifts with species distribution models and lapse rate

Our mapping of potential future habitat consisted of three steps. First, we identified the spatial habitat characteristics and extent (e.g., talus for pika) of present-day species occurrence. This was accomplished via literature review and application of species distribution and persistence models (SDMs) (Beever et al. 2011; Nussear et al. 2009; Miller et al. 2007). Then we used the lapse rate to predict the elevation range where temperatures favorable to the species may occur in 2100. In the third step we used the shift as input to each SDM, mapped the resultant habitat, and compared it with its present extent.

Temperature lapse rate is the change in mean annual temperature with elevation, which we estimated from quality-screened mean annual temperatures since 1993 collected from seven weather stations in and near Zion. The lapse rate of 7.3°C/km (4.0°F/1,000 ft) (90% confidence interval ± 0.9°C [1.62°F]) means the average annual temperature is 7.3°C (13.1°F) cooler for every 1,000 m (3,280 ft) increase in elevation. Although lapse rates vary by region and location, ours is within the range reported by others (Ray et al. 2010; Minder et al. 2010). We determined the vertical elevation shift where mean annual temperature today will be in 2100 by dividing the projected temperature increase by the MAT lapse rate. For example the lower range for scenario B1 projections suggests a +3°C (5.4°F) change in mean annual temperature by 2100, which results in a given MAT upslope shift of approximately 400 m (1,300 ft). Similarly, the higher range for the A2 projection indicates an upslope vertical range shift of approximately 650 m (2,100 ft) (fig. 1, previous page).

Actual range shift will vary by individual species and location, as has been observed in both paleontological and contemporary studies (Lyons 2003; Moritz et al. 2008). However, our coarse estimates are similar to rates of upslope habitat retraction already observed for some small mammals in Yosemite National Park and are about half the rate of upslope retraction observed for pika across the Great Basin region (Moritz et al. 2008; Beever et al. 2011).

For this project, we mapped the extent of talus patches that consisted of talus fragments greater than 25 cm (9.8 inches) in diameter as potentially suitable pika habitat. We then compared the elevation of mapped talus patches with a model of pika persistence from the Great Basin that quantifies the likelihood of pika persistence as a function of latitude, elevation, and available nearby talus (Beever et al. 2011) to predict latitude and elevation ranges favorable for pika survival.

The suitability of desert tortoise habitat was based on a spatial, statistical species-presence model (Nussear et al. 2009). Nussear used tortoise locations with an array of environmental factors to predict determinants of habitat suitability in the species' range and to calculate a numerical index of that suitability. Elevation and vegetation productivity were the most important contributors to the model and were used in this analysis.

The milk-vetch habitat model is based on a spatial intersection of factors that are strongly correlated with its distribution (Miller et. al. 2007). These include an obligate relationship to the Chinle geologic formation, an elevation range between 600 m and 1,700 m (2,000 ft and 5,580 ft), and slopes of less than 30%. The intersection of these landscape factors indicates potential habitat.

This research was conducted as our understanding of species habitat relationships continues to evolve. Important efforts aimed at refining our understanding of species vulnerabilities are the Pikas in Peril project (Garret et al. 2011), ongoing research on the habitat and drivers of Shivwits milk-vetch in Zion, and ongoing research on the desert tortoise.

Results and management implications

Understanding the effect of climate change on plant and animal habitat requires models at various levels of sophistication (from quantitative to conceptual) to identify possible future effects and opportunities. We integrated our modeling results with the elements used in vulnerability analysis to estimate magnitude and direction of impacts on habitat and occurrence within the park, on the species in general, and on park management. We realize that these interpretations are subjective but feel they must be made to effectively communicate results and stimulate discussion.

We considered the three elements of vulnerability: sensitivity (species traits, both genetic and behavioral), exposure (IPCC climate projections), and adaptive capacity (future habitat availability). These elements are subjectively ranked high, moderate, or low based on our interpretation of life history traits (either behavioral or genetic) that enable resistance and resilience to climate change. Ratings of potential impacts on the species within the park boundary are based on the modeled magnitude of habitat change combined with species presence data. Ratings of potential impacts on the species in general are based on the proportion of the species' presence in the park to its entire range, and to the potential threats to that range. Park management impacts relate to the potential for significant management action based on all the other ratings, as well as outside pressures, available park

Species	Components of Vulnerability			Potential Impacts on		
	Sensitivity	Exposure	Adaptive Capacity	Species Within the Park	Species in General	Park management
American pika	high	moderate	low	high (–)	low (–)	moderate
Desert tortoise	moderate	moderate	moderate	high (+)	moderate (+)	high
Shivwits milk-vetch	high	moderate	low	low (+)	high (+)	high

Table 1. Species vulnerability to and potential impacts of climate change scenarios on species in Zion National Park in 2100

Note: "+" indicates a positive effect of increased mean annual temperature under climate change, while "–" indicates a negative effect.

resources, and priorities. These data are summarized in table 1 and each impact is discussed below by species.

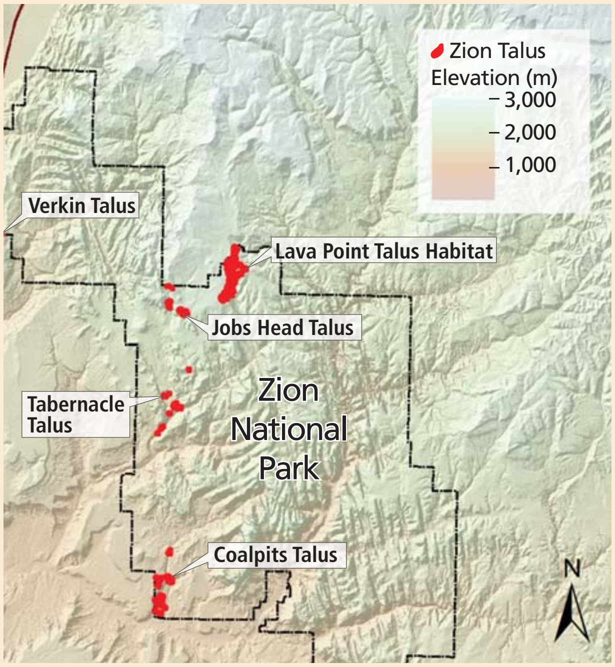


Figure 2. Talus patches in Zion with rock fragment sizes suitable for potential pika habitat. The pika persistence model, coupled with mean annual temperature projections, indicates that suitable pika habitat may not exist in Zion by 2100.

American pika

Pikas have a high normal resting body temperature of approximately 40°C (104°F), which is only 3.0°C (5.4°F) below the acute lethal upper limit for the species. Hyperthermia or death can occur after brief exposure (as little as six hours) to temperatures greater than 25.5°C (77°F), and chronic exposure above 28°C beneath talus is a good predictor of local extirpations (Smith 1974; Beever et al. 2010). High body temperature and year-round activity result in high energy expenditures and thermoregulation challenges for the species.

In warmer environments pikas typically become inactive during midday hours and withdraw into cooler spaces below the talus surface. Pikas persist in low-elevation, thermally undesirable environments by selecting habitat that contains spaces for underground movement and provides physical protection and cool refugia during hot conditions (U.S. Fish and Wildlife Service 2010; Smith 1974). Although we did not consider it in our work, pikas are also susceptible to freezing temperatures in the absence of an insulating snowpack (Beever et al. 2010; Beever et al. 2011). Unfortunately, we did not have interstitial talus temperatures available for evaluation.

We mapped physical components of pika habitat (talus slopes) using air photography and on-site inspection (fig. 2). Surveys at Lava Point indicated that in 2011 and 2012, pika were present. However, based on the pika persistence model (Beever et al. 2011) that relates pika survival to latitude and elevation (our proxy for temperature), the two highest-elevation talus patches (Lava Point and Jobs Head) are more than 1,400 m (4,593 ft) below the elevation where other populations have persisted at similar latitudes in the Great Basin. This may indicate the Lava Point habitat has unique characteristics that have enabled survival up to this point. However, unless these populations have access to thermal microrefugia deep under the talus or possess higher adaptive capacity than the pikas in the Great Basin, pikas in Zion are probably on the brink of survival and are not likely to survive even minimal future warming. Although pikas are not likely to survive in Zion through 2100, some suitable habitat may remain at higher elevations north of the national park.

Because of its thermoregulation limits and specific talus habitat requirements, pika is rated "high" in sensitivity (table 1). Its adaptive capacity is rated "low" because of its generally low ability to move between potential habitats (Beever et al. 2010). Potential impacts on pika in the park are "high" (negative) in spite of available talus. Those areas are too low in elevation to support viable populations under warming scenarios. Potential impacts on the species in general are rated "low" because of the species' wide geographic distribution. Its loss from Zion would not highly affect the species distribution as a whole, unless the local populations have some unique genetic characteristics (Rodhouse et al. 2010). However, potential impacts on park management are "moderate." All native species are important to the preservation of park ecosystems, and this species is at great risk of local extirpation because of expected increases in temperature.

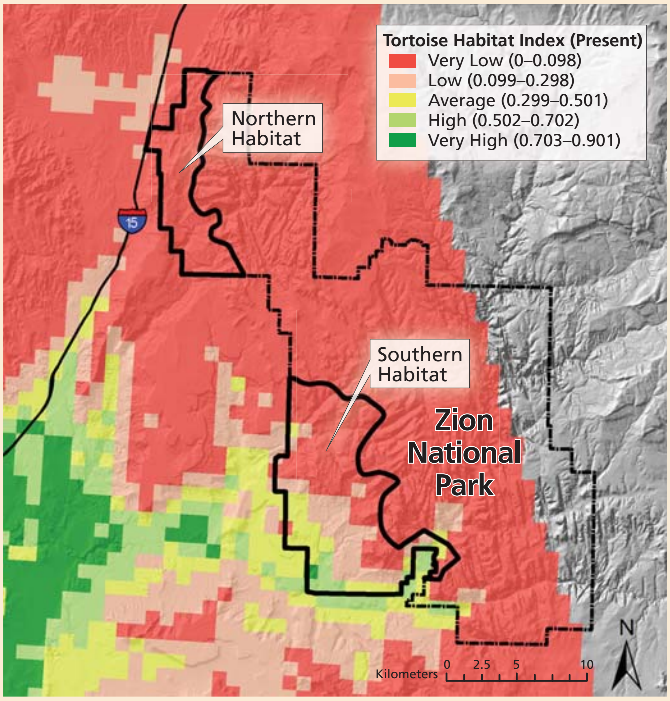


Figure 3. Suitability of potential desert tortoise habitat today and in 2100 under emission scenarios B1 and A2. Potential is rated "low" (red) to "high" (green). Northern and southern habitat zones are based on vegetation and slopes appropriate for potential habitat.

Desert tortoise

The desert tortoise occurs in the Mojave Desert, where it occupies a variety of habitats, from flats and slopes dominated by creosote bush (*Larrea tridentata*) scrub at lower elevations to rocky slopes in blackbrush (*Coleogyne ramosissima*) and juniper (*Juniperus* spp.) woodland ecotones (transition zones) at higher elevations (U.S. Fish and Wildlife Service 2008; Meyer 2008). Two areas in Zion (northern and southern habitats) that have suitable soil substrate and vegetation were coarsely delineated as focus areas in this project via consultation with park staff and literature review (fig. 3). There are no known tortoise observations for the northern area. Monitoring by park staff shows desert tortoise are present in the southern area and are a reproducing population, as evidenced by the presence of eggshell fragments and young tortoises with only one annular ring on their scutes.

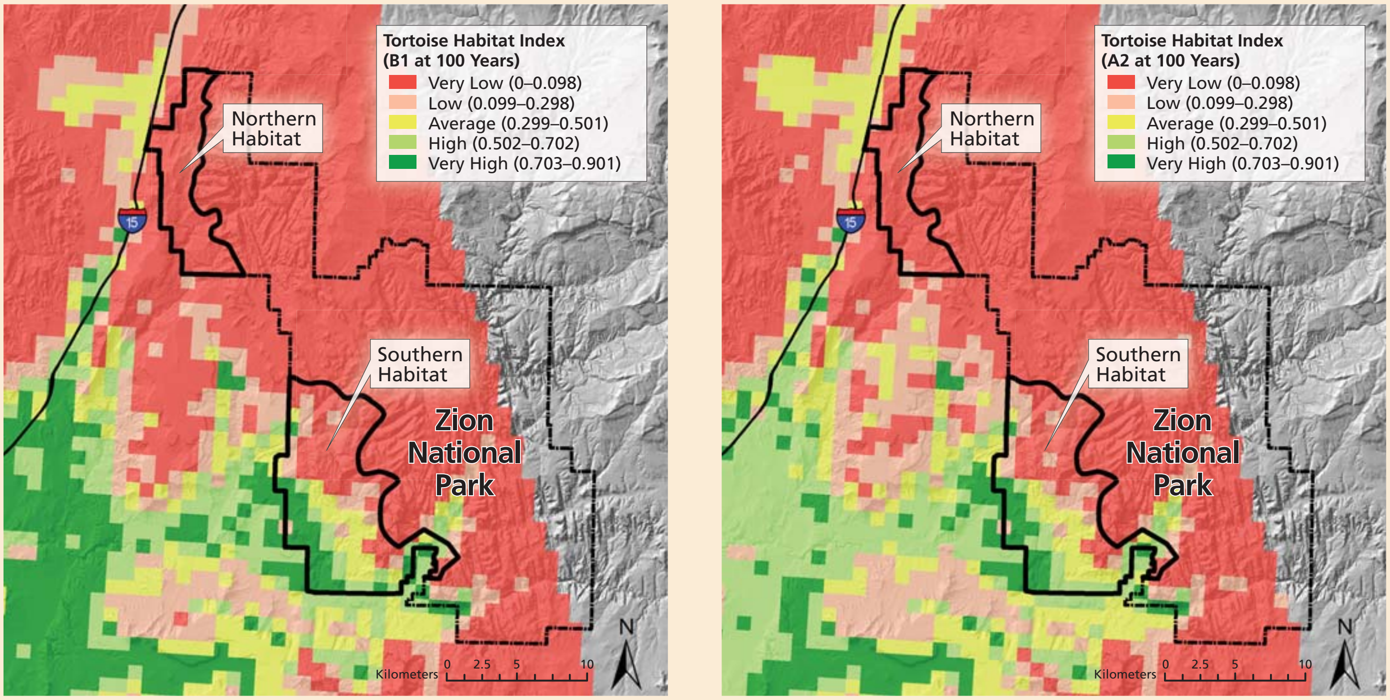
The northern habitat suitability (vegetation productivity within favorable elevations) stays very low under both of the modeled climate scenarios for the next 100 years. In the southern area, climate warming is expected to substantially enhance the suitability of tortoise habitat. The modeled habitat suitability index, ranging from 0 to 1 at present, averages 0.2 in the southern area and increases to 0.3 under both climate scenarios, an increase of 66%. Within the southern area, the southwestern corner of Zion National Park is closer to the current Mojave Desert range of the species and shows the largest increase in habitat suitability.

The species is dependent on certain vegetation types, but because of its physiology and behavioral adaptations to high temperatures we rate it "moderate" in sensitivity. Though slow moving and slow growing, the species *is* capable of migrating to connected habitats (U.S. Fish and Wildlife Service 2008; Meyer 2008) and is therefore rated "moderate" in its ability to adapt to warming temperatures.

Potential impacts on the species in the park are rated "high" and positive because the model indicates an increase in area of suitable habitat by 2100 in Zion. The quality of that potential habitat depends on many factors, but presently there is evidence of population stability. Impacts on the species in general are "moderate," because though the park is only a small part of its existing range its environment in the park is protected from habitat destruction and human activities common on other private and public lands. Potential impacts on park management are "high" because of the species federal listing as threatened, its high public profile, and the proximity of its habitat to the busy community of Springdale, Utah, which is becoming increasingly "tortoise aware" through education.

Shivwits milk-vetch

Shivwits milk-vetch was first identified as a new plant species in 1997 and was listed as federally endangered in 2001. Depending on temperatures and precipitation, emergence and flowering occur from April to late May, and plants senesce (die back aboveground) by mid-June. The peren-



nial rootstock allows Shivwits milk-vetch to survive dry years, and in a drought year plants may not emerge or fruit production may be diminished (Miller et al. 2007). This adaptation allows the plant to conserve energy for reproductive effort when resources are available (U.S. Fish and Wildlife Service 2001). It is unknown whether milk-vetch is truly a Chinle "specialist" (primarily obligated to that geologic type) or whether the Chinle geologic formation is inhospitable to competitors like native blackbrush (*Coleogyne ramosissima Torr.*) and nonnative red brome (*Bromus rubens*). If the Chinle formation is a "refuge" from competitors, then milk-vetch response to climate change will be highly contingent on competitor response to climate change. Herbivory and dispersal are also important but poorly understood determinants of survival and will undoubtedly influence realized habitat. In our work the species is modeled as a Chinle specialist where present and potential habitat is defined as the spatial intersection of geologic type, elevation, and slope based on known populations.

Mapping the intersection of important landscape parameters in and near parks and climate in relation to species distributions provides clues to help predict where suitable habitat may exist in the future.

Climate warming is expected to raise the elevation range of potential milk-vetch habitat and its extent in Zion (fig. 4, next page). Presently there are 1,669 ha (4,124 ac) of potential habitat in Zion, with 1,914 ha (4,730 ac) of potential habitat in 2100 under climate B1 (an increase of 15%) and 1,840 ha (4,547 ac) of potential habitat in 2100 under climate A2 (an increase of 10% over present). The primary change in potential habitat comes in its distribution, with most of the increase in the northern part of the park and a slight decrease in the southern part of the park near Springdale. Occupied habitat outside the park is at lower elevations on a mixture of private and public lands having lower protection potential, and may become too warm for a viable population, raising the importance of the Zion habitat.

Sensitivity is rated "high" in table 1 because of the species' strong relationship to elevation and small spatial extent. Adaptive capacity is rated "low" because of its strong tie to a specific geologic type, limiting its potential range. Also, though its potential habitat is relatively widespread in Zion, its presence has been verified in only a few areas.

Potential impacts on the species in the park are rated "low" and positive. The modeled future habitat exhibits only a moderate increase in extent over present conditions. Impacts on the species in general are "high" and positive. This is because most of the present and projected habitat is within the park, a protected area. Impacts on park management are probably also "high" because of the species' federally endangered status, since it is possible that most of its remaining range outside the park will degrade significantly, raising the importance and visibility of the remaining habitat.

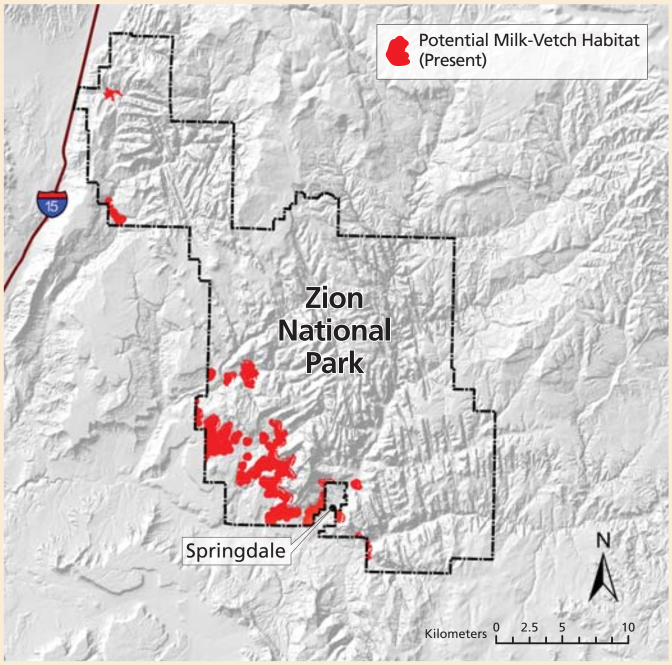


Figure 4. Potential milk-vetch habitat at present and in 2100 under emission scenarios B1 and A2 in Zion.

Uncertainty

Our modeling provides a starting point for understanding direction and magnitude of shifts in potential suitable habitat. We speculate on climate change impacts to species but do not make predictions because we did not consider additional complexity, such as interspecies competition, microclimates, extreme weather events, genetic diversity, behavioral plasticity, or whole ecosystem effects. It was beyond the scope of this research to test the sensitivity of species to environmental variables. Species-environment relationships today are assumed to hold in the future, and no adaptation or evolution is assumed to occur that would affect species-environment relationships. But all of these factors may affect realized habitat occupancy.

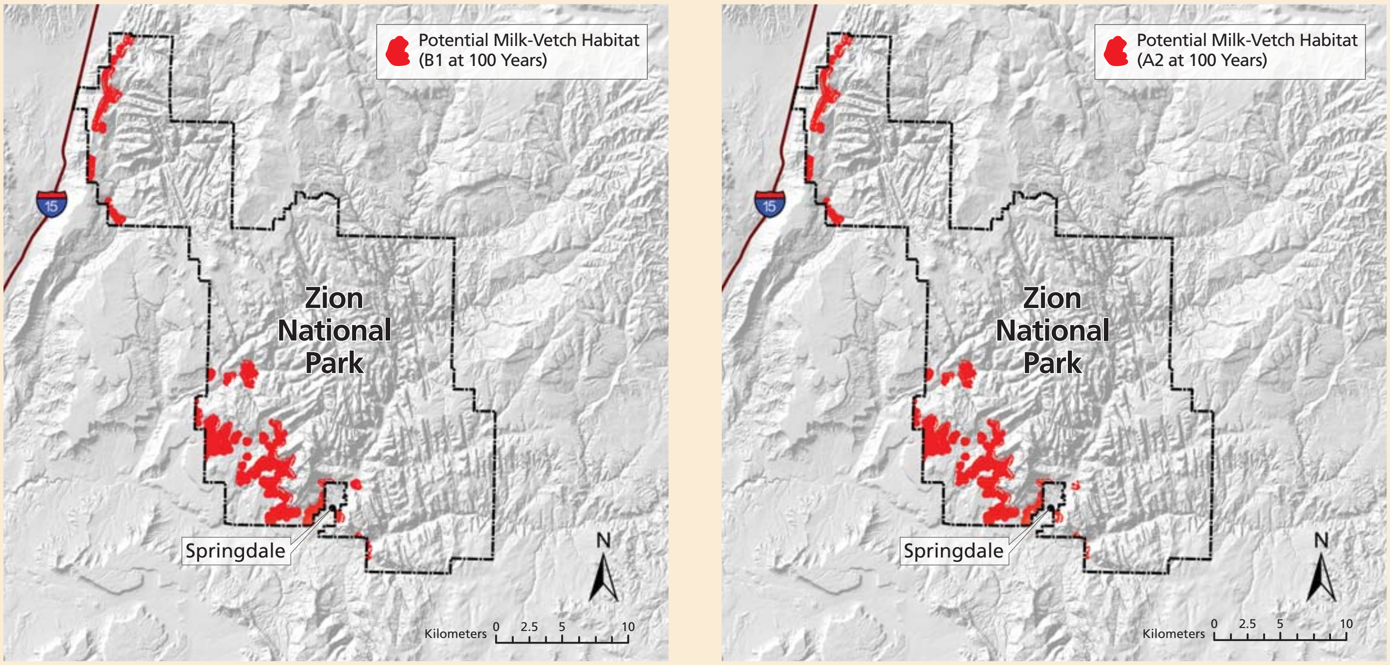
In this research we focused on mean annual temperature effects, but seasonal temperature and precipitation effects, as well as temperature minima, variability, or cumulative effects, could also be modeled. For instance, seasonal lapse rates can be used with seasonal climate projections to give a clearer picture of seasonal effects on species with different seasonal sensitivities to climate (e.g., summer and winter extremes for pika).

For example, continuing with temperature as a driver, our locally derived June, July, and August summer lapse rate of 2.2°C/km (1.2°F/1,000 ft) with a projected western U.S. summer warming of about 2.8°C (5.0°F) (Ray et al. 2010) by 2100 would shift today's thermal habitat boundaries upward approximately 1,250 m (4,100 ft), considerably more than the 400–650 m (1,300–2,130 ft) per century upslope shift determined using the MAT lapse rate of 7.3°C/km (4.0°F/1,000 ft). The alarming aspect of this example is that upslope range retraction of pika in the Great Basin (145 m [475 ft] per decade or 1,450 m [4,750 ft] per century) observed during 1999–2008 has already outpaced our predicted future rates of retraction (Beever et al. 2011) that we modeled using an MAT lapse rate. While we cannot predict with certainty how conditions will evolve at any given location, it may be wise for managers to consider in their planning the likely upslope range shift of suitable habitats in the future and the potential magnitude of these retractions.

Our intent was to use readily available information to model a range of possible changes in habitat suitability and distribution affected by temperature that bracket much of the range in projected temperatures expected for different carbon dioxide emission scenarios. The scope of this research is a relatively rapid screening in which we mapped potential future habitat, while not suggesting those habitats can or will be occupied. This level of effort results in predictions with a high degree of uncertainty, but provides a baseline for discussion, focused monitoring, and planning.

Conclusions

Literature review, consultation with academic and agency science experts, and use of existing models were brought together for mapping future potential species-specific range shifts under IPCC climate scenarios in and near Zion National Park. The maps of future potential habitat suggest there will be opportunities for some species and limitations for others in Zion. For instance, potential area of suitable



Mitigating impacts and giving species time to adapt will improve the likelihood of species survival, yet inaction will result in lost opportunities if ecological thresholds are surpassed.

tortoise and milk-vetch habitat may increase in and near Zion while pika habitat may disappear entirely from within park boundaries. The realized species response to climate change may depend on many interacting factors that we did not model, including management actions.

We acknowledge that our approach to modeling vulnerability is narrowly focused primarily on temperature and habitat characteristics, but suggest the possibility—even necessity—of learning as we go by iterating modeling efforts as new and better information becomes available. For instance an explicit accounting of coupled changes in projected precipitation and temperature will be an improvement on this work. This is a process in which scientists and park staff will benefit by working together through the complexities of modeling and planning so that collectively we increase our understanding of interactions, vulnerability, and uncertainty.

This process helps develop options supported by science. Mitigating impacts and giving species time to adapt will improve the likelihood of species survival, yet inaction will result in lost opportunities if ecological thresholds are surpassed. Interactively working through analyses like these helps to put bounds on uncertainty so that it does not hinder planning or management action, if necessary. Science-based options are an integral part of adaptation frameworks that enable conservation through management. Considering the complexity and magnitude of climate change effects on park resources in the next 100 years, there will be many opportunities for learning and collaboration in conservation.

Acknowledgments

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Schrage, Sarah Haas, Kristin Legg, Emily Wellington, Matt Betenson, Clair Crow, John Gross, and Greg Comer, all of whom provided support, input, and insight throughout the project. Conclusions expressed herein are those of the authors and may not reflect thoughts of subject-matter experts or park staff.

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PS

Resource-conflict analysis:

A geospatial approach to assessing energy development threats to landscapes in the Southwest

By Dan McGlothlin, Peter Budde, and Kirk Sherrill

Abstract

Responding to cumulative impacts with consistency across park and regional boundaries at landscape scales requires establishing an objective, consistent, and proactive approach to identifying adjacent or proximal areas with explicit or potential connection to NPS-administered resources. Use of available geospatial data and analytic tools to assess potential risks of proposed external land use actions represents a viable approach for dialogue among National Park Service managers, other agencies, and groups proposing land use actions. Our response to the Programmatic Environmental Impact Statement for Solar Energy Development in Six Southwestern States highlights the benefit of adopting this approach for addressing potential resource conflicts across broad geographic extents. This resource conflict analysis engaged multiple levels in the NPS organization and incorporated authoritative resource data. Moreover, the experience highlights the potential to respond in a consistent and timely manner, acting as an initial screening procedure.

Key words

broad-scale assessment, geospatial analysis, protection of landscapes, resource conflict analysis, solar energy, solar energy development exclusions, utility scale

ANALYZING AND MITIGATING CUMUlative environmental, social, and economic impacts for the protection of national park resources and values is a difficult task that is made more complex when landscape-scale actions may affect multiple parks and regions. In order for the National Park Service to respond with consistency to these types of situations a bureau-wide methodology needs to be established. Use of available geospatial data and analytic tools to assess potential risks of proposed land use actions external to parks presents a viable approach for stimulating a critical dialogue among NPS resource management specialists and with groups proposing land use actions. The recent process outlined in the *Programmatic Environmental Impact Statement for Solar Energy Development in Six Southwestern States* (Solar PEIS) highlighted the benefit of adopting this approach to addressing potential resource conflicts across broad geographic extents (fig. 1, next page). The geospatial resource conflict analysis (RCA) approach we report here engaged multiple levels in the NPS organization and incorporated authoritative resource data sources (see sidebar "Data sources," page 25) in the assessment. Moreover, the experience highlighted the potential for the National Park Service to respond in a way that minimizes park-by-park variability in evaluation of risk and consistently reflects bureau-wide policy and program decisions.

Solar energy development in the Southwest

Efforts in the United States to reduce dependence on imported energy supplies with increased development of renewable domestic sources is a large part of an ongoing dialogue about balancing economic growth with lessened strain on the nation's natural resources. A 2006 report of the U.S. Department of Energy (DOE) projects that by 2030, the U.S. population, and correspondingly electricity demand, will increase by 70 million and 50% respectively. Much of this growth is expected to occur in the American Southwest (DOE 2006). The potential for solar energy power generation is a large part of this dialogue, because the solar power industry is ideally situated to help achieve U.S. renewable energy goals by deploying utility-scale power generation plants in this region where insolation levels are ideal for solar energy. Utility-scale solar energy plants are electricity-generating facilities and present siting challenges similar in most respects to those of traditional coal, natural gas, and nuclear thermo-electric plants. The main difference between a solar energy plant and a traditional plant is the larger overall land area required for utility-scale solar power installations (Glennon and Reeves 2010). Unlike traditional plants that often are strategically located near energy customers and transmission lines, solar energy facilities are located where conditions are most ideal to capture the sun's energy, including remote areas near national parks and monuments, and other special places administered by the National Park Service, such as

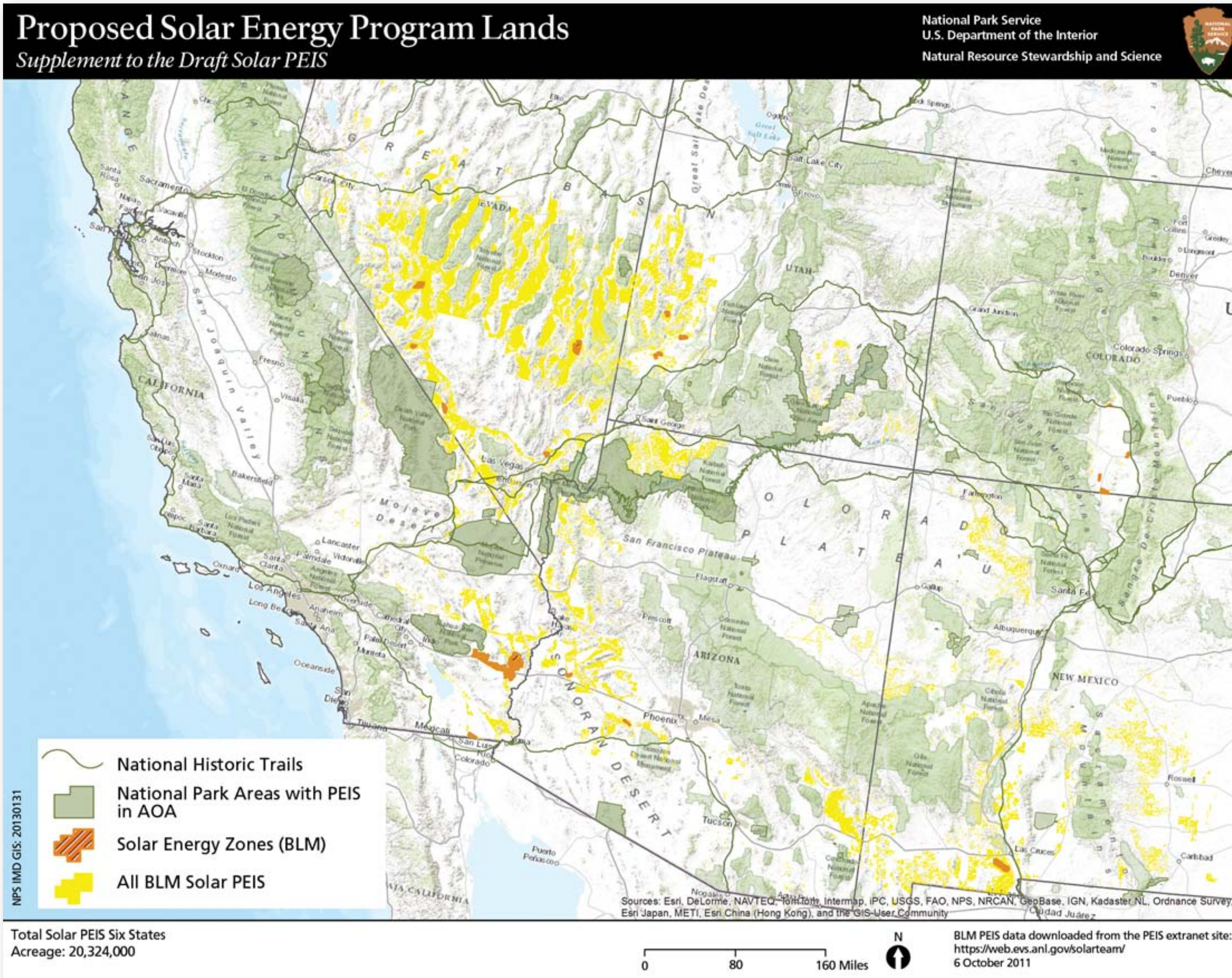

Figure 1. This map depicts lands in the Supplement to the Draft Solar PEIS preferred alternative as potentially available for utility-scale solar development.

national historic trails or national historic or natural landmarks. Thus, numerous recent utility-scale solar facilities have been proposed in locations far from urban areas on undeveloped public lands, accompanied by infrastructure upgrades such as interconnecting electric transmission lines and transportation routes. Collectively this increased development across the landscape represents considerable potential for impacts on a variety of natural, visual, and cultural resources.

Solar PEIS overview

The U.S. Department of the Interior (DOI) Bureau of Land Management (BLM) and the U.S. Department of Energy are taking actions to facilitate utility-scale solar energy development in six southwestern states. The Solar PEIS defines utility-scale development as a facility that produces greater than 20 megawatts (MW) of electricity. One megawatt (106 watts) of electricity can provide instantaneous power to 1,000 homes. The Solar PEIS evaluates a range of potential environmental, social, and economic effects and comprehensive policies for authorizing this development on public lands. The Solar PEIS identifies BLM-administered lands that are suitable for solar energy development and DOE guidance for advancing this development in Arizona, California, Colorado, Nevada, New Mexico, and Utah and a comprehensive solar energy program responsive to various federal mandates, including state-generated Renewable Portfolio Standards for a certain percentage of a

The Solar PEIS analyzes proposed policies that establish national consistency for the implementation of application review requirements and criteria for environmentally responsible renewable energy development on public lands.

Data sources

Once we had developed the list of potential cross-boundary resource conflicts summarized in table 1 (page 28) we identified and harvested corresponding geospatial data from the following readily available data sources:

- "Streets" GIS layer, ESRI (Economic and Social Research Institute) Map and Data DVD, dated 2005.
- National Land Cover Database (2006). U.S. Geological Survey. Available at http://www.mrlc.gov/nlcd2006.php.
- National Park Service. 2011. NPScape Upstream Watershed Delineation Processing SOP. Upstream Watershed Analysis for Select National Park Units. National Park Service, Natural Resource Program Center, Fort Collins, Colorado, USA. Available at https://irma.nps.gov/Reference.mvc/Profile?Code=2173077.
- National Hydrography Dataset—NHDPlus. U.S. Geological Survey. Available at http://www.horizon-systems.com/nhdplus/data.php.
- State Soil Geographic (STATSGO) Database, May/2011. USDA Natural Resources Conservation Service. Available at http://soildatamart.nrcs.usda.gov/USDGSM.aspx.
- National Wetlands Inventory (NWI). U.S. Fish and Wildlife Service. Available at http://wetlands.fws.gov.
- Critical Habitat Portal. U.S. Fish and Wildlife Service. Downloaded 3 August 2011at http://criticalhabitat.fws.gov/crithab/.
- Protected Areas Database of the United States (PAD-US), version 1.2. U.S. Geological Survey, Gap Analysis Program. Available at http://www.protectedlands.net.
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- Defense Meteorological Satellite Program. NOAA National Geographic Data Center, Earth Observation Group. Available from http://www.ngdc.noaa.gov/dmsp.
- National Elevation Dataset (NED) 30-meter digital elevation model (DEM). Available at http://ned.usgs.gov/.

Many of these data sources needed to be used in combination to derive useful information for the resource conflict analysis. For example, the NPScape landscape dynamics monitoring project supplied roads data for use in conjunction with National Land Cover data to determine roadless natural areas. Likewise, NPScape data coupled with National Hydrography Data Sets allowed us to delineate upstream watersheds. We combined STATSGO soils data and digital elevation models with the logic of BLM's Mojave and Central Basin and Range Rapid Ecoregional Assessments (REAs) to obtain wind and water erosion potential. U.S. Fish and Wildlife Service wetlands and critical habitat for threatened and endangered species were used to identify habitats of concern. We evaluated habitat quality and landscape connectivity through data from two research-based Naturalness and Landscape Permeability data sets. The Protected Areas Database of the United States facilitated our understanding of landownership of various protected areas. Finally, we performed a GIS analysis of potential visual resource impairments that included ambient light pollution measurements from a nighttime lights data set.

state's electricity capacity requirements to be supplied from renewable sources (e.g., solar, wind, geothermal, or biomass). The Solar PEIS analyzes proposed policies that establish national consistency for the implementation of application review requirements and criteria for environmentally responsible renewable energy development on public lands. The solar energy program creates (1) areas of public lands that are excluded from utility-scale development in the six-state area; (2) priority areas, called solar energy zones (SEZs), that are best suited for production of solar energy; (3) a process for considering solar facilities outside these zones; (4) facility design and mitigation requirements; and (5) amendments to BLM land use plans. The Bureau of Land Management anticipates that ongoing and future solar energy development decisions, such as land use plan amendments, may result in further refinements of the program footprint (BLM and DOE 2011).

Scale of potential development on public lands and implications

Depending on its location, a single solar facility adjacent to a national park area can produce large, irreversible impacts on park resources. To describe the full range of potential environmental impacts under the assessed alternatives, the Solar PEIS analyzes reasonably foreseeable development for the next 20 years and estimates the potential solar power production on BLM-administered lands to be 24,000 MW by the year 2030. To attain this goal, the PEIS initially identified 20.3 million acres (8.2 million ha) of public lands (called solar program lands) (fig. 1), including designated SEZs, needed to accommodate states' renewable power production goals. The reasonably foreseeable development of 24,000 MW translates to an estimated land requirement of 214,100 acres (86,670 ha), or about 1% of the land area available under the solar energy program.

The solar program lands are represented as areas possessing optimal solar development potential, with direct normal insolation values greater than or equal to 6.5 kilowatts per square meter per day (5.4 kW/sq yd), and with slopes less than or equal to 5%. Four types of utility-scale solar technologies are evaluated in the Solar PEIS: parabolic trough and power tower systems (hereafter referred to as concentrating solar power [CSP]), dish engine systems, and photovoltaic (PV) systems. These systems cumulatively consist of the solar field where solar collectors capture and convert the sun's energy to thermal energy (CSP systems) or directly into electricity (dish, PV systems). Considerable ancillary infrastructure is required, including power-block, steam-cooling, waste-management, thermal-storage facilities, connecting transmission lines, and access roads.

To illustrate the imprint a typical solar energy facility may have on land and water resources, a 250 MW CSP facility employing a power tower design requires a total plant area of about 2,250 acres (911 ha) and 4,700 acre-feet (about 6 million cubic meters) per year of operational water use (BLM and DOE 2010).[1] The facility would require the complete removal of vegetation, produce a visually impaired skyline (e.g., the Solar PEIS analyzes visual resource impacts for a power tower height of 650 feet [198 m]) seen from a great distance, and use significant amounts of water in a desert environment. It is worth noting that not all solar facilities require a high tower or consume large quantities of water.

1 The CSP technologies operate like coal, natural gas, or nuclear plants with one exception: they use the sun's heat instead of heat from coal, nuclear fuel, or natural gas to boil water and initiate the power generation cycle.

NPS involvement

Because of the significant land area and resource consumption requirements, the broad-scale development of solar energy on public lands throughout the American Southwest poses a substantial potential for cross-boundary conflict with resources administered by adjacent land management agencies, including the National Park Service. For this reason the Park Service became a cooperating agency in the preparation of the Solar PEIS to ensure that specific solar energy program policies and requirements are designed to avoid adverse direct and indirect impacts on park lands and resources. In our analysis of the Draft Solar Energy PEIS, we determined that more than 40% of the proposed solar energy program footprint is located near 53 National Park System units and six national historic trails (hereafter referred to as national park areas). The proximity of solar program lands to these special places raises concern about the potential direct and cumulative adverse effects in these areas. Because the Solar PEIS is programmatic in scope and not designed to authorize site-specific projects, the National Park Service embarked on a project to identify solar energy program lands that represent a high potential for conflict with natural, visual, and cultural resources administered by the Service. The Service's goal was to advise the Bureau of Land Management of program land adjustments that would more fully protect park-specific landscapes.

To effectively communicate park-specific alterations to the program, the National Park Service needed to develop a process to identify areas within the program footprint that pose a high potential for conflict with NPS-administered natural, visual, and cultural resources. The process needed to be capable of providing the Bureau of Land Management with a first-order approximation of those areas where additional screening must be performed to ensure appropriate information is gathered for making future solar facility siting decisions. The desired outcome of the process was to demonstrate a resource conflict–based analysis, by which exclusion of the available program lands is needed to avoid high potential cross-boundary effects at both landscape and local scales. The objective of the process was to apply the best available science-based information from credible sources that enables a defensible description of the potential conflicts.

Generally speaking, there is minimal park-scale information about resource conditions external to areas administered by the National Park Service. Typical park-level data only cover the extent of a park's administered lands and are too detailed for landscape-level analyses, or are inconsistent from park to park. As a result, the project relied on geospatial information available at regional levels or other surrogate information to represent NPS interests or concerns. Using geographic information systems (GIS) to capture available natural, visual, and cultural resource information at the park level, we embarked on a project to develop a methodology using a park's geographic context to assess implications of solar energy development on the proposed solar program lands near parks. To establish a reasonable area of analysis (AOA), we examined resources from 0 to 25 miles (40.2 km) from each of the 53 parks' boundaries.[2] This mapping process revealed generalized resource conditions external to the parks, and allowed analyses based on park-specific knowledge to determine whether utility-scale solar development would produce a high potential for conflict with park resources and values.

2 Because more extensive data collection and analysis would have been required, the Solar PEIS did not allow for a resource conflict assessment of the six identified national historic trails.

Analysis approach and methods

We used a geospatial resource conflict analysis (RCA) in a pilot effort to develop a systematic and objective methodology for identifying solar program lands having the potential for direct and landscape-scale cumulative impacts on national park values and resources. The analysis involved two primary processes: (1) *examination of select resource conditions*, and (2) *determination of potential resource conflicts, which form a basis for recommended exclusions*.

An *analysis of resource conditions* was the initial RCA step. This involved identifying the proposed solar program lands that were adjacent to and within the NPS area of analysis, and searching for the best available landscape- to regional-scale, resource-based geospatial data for use in the RCA (see "Data sources"). Given that development of utility-scale solar energy facilities creates the potential for landscape- and local-scale resource conflicts, the RCA focused on the following cross-boundary potential effects:

- Increased loading of particulate air pollutants and reduced visibility in Class I and sensitive Class II air quality areas
- Vulnerability of sensitive cultural sites and landscapes and loss of historical interpretive value through destruction or vandalism
- Altered water quality and quantity, including the frequency and magnitude of floods, and reduced levels of groundwater
- Reduced habitat quality and integrity, and wildlife movement along migration corridors; increased isolation and mortality of key species
- Fragmentation of natural landscapes
- Diminished wilderness, scenic viewsheds, and night sky qualities on landscapes within and beyond boundaries of areas administered by the National Park Service
- Diminished cultural landscape qualities within and beyond boundaries administered by the Service

We used these potential cross-boundary effects in the next step to gather input from an interdisciplinary cross section of NPS Natural Resource Stewardship and Science (NRSS) staff for indicators of potential resource conflict. We developed a "potential resource conflict–geospatial data matrix" to identify the geospatial data-resource relationships (table 1, next page). We then identified and harvested geospatial data from readily available data sources in order to assess the potential resource conflicts within each area of analysis. One source of data was the NPScape landscape dynamics monitoring project, which provides landscape-level data, maps, analyses, and interpretations to help direct natural resource management and planning at local, regional, and national scales (Monahan et al. 2012). Another source of landscape data and analysis logic was the BLM's Mojave and Central Basin and Range Rapid Ecoregional Assessments (REAs) (BLM 2013). REAs have been initiated by the Bureau of Land Management to address climate change and other landscape-level ecological drivers, such as renewable energy development in seven large ecoregions in the western United States.

Cumulatively, the data-harvesting exercise resulted in the compilation of 12 geospatial data sets that were intended to indicate a range of potential resource conflicts (see "Data sources"). Data sets included critical habitat, landownership, landscape permeability, a naturalness index, nighttime lights, protected areas, roadless natural areas, upstream watersheds, viewsheds, wetlands, and water and wind erodibility. Data were processed into park-specific geospatial databases and map products. (Further data source information and

Table 1. Potential resource conflict analysis matrix

Geospatial Data	Potential Resource Conflict													
	Air Quality	Cultural Landscape	Flood Potential	Fugitive Dust	Habitat Connectivity	Habitat Quality	Historic Integrity	Landscape Fragmentation	Scenic Views	Visitor Experience	Water Quality	Water Quantity	Wildlife Migration	Wildlife Mortality
Critical Habitat					x	x		x					x	
Land Ownership		x			x		x	x					x	
Landscape Permeability		x			x			x					x	x
Naturalness Index		x				x		x						
Nighttime Lights						x	x		x	x				
Protected Areas					x	x	x	x						x
Roadless Natural	x	x		x	x		x	x	x				x	x
Upstream Watersheds			x								x	x		
Viewsheds		x					x		x	x				
Water Erodibility			x		x	x					x	x		
Wetlands			x			x					x	x		
Wind Erodibility	x			x	x	x								

Note: Key resource data definitions and descriptions are found at https://irma.nps.gov/App/Reference/Profile/2175854.

products are available from the NPS Data Store at https://irma.nps.gov/App/Reference/Profile/2175854.)

The *determination of potential resource conflicts and recommended exclusions* involved distributing park-specific key resource GIS data and cartographic maps to parks for review and feedback. Using local park management and resource specialist expertise and knowledge, parks were tasked with delineating areas of high potential resource conflict using the provided key resources GIS data and other local data sources (when available). The solar program lands intersecting these areas were attributed as recommended areas for exclusion from the proposed solar energy program lands.

In the final step, recommended exclusions were spatially referenced and justified with descriptive narratives. For consistency, park-recommended exclusions and justifications were compiled by Intermountain Region, Pacific West Region, and NRSS Solar PEIS team members into a single GIS database with standardized park-specific maps cross-referenced to justifying narratives. In January 2012 we submitted the maps and narratives to the Bureau of Land Management as part of the NPS response to the Supplement to the Draft Solar PEIS (BLM and DOE 2011), to assist the BLM in its final decision on the preferred alternative in the Solar PEIS. Figures 2a and 2b illustrate a compiled park map and cross-referenced geospatial attributes and justifying narratives. We also provided the geospatial data with GIS polygons representing discrete single or combinations of multiple resources reflecting a high potential for conflict.

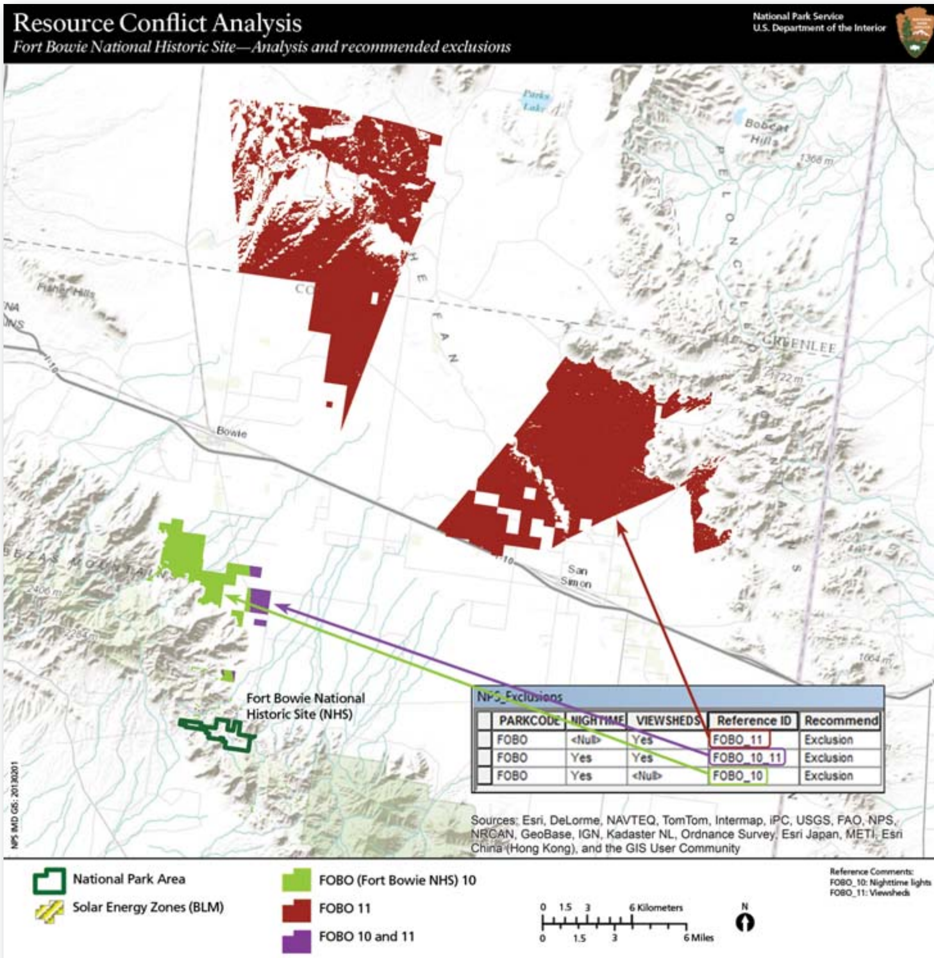

Figure 2a. This map is excerpted from the January 2012 National Park Service response to the Supplement to the Draft Solar PEIS requesting development exclusions. The map delineates GIS polygons with discrete single and combinations of overlying potential resource conflicts. The accompanying descriptive narratives in figure 2b (below) apply to the nongray-shaded areas.

Park Name: Fort Bowie NHS (FOBO)		
Resource of Concern	**Spatial Reference ID#**	**Resource Conflict Justification**
Nighttime Lights	FOBO_10	All lands 10–15 miles from the park have significant night sky values for the park. Variance lands north and south of the park for 20 miles from the park are in an area of particular dark skies too. Lands farther to the northwest have night sky potential impacts for the park but lie closer in alignment with a significant light source in that direction. NPS requests areas north and south of the park be excluded, and the BLM considers the lands to the northwest of the park as acceptable to the NPS if adequate light mitigation is applied.
Viewshed	FOBO_11	Narrow cones of viewshed exist to the north-northeast from the park, intersecting variance lands proposed for solar development. These areas would be of lower priority from a view-shed sense than the lands identified below, but they still maintain their value as high-priority night sky lands. Two variance areas immediately west-northwest of the park lie within 1–4 miles of the park boundary and are within the viewshed from the park. We would expect potentially significant viewshed impacts from these lands, as the utility-scale solar development would be a unique, large, man-made structure, with possible reflectance potential visible by park visitors. We request those areas be excluded.

Figure 2b. This text is excerpted from the January 2012 NPS response to the Supplement to the Draft Solar PEIS and provides an example of a descriptive narrative for requested exclusions based on the high potential for resource conflicts near Fort Bowie National Historic Site (Arizona), as shown in figure 2a (top), with geospatial data cross-references.

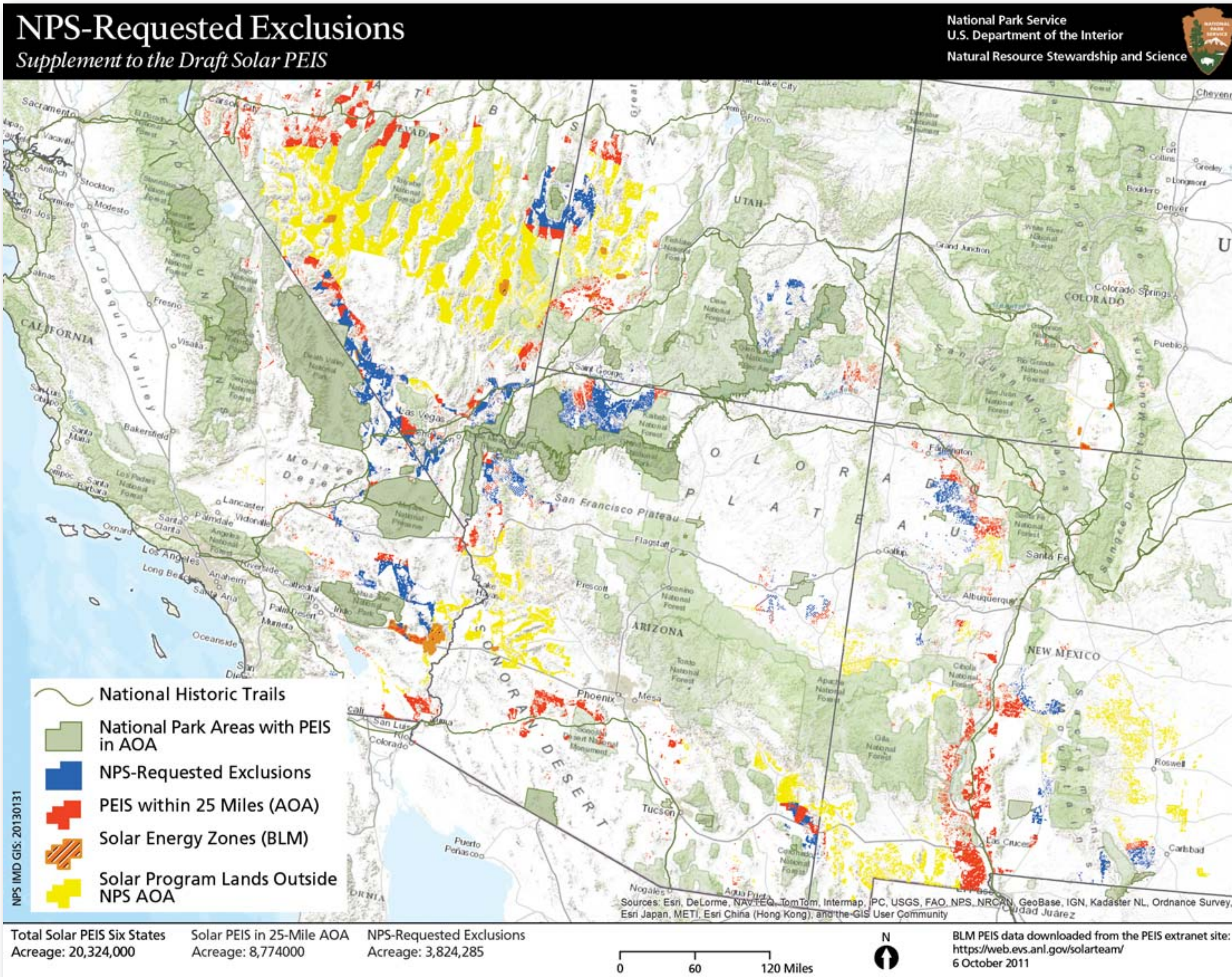

Figure 3. This map depicts the areas requested by the National Park Service in January 2012 for exclusion from the solar energy program. Areas requested for exclusion are shaded in blue; orange-shaded areas represent solar program lands within 25 miles of an NPS-administered area that were not requested for exclusion.

Results of analysis

Resource-based data from authoritative sources facilitated data use and subsequent decision(s) based upon the best available resource management information, scientific knowledge, and local understanding of resource conditions. Within the 20.3 million–acre (8.2 million ha) footprint of the proposed solar energy program the *analysis of resource conditions* process identified 5.6 million acres (2.3 million ha) (28%) of proposed solar program lands as being within the NPS-defined area of analysis.

The *determination of high potential resource conflicts* with national park resources and values resulted in a request to exclude 3.8 million acres (1.5 million ha) of proposed program lands from the Solar PEIS (fig. 3, blue areas). Acreage distributions of NPS-requested exclusions, represented as areas of high potential for resource conflicts, by GIS key resource type are shown in figure 4. Though not an indication of resource conflict priority, wind erodibility and nighttime lights GIS data sources had the most requested exclusion acreage at 2.25 and 2.02 million acres (0.91 and 0.82 million ha), respectively.

The identification of proposed solar energy program lands where utility-scale solar energy development produces a high potential for conflict with resources administered by the National Park Service was a critical step in the Bureau of Land

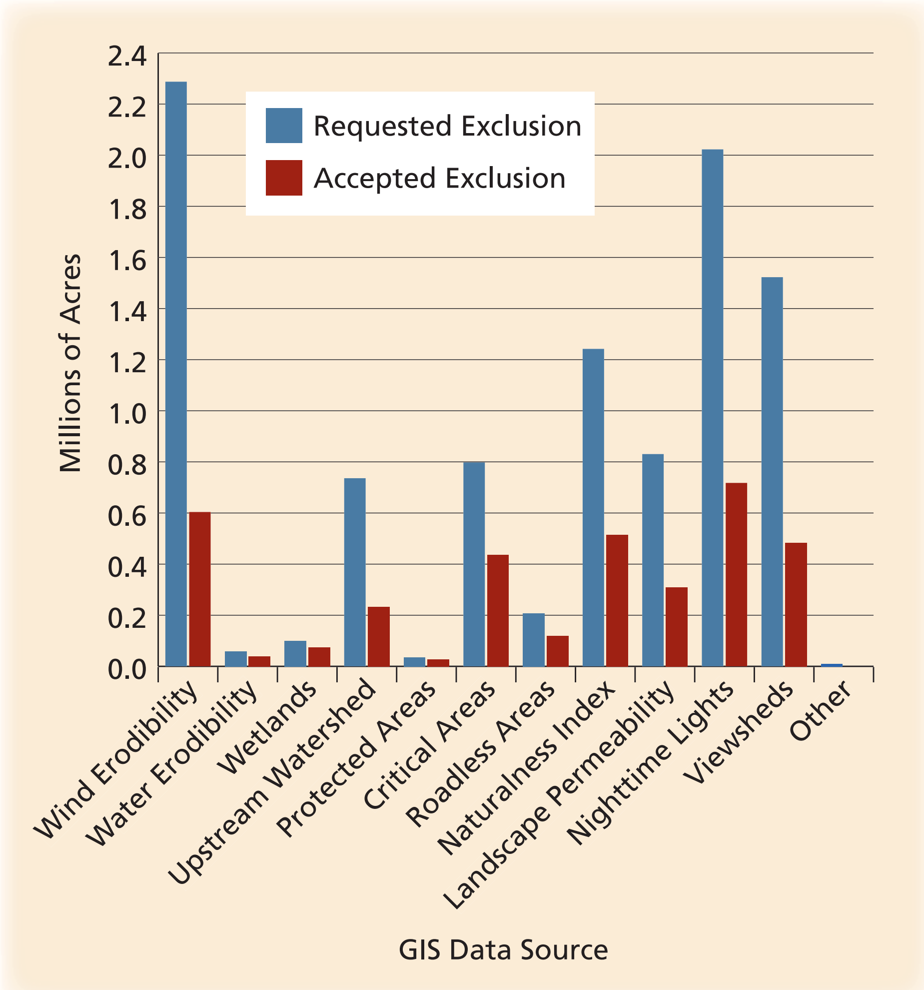

Figure 4. National Park Service–requested and BLM-accepted solar program exclusion acreage by GIS data source.

Management's final determination of the footprint for the proposed solar energy program. The BLM response to the National Park Service comments on the Supplement to the Draft Solar PEIS resulted in the exclusion of more than 800,000 acres (324,000 ha) of program lands that coincide with NPS-identified areas of high potential for conflict (fig. 5, next page, red areas). The remaining 3.02 million acres (1.22 million ha), or about 16% of the lands potentially available for solar energy development—not excluded from the solar energy program—were identified by the BLM as areas of high potential for resource conflict (fig. 5, blue areas) and carried forward to the Final Solar PEIS. These maps will be referenced by the BLM solar energy program in the screening and siting of proposed solar energy projects. Applicants for solar energy projects on lands identified as having a high potential for resource conflict will be required to demonstrate that project development can avoid or minimize resource impacts. The distribution of NPS-requested and BLM-accepted Solar PEIS exclusions by resource reveals that nighttime lights and wind erodibility GIS data sources were associated with the largest accepted exclusion acreage values (fig. 4).

Lessons learned from case study

With increasing energy development and external threats to national parks in the foreseeable future, there is need and opportunity for continued expansion and development of a systematic approach for the resource conflict analysis process to evaluate proposed external development actions. With the methodology we employed in this study, a well-reasoned and defensible resource-specific conflict analysis approach was presented and used to inform the Solar PEIS decision. However, there is ample opportunity for the development and adoption of more robust analytic tools and methodologies. The National Park Service should focus on developing and adopting qualitative thresholds (i.e., high, medium, and low resource conflicts) and quantitative methods (metrics) to refine conflict criteria and resource indicator data in order to further evolve NPS resource conflict analysis capabilities. Refinements would support a range of analysis requirements to accommodate local-scale park and project-centered to broader regional landscape-scale analyses. The goal of any refinement is to strengthen the validity of resulting end products and recommendations. Additionally, the continued compilation and development of readily available key resource geospatial data would be beneficial for subsequent RCA projects.

Lands administered by the National Park Service are established in areas throughout the country where the Park Service is authorized to protect and preserve outstanding, nationally significant natural and cultural resources. In many cases these locations, along with their attendant remote setting, high potential for neighboring development opportunities, or proximity to outstanding recreational, cultural, and scenic resources, create the increasing potential for incompatible

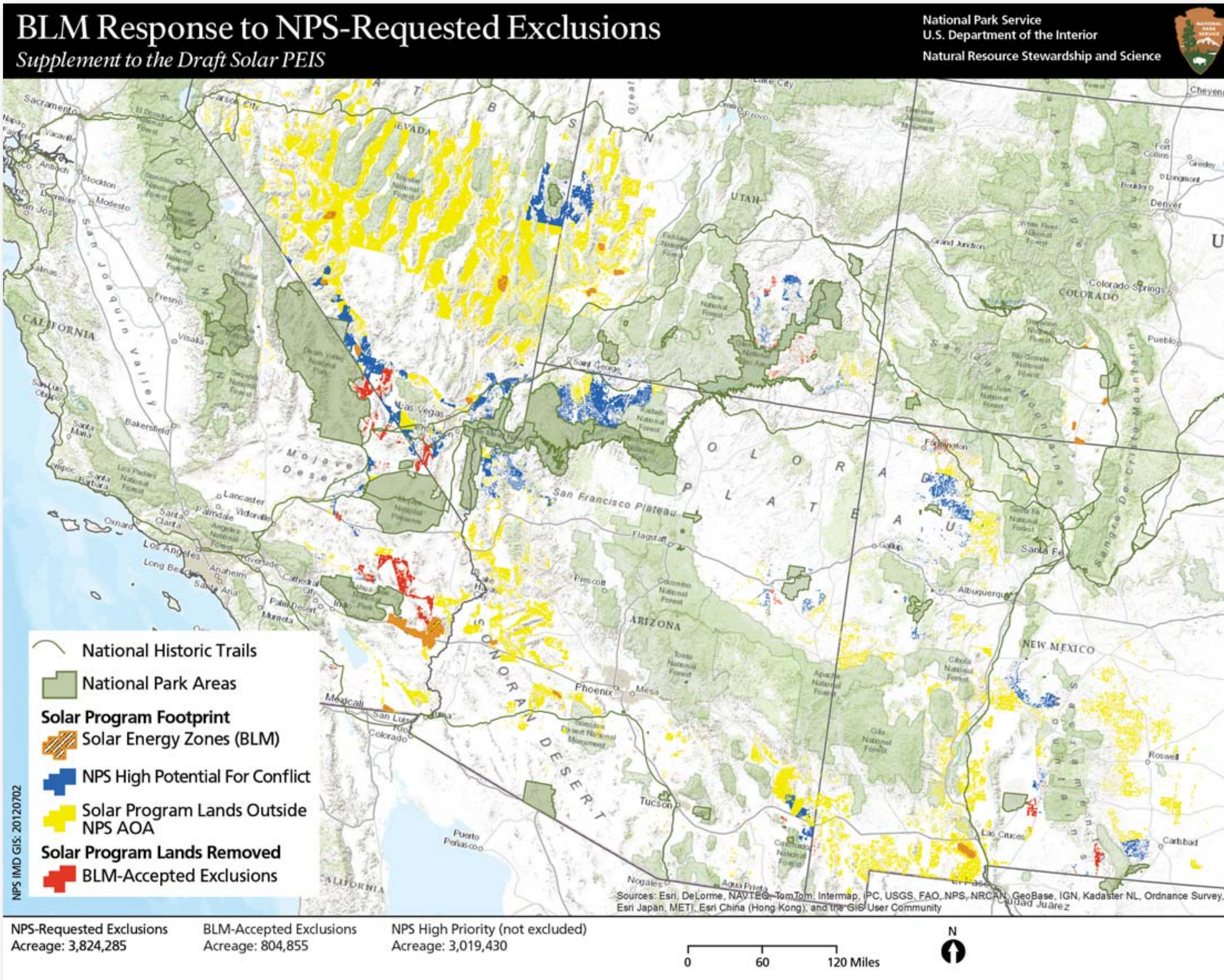

Figure 5. This map depicts the distribution of BLM-accepted exclusions from the solar energy program (orange) and high potential for conflict areas (blue) that are subject to further analysis. The accepted exclusions were carried forward into the Final Solar PEIS. (Final solar energy program acreage may vary slightly in the Final Solar PEIS.)

adjacent land use activities. The National Park Service needs to develop an objective, consistent, and proactive approach to identifying adjacent or proximal areas that have an explicit or potential connection to resources it is entrusted to maintain for future generations.

Traditionally, the National Park Service assesses the implications of adjacent land use development on a site-specific (i.e., park-by-park and project-by-project) basis. Within a park-centered geographic context, these analyses provide valuable information for assessing project development effects and responding with appropriate recommendations. As the geographic extent of land use decisions becomes increasingly broad (scale) and diverse (complex), tools for assessing landscape-level effects must be capable of examining cumulative, far-reaching impacts. As a result the National Park Service is increasingly required to perform rapid, broad-scale assessments to determine the potential consequences of development actions across numerous landscapes affecting a diverse array of resource conditions. While park-specific analyses are necessary to confirm site-level conditions, this case study highlights the need for the Park Service to adopt analytical tools and information sources that can be used to better understand and communicate potential cumulative, cross-boundary impacts on resources and values of National Park System areas.

Conclusion

Over a two-year period NPS staff at national, regional, and park levels performed an unprecedented, labor-intensive analysis of potential resource conflicts in the Southwest. The pilot RCA project explicitly assessed the benefit of incorporating this methodology in an external programmatic energy policy setting. From a tactical perspective, the results produced valuable information for the National Park Service and the Bureau of Land Management to assess policy-level implications of the BLM-proposed solar energy program. Results also confirm the strategic advantage of using geospatial-based resource conflict analysis as a policy-level decision support tool to provide first-order approximations of potential external threats to NPS-administered resources for a broad spectrum of park resources and settings. Furthermore, the applied methodology demonstrates the potential usefulness of this application in other venues, such as local or regional land use, renewable energy, and other planning activities. The method is resource- and science-based and provides a credible starting point from which more focused data and analyses can be performed as needed.

For purposes of the BLM solar energy program, the maps and data from the NPS resource conflict analysis will be used to direct the siting of solar energy development in the most appropriate places in six southwestern states. During the formulation of the Solar PEIS, the information developed by the National Park Service was applied by the Bureau of Land Management to refine the footprint of the program by removing certain high-solar-potential lands. The maps and data will also be used to further prioritize development and facilitate identification of monitoring and mitigation protocols in the proposed solar energy zones. More importantly, the maps and data will be relied upon to inform industry and the Bureau of Land Management in the pre-application review phase of the need for focused data and analyses for projects located outside the solar energy zones. Through the solar energy program's rigorous pre-application screening phase, prospective projects located outside the designated solar energy zones will be required to demonstrate that a project represents a low potential for conflict with sensitive natural, visual, and cultural resources, that is, it avoids a higher level of potential for conflict. The documentation provided by the applicant must be sufficiently detailed to allow the Bureau of Land Management and the National Park Service to confirm that a low potential for resource conflict is likely to occur and impacts on sensitive resources can be minimized through alternative project design, mitigation, or project relocation.

The National Park Service's ability to better understand consequences of potential cross-boundary effects in multiple landscapes and diverse resource conditions requires readily available tools to perform rapid, broad-scale assessments. Given the magnitude of the decisions to be made (such as those manifested through the Solar PEIS planning process), we have demonstrated our ability to identify and express a broader perspective for NPS resource protection concerns. Based purely on the experiences of the NPS response to the Solar PEIS planning process, the BLM was able to exclude more than 800,000 acres (324,000 ha) of high-resource-potential lands from future solar energy development and identify more than 3 million acres (1 million ha) where the National Park Service will be engaged in the screening of proposed solar energy projects. The precedent for future applications of an RCA approach has been established.

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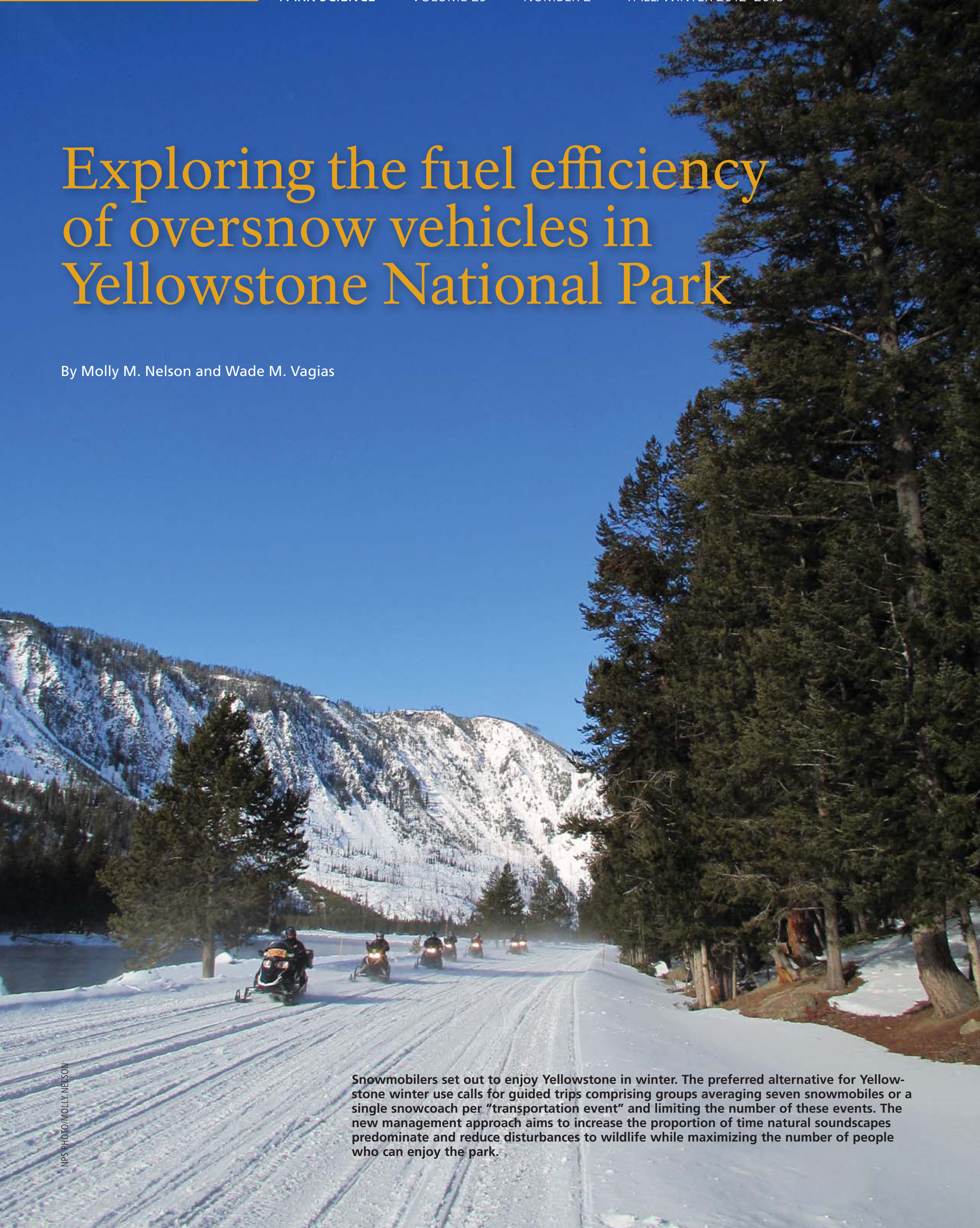
Exploring the fuel efficiency of oversnow vehicles in Yellowstone National Park

By Molly M. Nelson and Wade M. Vagias



NPS PHOTO/MOLLY NELSON

Snowmobilers set out to enjoy Yellowstone in winter. The preferred alternative for Yellowstone winter use calls for guided trips comprising groups averaging seven snowmobiles or a single snowcoach per "transportation event" and limiting the number of these events. The new management approach aims to increase the proportion of time natural soundscapes predominate and reduce disturbances to wildlife while maximizing the number of people who can enjoy the park.

Abstract

Winter use planning for Yellowstone National Park is one of the most contentious issues in the National Park Service, with the debate primarily centered upon the impact of oversnow vehicles (OSVs, or snowmobiles and snowcoaches) on park resources, including wildlife, air quality, and natural soundscapes as well as the visitor experience. Recently, several conservation advocacy groups have suggested that snowcoaches are more fuel efficient at the per-person level than snowmobiles. The purpose of this research was to assess fuel efficiency for a representative cross section of oversnow vehicles from Yellowstone's commercial tour operators' fleet regarding two primary metrics: miles per gallon (MPG) and person-miles per gallon (PMPG). Our analysis shows snowcoaches to have fuel efficiency averages ranging from 1.7 to 5.3 MPG (0.72 to 2.3 kilometers per liter) and 15 to 45 PMPG (6.4 to 19 passenger-kilometers per liter) and snowmobiles to have averages of 14 to 25 MPG (6.0 to 11 kilometers per liter) and 16 to 30 PMPG (6.8 to 13 person-kilometers per liter). Average fuel efficiency rates vary considerably among different models of snowcoaches and snowmobiles, but for the most popular models of OSVs in use in the park, neither category is decidedly more fuel efficient than the other at the PMPG level.

Key words

fuel efficiency, oversnow vehicles, snowcoaches, snowmobiles, winter use, Yellowstone National Park

WINTER USE IN YELLOWSTONE NAtional Park (Wyoming, Montana, and Idaho) has been the subject of ongoing public debate for more than 75 years. Since the 1930s the National Park Service (NPS) and interested stakeholders have debated if and how the park should be accessed in winter. The sidebar below explains the laws that necessitate special winter planning. The past decade of winter use planning and associated rulemaking efforts has been particularly contentious, with debate primarily centered upon the impact of oversnow vehicles (snowmobiles and snowcoaches, collectively OSVs) on wildlife, air quality, and natural soundscapes. To help address these questions, since 1997 Yellowstone has completed four environmental impact statements (EISes)—a fifth is currently in development—and two environmental assessments (EAs) and promulgated three long-term rules, only to have those regulations overturned by federal courts. The 2001 rule to phase out snowmobiles from Yellowstone, signed off on the last day of the Clinton administration in January 2001, was delayed by the incoming Bush administration and eventually vacated by the U.S. District Court of Wyoming. Subsequent EISes were completed in 2003 and 2007, both of which were vacated by the U.S. District Court for the District of Columbia (see Yochim 2009 for a discussion of winter planning use in Yellowstone).

Not surprisingly, given the role of Yellowstone National Park in the conservation movement and the American psyche, the ongoing debate about what is best for Yellowstone in winter has polarized stakeholders and elevated the issue to the national spotlight. Organizations, including the Greater Yellowstone Coalition (GYC), National Parks Conservation Association (NPCA), Sierra Club, and Coalition of National Park Service Retirees (CNPSR), have, for more than a decade, advocated for the abolition of snowmobiles in favor of a snowcoach-only transportation paradigm. The GYC describes its goal as "to phase out snowmobiles in Yellowstone in favor of cleaner, quieter, more efficient snowcoaches" (Greater Yellowstone Coalition 2012). Access-oriented organizations and stakeholders, including the Blue Ribbon Coalition, International Snowmobile Manufacturers Association, and various state-level snowmobile clubs, have advocated for continued access by snowmobiles, but have not advocated for the elimination of snowcoaches.

Stakeholders' substantive observations and comments have elevated the level of discourse throughout the numerous winter use planning processes that have transpired over the past 15 years. This continual external examination of data and analyses has worked effectively alongside the park's own, raising important questions and helping ensure fidelity to the law, use of the best available science, and management decisions that are in the long-term interest of the park and the American people. All the while, new management strategies and OSV technologies introduced in the past decade have served to significantly improve resource conditions.

Need for special rule to authorize oversnow vehicle use

The necessity for a special rule to authorize oversnow vehicle use in national parks stems from Executive Orders (EO) 11644 and 11989, which together require off-road vehicle use to immediately discontinue if such use will cause "considerable adverse effects on the soil, vegetation, wildlife, wildlife habitat, or cultural or historic resources of particular areas or trails of the public lands" (snowmobiles are considered off-road vehicles by the orders), and such areas must remain closed until the agency implements measures to prevent those adverse effects. Colloquially, this is known as the "closed unless open" rule.

For instance, requiring best available technology (BAT) snowmobiles eliminated the "blue haze" that was common in the park in the 1990s and capped the maximum noise output of a snowmobile (currently the loudest commercial OSVs in the park are snowcoaches). The requirement that all trips be led by guides greatly reduced instances of wildlife harassment.

As resource conditions have improved, some stakeholder groups have sought new reasons to support their respective positions. A concern recently brought to the attention of winter use planning staff is the relative fuel efficiency of OSVs in use in the park. In comments received during the scoping process for the 2012 Winter Use Plan/Supplemental Environmental Impact Statement, the CNPSR, GYC, Natural Resources Defense Council, Sierra Club, and Winter Wildlands Alliance expressed interest in comparing the two different forms of winter transportation modes (snowmobiles and snowcoaches) using "per-visitor" impacts, contending that such analysis "might be most revealing in the context of *fuel efficiency* and emissions" (emphasis added) (Coalition of National Park Service Retirees et al. 2012). The working assumption is that because snowcoaches hold more people, they are more fuel efficient at the per-person level than snowmobiles.

Previous OSV fuel use studies

Our review of the literature and the administrative record found few instances of data or analyses to support the contention that snowcoaches are more efficient at the per-person level than snowmobiles, and the data that were present were not convincing. Those few analyses evaluated fuel efficiency peripherally, usually as a minor subset of tailpipe emission studies (see Bishop et al. 2006 and 2007, and Ray et al. 2012). Furthermore, those studies have been limited by small sample sizes, varying fuel efficiency estimation methods, or used fuel efficiency estimations provided by manufacturers. These limitations reinforced the need for more thorough analysis of the fuel efficiency of OSVs in use in winter in Yellowstone National Park.

The 2012 Yellowstone Final Winter Use Plan/ Supplemental EIS

The preferred alternative in the 2013 Final Winter Use Plan/Supplemental Environmental Impact Statement (SEIS) is to manage OSV access by "transportation events," defined as one snowcoach or a group of seven snowmobiles (averaged seasonally and with a daily maximum of 10 snowmobiles per event) traveling together within the park (Yellowstone Final Winter Use Plan/SEIS 2013). This approach differs from previous management alternatives that were based on managing by absolute numbers of OSVs rather than managing by groups (or transportation events). The rationale for the shift is based on the empirical evidence that impacts on soundscape and wildlife resources stem from transportation events rather than absolute numbers of vehicles. By packaging traffic into transportation events and limiting the total number of transportation events allowed access into the park each day, the park is able to lessen disturbances to wildlife and improve natural soundscape conditions, in addition to allowing more visitors to see the park in winter. Data collected and analyzed during the 2012 SEIS process indicate that snowmobile and snowcoach transportation events have comparable adverse impacts on Yellowstone's resources and values. However, greater insight into the fuel efficiency of OSVs could shed additional light on the comparability of the two types of transportation events. We also note that fuel efficiency is distinct from tailpipe emissions and air quality as an impact topic, and is therefore not directly under evaluation in the SEIS. Nevertheless, this issue has been raised by stakeholders commenting on the current planning process, could influence the vehicles that commercial tour operators and the park choose to use, and provides insight into the amount of fossil fuels required to power OSVs in Yellowstone.

Study purpose

We sought to advance understanding of the relative fuel efficiency of a representative cross section of OSVs used in Yellowstone in winter for two primary metrics:

- Miles per Gallon (MPG): The number of mile(s) a vehicle travels using one gallon of fuel; calculated as miles traveled divided by gallons of fuel expended on a trip. Miles per gallon is commonly used to describe the fuel efficiency of a vehicle but does not provide insight into fuel efficiency on a per-person basis. It is also expressed in kilometers per liter (KPL).

- Person-Miles per Gallon (PMPG): Fuel efficiency on a per-person basis; calculated as miles traveled times the number of persons on board divided by fuel expended. The person-miles per gallon metric is often used to compare fuel efficiency of various mass transit systems and allows for a more appropriate comparison of relative rates of fuel consumption. It is also expressed in person-kilometers per liter (PKPL).

Methods

Data collection

Five commercial OSV tour operators based in West Yellowstone, Montana, and one commercial OSV tour operator based in Jackson, Wyoming, were asked to record fuel consumption during the 2011–

2012 winter season for a variety of OSVs from their respective fleets. The goal was to generate a fuel consumption data set for a representative cross section of OSVs currently in use in the park. We provided each operator with a standardized data input form that requested information related to the date of each trip, the type of OSV (including associated engine and ski/track configuration), a description of the trip (origin, destination, and number of miles traveled), the number of persons per vehicle for the trip, and the total amount of fuel consumed.

The person-miles per gallon metric is often used to compare fuel efficiency of various mass transit systems and allows for a more appropriate comparison of relative rates of fuel consumption.

NPS PHOTOS (3)

Figure 1. Four of the snowcoaches represented in the data set, clockwise from top left: 1956 Bombardier, 2011 Chevrolet, 2011 Turtle Top, and 2001 Chevrolet.

Our *unit of analysis* was a single OSV; we used this term to denote either a specific snowcoach in the commercial fleet or all snowmobiles of a certain make, model, and year. For example, the “2011 Ford” is a single snowcoach owned by a single operator in West Yellowstone. A “2012 Ski-Doo GT1200” represents data from many individual snowmobiles of this particular make, model, and year that were reported separately but averaged together. Our *level of analysis* (a “data point”) was a single OSV making a single round-trip from a known point of origin to a known destination and back. We analyzed trips to the most popular destinations in Yellowstone: between West Yellowstone and Canyon Village, between West Yellowstone and Old Faithful, and from the South Entrance to Old Faithful and back. Filters were applied to ensure that all data used in the fuel efficiency calculations were as reliable and representative as possible and not unduly influenced by outlying cases. We retained for analysis only OSVs with six or more reported trips. We included trips with passenger loads falling within two standard deviations of the arithmetic mean for each individual snowcoach and did not use trips with outlier-load characteristics like those in which an OSV towed a luggage trailer. We did not take out any snowmobile trips based on outlier ridership, as ridership for a snowmobile is always between 1 and 2, and both values are common. We retained 1,249 snowmobile and 137 snowcoach data points (individual round-trips by a single vehicle) after data filtering and processing.

Distance and passenger estimates

When available, exact round-trip distances for snowmobile trips were used; these ranged from 63 to 71 miles (101–114 km) for West Yellowstone to Old Faithful and 106 to 115 miles (171–185 km) from West Yellowstone to Canyon Village. When exact mileage data were not provided, the arithmetic mean for known trip mileage events (equal to that used for snowcoaches) or the operator-estimated mileage (in the case of South Entrance trips) was used. We did not use snowcoach odometer readings because the circumference differences between track systems and standard tires rendered the values invalid, and we were not in a position to fit OSVs with GPS tracking devices to record total mileage. Round-trip distances for all snowcoach trips were estimated at 65 miles (105 km) for West Yellowstone to Old Faithful and 111 (179 km) miles for West Yellowstone to Canyon Village. Round-trip distances from the South Entrance to Old Faithful were estimated at 94 miles (151 km) during December and 100 miles (161 km) in January through March, the difference owing to additional site visits in the Old Faithful area later in the season when road conditions improved. These estimates were based on conversations with operators and

Table 1. Attributes of analyzed oversnow vehicles

	Study Name	Data Points	Vehicle Year, Make, Model	Engine Size (cylinders/liters displacement)	Fuel	Track Type	Max. Capacity	Gate of Origin
Snowcoaches	1956 Bombardier	14	1956 Bombardier B-12	8 cylinders, 5.3 L	Gas	Bombardier Skis/Tracks	11	West
	2001 Chevrolet	9	2001 Chevrolet Express Van Terra	8 cylinders, 8.1 L	Gas	Mattracks 150, YS3-175*	15	West
	2011 Chevrolet	28	2011 Chevrolet Passenger Van	8 cylinders, 6.0 L	Gas	Mattracks 150	15	South
	2006 Ford	6	2006 Ford E-350 Passenger Van	8 cylinders, 5.4 L	Gas	Mattracks 150	15	West
	2010 Ford	7	2010 Ford E-350 Passenger Van	8 cylinders, 5.4 L	Gas	Mattracks 150	15	West
	2011 Ford	24	2011 Ford E-350 Van Terra	10 cylinders, 6.7 L	Gas	Mattracks 150, YS3-175*	15	West
	2011 Turtle Top	49	2011 Ford F-550 Turtle Top	8 cylinders, 6.7 L	Diesel	GripTrac	31	West
Snowmobiles	2012 Arctic Cat TZ1	58	2012 Arctic Cat TZ1	2 cylinders, 1,056 cm^3	Gas	N/A	2	West
	2011 Arctic Cat TZ1	89	2011 Arctic Cat TZ1	2 cylinders, 1,056 cm^3	Gas	N/A	2	West
	2012 Ski-Doo GT1200	24	2012 Ski-Doo GT1200	3 cylinders, 1,170.7 cm^3	Gas	N/A	3**	West
	2012 Ski-Doo GT600 ACE	130	2012 Ski-Doo	2 cylinders, 600 cm^3	Gas	N/A	2	West
	2011 Ski-Doo GT600 ACE	948	2011 Ski-Doo	2 cylinders, 600 cm^3	Gas	N/A	2	South

*YS3-175 tracks are experimental tracks used by one operator out of West Yellowstone; they are intended to improve vehicle operation in several ways, so trips using these tracks are specifically noted in the data.

**According to the manufacturer, this vehicle can hold three people. Operators usually only fill it to this capacity if the group consists of one adult and two small children.

reported snowmobile mileage (snowmobile odometers are correctly calibrated).

Exact passenger numbers were provided for all snowcoach trips so no passenger number estimations were necessary. Exact passenger numbers were provided for many of the snowmobile trips and when known were used to inform calculations. When exact passenger numbers were unavailable (as with some of the data points starting at West Yellowstone), estimations were based on the average snowmobile ridership, 1.4 persons per snowmobile, from the 2009–2010 through 2011–2012 seasons' visitation data from the West Entrance (Yellowstone Draft Winter Use Plan/Supplemental Environmental Impact Statement 2012).

Results

Our data set contained data on 10 individual snowcoaches and three different makes/models of snowmobiles. We attempted to get a representative cross section of the park's OSV fleet, and the majority of the vehicles in our data set are very popular models. Table 1 describes characteristics of each OSV retained for analysis, and figure 1 (previous page) contains photos of 4 of the 10 snowcoaches we analyzed. Snowcoaches ranged from a repowered 1956 Bombardier B-12 to a 15-passenger Ford, and Chevrolet vans up to a large 30+ passenger bus. During the winter of 2011–2012, approximately 27% (N = 21) of the snowcoaches used in the park were Bombardiers (primarily model B-12), while 47% (N = 37) were standard vans and SUVs (Ford E-350 15-passenger vans, Chevrolet Express), and 26% (N = 20) were small and mid-sized buses (Van Terra, Odyssey, Krystal). The three snowmobile models retained for analysis (Arctic Cat TZ1, Ski-Doo GT600, and Ski-Doo GT1200) are among the most popular makes and models in use in the park and all meet Yellowstone's best available technology (BAT) requirement.

Figure 2 presents the range of fuel consumption in miles per gallon for snowmobiles and snowcoaches. Overall, snowmobile fuel efficiency ranges from 14 to 25 MPG (6.0 to 11 KPL). Snowmobiles with smaller engines, such as the Ski-Doo GT600 ACE, which has a 600 cc engine, obtain nearly twice the MPG of those with larger engines, such as the Arctic Cat TZ1 and Ski-Doo GT1200. Ski-Doo GT 600 ACE snowmobiles based at the South Entrance, and traveling on the steep grade of the south entrance road, averaged 23 MPG (9.8 KPL), slightly less than the 25 MPG (11 KPL) the same snowmobiles originating at West Yellowstone averaged. In terms of fuel consumed per mile, the most efficient snowcoach was the 1956 Bombardier, which attained 5.3 MPG (2.3 KPL) on average, and the least efficient was the Ford F-550 Turtle Top, which attained 1.7 MPG (0.72 KPL) on average. The Bombardier is nearly twice as fuel efficient in terms of MPG as the next most efficient snowcoach, the 2010 Ford, which averaged 2.7 MPG (1.1 KPL).

Figure 3 shows person-miles per gallon for all vehicles tested, segmented into vehicles operating out of West Yellowstone and the South Entrance and ordered from most to least efficient. Table 2 (next page) gives additional statistics of person-mile per gallon calculations for each vehicle. Fuel efficiency at the PMPG level is not consistently different between snowmobiles and snowcoaches; however, it does vary considerably among different models of snowcoaches and snowmobiles. The top three vehicles out of the West Entrance in terms of PMPG efficiency are the 1956 Bombardier with a fuel-injected V-8 motor, which averages 45 PMPG (19 PKPL); the 2011 Ford F-550 Turtle Top snowcoach, which averages 38 PMPG (16 PKPL); and the Ski-Doo ACE 600 snowmobile,

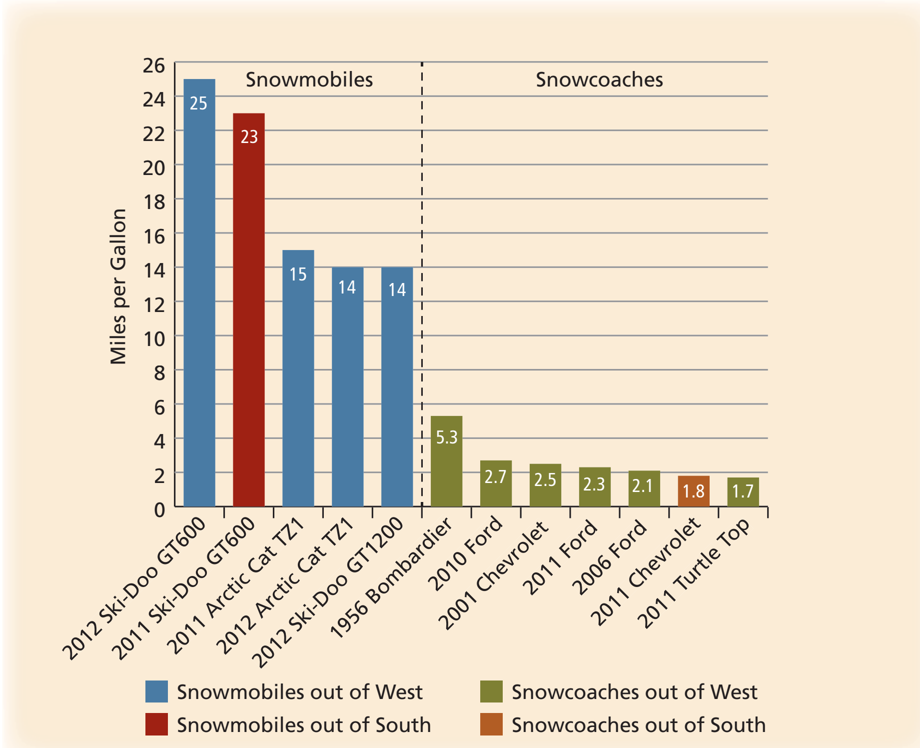


Figure 2. Miles per gallon for snowmobiles and snowcoaches, listed from most to least efficient and segmented by vehicle type.

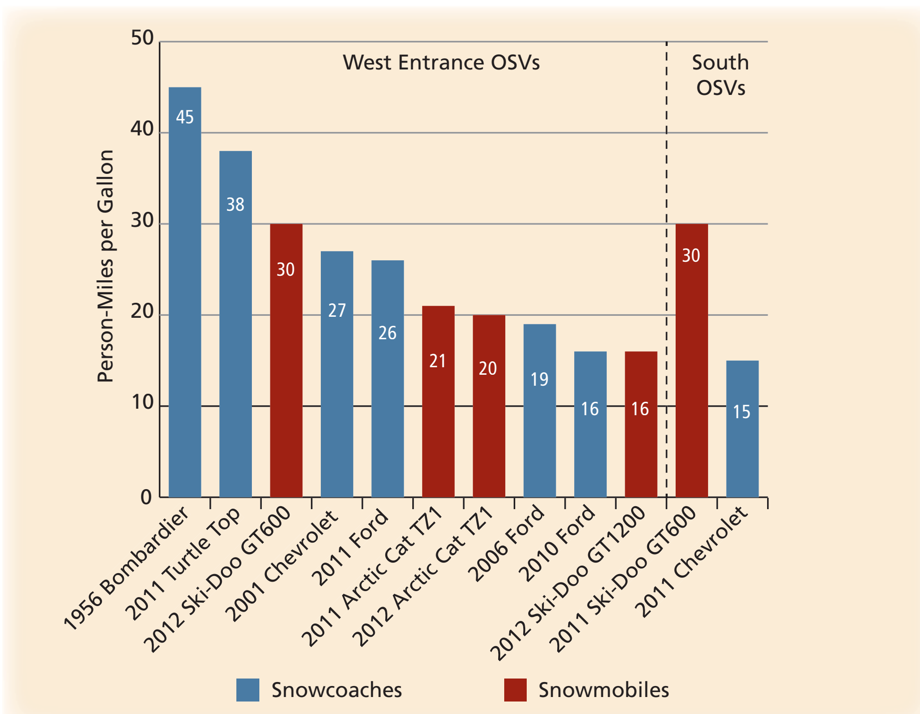


Figure 3. Person-miles per gallon for snowmobiles and snowcoaches, listed from most to least efficient and segmented by park entrance gate.

Table 2. Final MPG and PMPG values

Vehicle	Miles/ Gallon (avg.)	Persons/ Vehicle (avg.)	Person-Miles/ Gallon (avg.)	Min. PMPG	Median PMPG	Max. PMPG	SD PMPG
1956 Bombardier	5.3	8	45	26	42	82	14
2011 Turtle Top	1.7	22	38	14	40	60	12
2012 Ski-Doo GT600	25	1.2	30	19	29	49	6.8
2001 Chevrolet	2.5	11	27	17	26	38	6.9
2011 Ford	2.3	11	26	15	26	37	6.9
2011 Arctic Cat TZ1	15	1.4	21	15	20	38	4.3
2012 Arctic Cat TZ1	14	1.4	20	16	20	26	2.2
2006 Ford	2.1	9	19	11	20	26	5.8
2010 Ford	2.7	6	16	9.0	15	25	6.0
2012 Ski-Doo GT1200	14	1.2	16	10	13	48	7.9
2011 Ski-Doo GT600	23	1.3	30	13	28	74	10
2011 Chevrolet	1.8	8	15	7.9	15	26	3.9

which averages 30 PMPG (13 PKPL). For the South Entrance, the 2011 Ski-Doo Ace 600 is two times as fuel efficient at 30 PMPG (13 PKPL) as the 2011 Chevrolet snowcoach, which averages 15 PMPG (6.4 PKPL). There appears to be no relationship between the model year of an OSV and its fuel efficiency.

Discussion and implication

Overall snowcoach fuel efficiency ranged widely, a fact likely attributed to varying track types, power-to-weight ratios, snow conditions, road grades, engine sizes, and differential gearing, among other variables. Without question, the most fuel-efficient OSV in our analysis at the PMPG is the repowered Bombardier snowcoach, which averages 45 PMPG (19 KPKL). This vehicle is purpose-built for oversnow travel and has a relatively long track design allowing it to stay at the top of the snow-road surface, a lightweight frame and body, and ample power from its V-8, fuel-injected motor. These attributes combine to afford it the ability to operate in higher gears while under power and cruising in the park. The second most efficient snowcoach at the PMPG level is the Ford F-550 Turtle Top at 38 PMPG (16 PKPL). Unlike the Bombardier, which has a relatively high power-to-weight ratio but only carries up to 11 people, the Ford is efficient at the PMPG level because it has a very large diesel motor and carries up to 31 people. Snowmobile fuel efficiency also varies widely. The Ski-Doo GT ACE with the 600 cc engine is nearly twice as fuel efficient at approximately 30 PMPG (13 PKPL) as snowmobiles with larger engines, such as the Ski-Doo GT1200 and Arctic Cat TZ1, which averaged approximately 16 and 21 PMPG (6.8 and 8.9 PKPL), respectively.

Though limited, this study is informative. By analyzing OSVs in the current Yellowstone commercial operator fleet under a wide range of operating conditions and with various passenger loads, we have been able to ascertain fuel efficiency rates for a representative cross section of these vehicles. The repowered Bombardier and large Ford bus are considerably more fuel efficient at the per-person level than even the most efficient snowmobile we analyzed; however, both of these vehicles have significant limitations. Bombardiers have been out of production for decades, and acquiring replacement parts can be very difficult. Traveling in a "Bomb" (as they are affectionately called) is a unique experience and is one that does not appeal to all winter visitors to Yellowstone. The Ford F-550 Turtle Top also has significant limitations. Given its size and weight, this coach is only capable of making trips between West Yellowstone and Old Faithful and is unable to travel to the Canyon Village area or to the South, North, or East Entrance. There is also concern that snowcoaches of this size and weight may cause rutting of snow roads, affecting all winter vehicular travel, and pose safety risks to visitors in smaller snowcoaches and on snowmobiles.

The third most fuel-efficient OSV on a per-person level is the Ski-Doo ACE 600, which was more efficient than five of the seven snowcoaches we measured. Interestingly, compared with the two other snowmobile models measured (the Arctic Cat TZ1 and the Ski-Doo GT-1200), the Ski-Doo Ace was approximately 65% more efficient in terms of miles per gallon. This is an important finding for commercial tour operators and for the park's administrative snowmobile fleet. In terms of fuel efficiency across the various OSVs in use in Yellowstone and given the known limitations of the various OSVs, we conclude there is insufficient evidence to support a compelling advantage for one type of OSV transportation mode over another.

Study limitations

This analysis has several limitations that could be addressed in subsequent evaluations. Data were self-reported by operators. Variables such as road and weather conditions may influence fuel efficiency for a given vehicle, and the ability to assess these potential effects could be insightful. Estimation of distance traveled would be more accurate if OSVs were fitted with GPS units.

The shift [in management tactics] is based on the empirical evidence that impacts on soundscape and wildlife, stem from resources/transportation events rather than absolute numbers of vehicles.

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Research Reports

Enhancing native plant habitat in a restored salt marsh on Cape Cod, Massachusetts

By Jesse S. Wheeler, Rachel K. Thiet, and Stephen M. Smith

Abstract

The tidal restoration of Hatches Harbor, a 100-acre (41 ha) salt marsh in Cape Cod National Seashore, Massachusetts, has resulted in substantial native halophyte (salt-tolerant taxa) reestablishment in portions of the marsh. However, extensive stands of the invasive *Phragmites australis* still occupy a large area of the marsh. These stands present a physical barrier to the dispersal and establishment of seeds from the adjacent, recovering salt marsh. The goal of this study was to evaluate the establishment success of native halophytes in response to manual cutting of *Phragmites* growth in *Phragmites*-dominated areas of Hatches Harbor where halophyte reestablishment has been poor. We measured species composition, abundance, and diversity in one hundred 10.76 ft^2 (1.00 m^2) plots at Hatches Harbor over two growing seasons in 2008 and 2009. Very few halophytes naturally grew within dense stands of untreated *Phragmites*, whereas halophyte abundance and diversity were significantly greater in plots where *Phragmites* was mechanically removed. Thus, mechanical removal of *Phragmites* improves conditions for halophyte establishment, presumably by reducing barriers to seed dispersal and through increased light exposure.

Key words

Cape Cod National Seashore, halophyte, *Phragmites*, salt-marsh restoration, *Spartina*

MANY ATLANTIC SALT MARSHES HAVE BEEN SEVERELY degraded by structures such as roads and dikes that restrict tidal flow. Tidal restriction causes a reduction in salinity and a shift in salt marsh to brackish, freshwater, and even upland plant species (Amsberry et al. 2000; Smith 2007; Smith et al. 2009). Many of these tidally restricted salt marshes are being restored by increasing tidal exchange (Roman and Burdick 2012). However, the restoration of native salt-marsh plant communities can still be limited by the presence of the invasive common reed (*Phragmites australis*). Persistent stands of this salt-tolerant species, which tends to proliferate in tidally restricted systems, exclude native halophytes by impeding seed dispersal and shading the seed bank (Rand 2000; Minchinton et al. 2006).

The recovery of salt-marsh plant communities is partly dependent upon seed germination, which is influenced primarily by salinity and light availability (Rand 2000; Carter and Ungar 2004; Smith and Warren 2012). Halophyte seeds are dispersed by tides. They may be free-floating or, more commonly, mixed in with dead plant biomass (wrack) that forms large mats. These wrack mats are prevented from dispersing across marsh floodplains when they become trapped by physical barriers, such as *Phragmites* stands (Smith 2007). Smith (2007) showed that pathways cut into *Phragmites* zones allowed wrack to advance with the incoming tide, dispersing viable seeds and increasing halophyte establishment in more interior areas.

Cape Cod National Seashore manages several tidal restoration projects on Cape Cod, Massachusetts, USA. One salt marsh undergoing restoration is Hatches Harbor, which was diked for 70 years for mosquito control (Portnoy et al. 2003). The ensuing degradation of this system led to efforts in 1999 to reestablish seawater exchange by installing culverts in the dike (fig. 1). This has resulted in significant expansion of salt-marsh vegetation within the formerly restricted floodplain (table 1). However, 10 years after tidal restoration at Hatches Harbor, *Phragmites* stands continue to flourish where salinities are still between 10 and 25 parts per trillion (ppt) (Sun et al. 2007; Smith et al. 2009).

The goal of our study was to evaluate whether the establishment of halophytes could be enhanced by manual cutting of *Phragmites* and to assess relationships among salinity, elevation, and vegetation. Specifically, we evaluated the composition, abundance, and diversity of extant halophyte vegetation and the seed bank within halophyte-dominated areas, Phragmites-dominated areas, and areas where *Phragmites* was mechanically removed.

Methods

We established one hundred 10.76 ft^2 (1.00 m^2) plots in three sections of the tide-restricted area of Hatches Harbor. These sections were characterized as (1) undisturbed halophyte-dominated areas between the tidal creek and wrack line (n = 31), (2) undisturbed dense *Phragmites* stands (n = 33) (fig. 2, page 44), and (3) areas where we mechanically removed *Phragmites* stems from *Phragmites*-dominated areas between the wrack line and the upland habitat (n = 36) (fig. 3, page 44). In each plot we measured halophyte composition, abundance (density of mature and emerging stems), and diversity. The undisturbed Phragmites-dominated plots acted as control for the neighboring Phragmites removal plots. Halophyte species diversity was quantified using

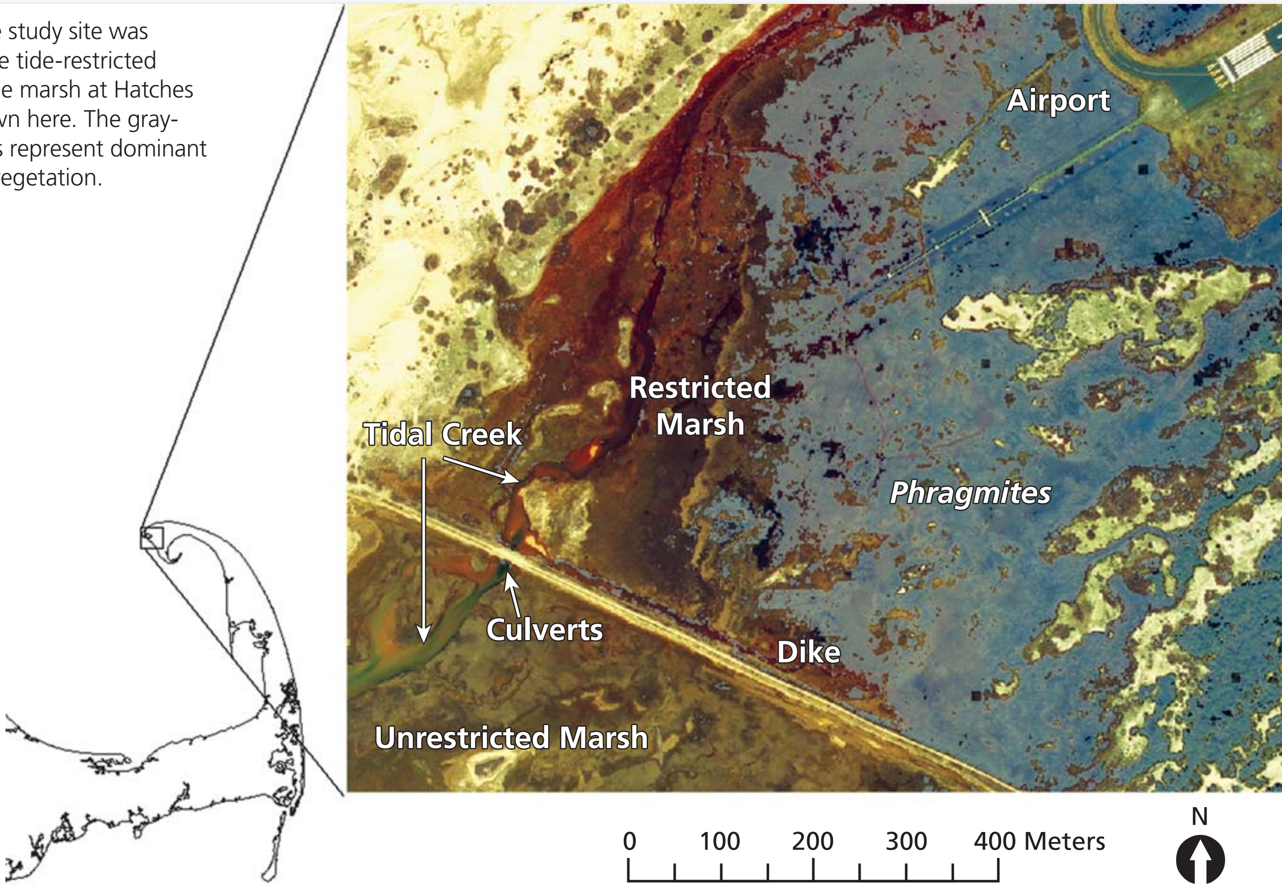


Figure 1. The study site was located in the tide-restricted portion of the marsh at Hatches Harbor, shown here. The gray-shaded areas represent dominant *Phragmites* vegetation.

Table 1. Halophyte abundance within study plots of the halophyte- (H) and Phragmites-dominated (P) areas of the restricted marsh at Hatches Harbor

		2008				2009				2008 + 2009			
Common Name	**Scientific Name**	**H**	**(SE[1])**	**P**	**(SE)**	**H**	**(SE)**	**P**	**(SE)**	**H**	**(SE)**	**P**	**(SE)**
salt marsh hay	*Spartina patens*	563	310	406	198	304	171	300	1	433	177	353	97
Virginia glasswort	*Salicornia depressa*	350	212	0		15	6	4		182	107	2	
slender glasswort	*Salicornia maritima*	243	78	0		27	11	<1	3	135	41	<1	1
salt marsh cordgrass	*Spartina alterniflora*	40	16	5	5	33	12	0	150	37	10	2	78
salt sandspurry	*Spergularia salina*	59	56	0		3	2	0		31	28	0	
seepweed	*Suaeda spp.*	13	7	2	2	3	2	1		8	4	2	1
sea lavender	*Limonium carolinianum*	1		0		0		0		1		0	
marsh spikegrass	*Distichlis spicata*	0		0		<1		0		<1		0	
spear saltbush	*Atriplex patula*	0		0		0		<1	22	0		<1	11
eastern baccharis	*Baccharis halimifolia*	0		9	9	0		32	150	0		20	79

Note: Halophyte abundance is the total (mature and seedlings) of stems per plot (i.e., stems/10.76 ft^2 [1.00m^2]). The perennial salt marsh hay *Spartina patens* and annual glassworts (*Salicornia* spp.) were the most abundant halophytes in both halophyte- and *Phragmites*-dominated areas of the salt marsh; however, the annual species were rarely seen within *Phragmites*-dominated areas of the higher marsh.

[1]SE = Standard Error

Figure 2. Halophyte seedlings grow in a 10.76 ft² (1.00 m²) study plot in a halophyte-dominated area of Hatches Harbor salt marsh in 2008.

Figure 3. Located in a *Phragmites*-dominated area of Hatches Harbor salt marsh, this plot (flags) has manually been cleared of Phragmites and includes a buffer to allow sunlight to reach the plot.

Simpson's diversity index (Simpson 1949) on a plot-by-plot basis for both 2008 and 2009. Simpson's diversity index measures the probability that two individual stems selected at random from one plot will belong to the same species.

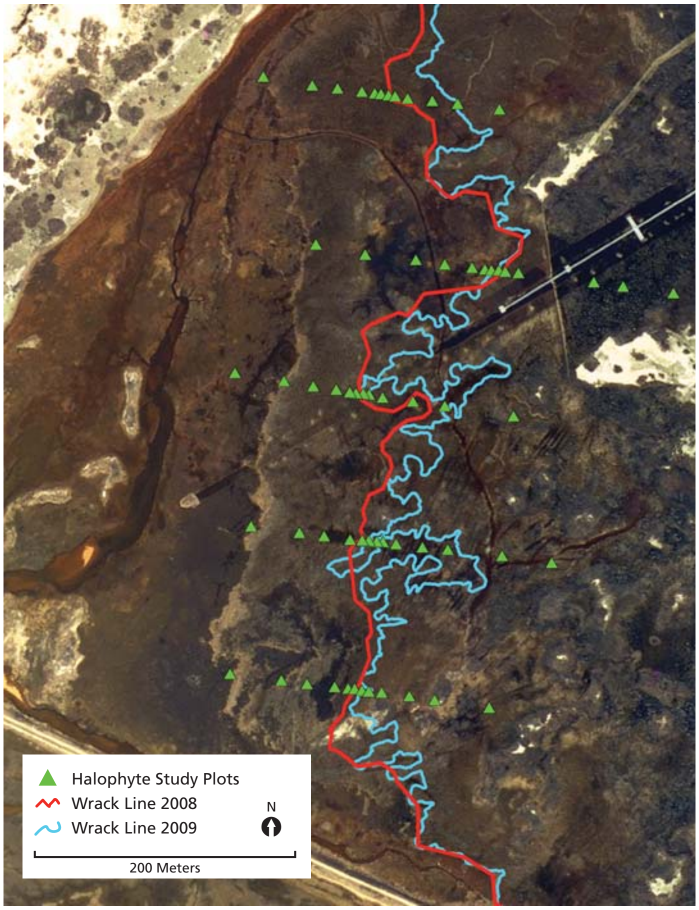
We located plots along five transects spaced 410 feet (125 m) apart and running perpendicular to the 2008 wrack line (the zone where wrack and debris accumulate). We placed plots on each transect at distances of 10 ft (3 m), 26 ft (8 m), 59 ft (18 m), 124 ft (38 m), 190 ft (58 m), and 321 ft (98 m) toward the upland and in the direction of the tidal creek, perpendicular to the wrack line (fig. 4). In mechanical removal plots, we cut *Phragmites* stems to a height of 4 inches (10 cm) with garden shears and kept plots clear of new *Phragmites* growth, as well as leaf and stem litter, to expose the soil throughout the growing seasons of 2008 and 2009. We also established a cleared buffer around each plot to reduce shading of halophyte seedlings by surrounding *Phragmites* (fig. 5). Mature and emergent halophyte seedlings were counted four times from June through August 2008 and three times in 2009. In plots where salt marsh hay (*Spartina patens*) was too dense to count, we estimated abundance using 1.6 in² (10 cm²) subplots. On each visit, halophyte seedlings were identified to species, removed, and discarded. In addition, any advancing *Phragmites* vegetative shoots were cut and removed. Distances from vegetation plots to halophyte seed sources (wrack line or established halophyte populations) were measured to the nearest meter and analyzed with ArcGIS 9.2 (Geographic Information System [GIS] mapping software), using vegetation-cover raster imagery.

We used nonparametric Wilcoxon rank-sum tests to compare total and dominant halophyte species abundance and diversity in plots from which *Phragmites* was mechanically removed against their abundance and diversity in undisturbed control plots. Halophyte abundance (log-transformed) and diversity were analyzed using Wilcoxon rank-sum correlations with distance from wrack line. Halophyte abundance results are reported for combined years. Halophyte diversity results are reported for 2008, 2009, and 2008 and 2009 combined. JMP version 7 (SAS Institute 2007) was used for all statistical tests, and statistical significance was determined at $\alpha \leq 0.05$ except where otherwise noted.

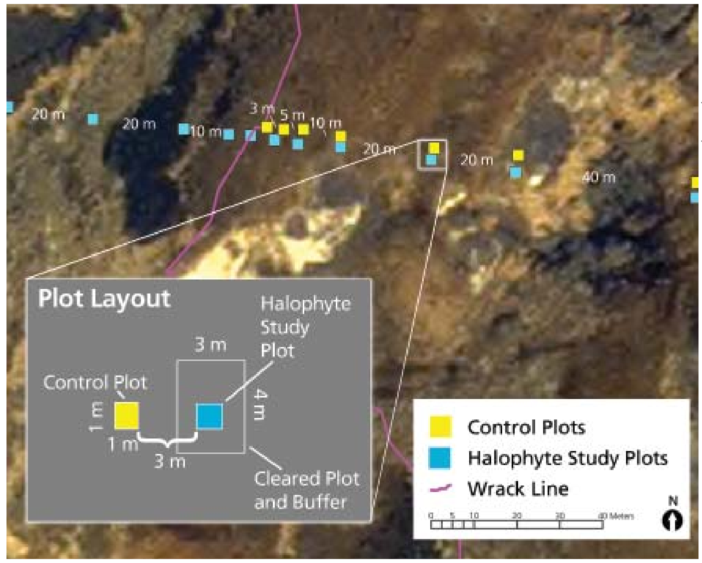
Results

Halophyte composition

A total of eight species (2008 and 2009 combined) were recorded in plots within the halophyte-dominated (i.e., non-*Phragmites*) portion of the marsh, and seven in undisturbed (control) plots in *Phragmites*-dominated areas (table 1). Four species (salt marsh hay [*Spartina patens*], slender glasswort [*Salicornia maritima*], salt marsh cordgrass [*Spartina alterniflora*], and herbaceous seepweed [*Suaeda maritima*]) were found in both halophyte- and *Phragmites*-dominated areas. Spear saltbush (*Atriplex patula*), eastern baccharis (*Baccharis halimifolia*), and common threesquare (*Schoenoplectus pungens*) were found only in the *Phragmites*-dominated area, while sea lavender (*Limonium carolinianum* [formerly *L. nashii*]), salt sandspurry (*Spergularia salina*), and Virginia glasswort (*Salicornia depressa* [formerly *S. virginica*]) were observed only in the halophyte-dominated area. Abundance of mature and seedling halophytes was significantly greater in plots from which *Phragmites* was mechanically removed than in control plots (Wilcoxon rank-sum $Z = 6.50$, $p < 0.001$) in



JESSE WHEELER, 2010; IMAGERY ARCVIEW 9.2



JESSE WHEELER, 2010; IMAGERY ARCVIEW 9.2

Figure 4 (left). The halophyte study plots (green triangles) were established along the five transects in Hatches Harbor. Wrack line locations for 2008 and 2009 are indicated by red and blue lines, respectively; transect origins were based on the 2008 wrack line.

Figure 5 (above). The diagram shows an example of halophyte study and control plots along a transect in Hatches Harbor; the inset describes specific plot layouts.

2008, 2009, and 2008 and 2009 combined. However, the increase in abundance was slight, with just 13% more seedlings than in the control plots. Mechanical removal plots yielded an average of 400 (± 142) individual halophytes per plot (i.e., 10.76 ft^2 [1.00 m^2]) while control plots averaged 353 (129) per plot (table 2, next page).

Although only one-third of the mechanically cleared plots contained a high abundance of mature and seedling halophytes (>100), most of the plots appeared to have a viable seed bank, as evidenced by the presence of emerging seedlings and mature halophytes in 74% of plots. *Spartina patens* abundance was slightly lower in mechanical removal plots than in control plots (Wilcoxon rank-sum Z = 1.70, $p < 0.09$, $\alpha = 0.10$). However, abundance of the annuals *Suaeda* spp. (Wilcoxon rank-sum Z = 3.74, $p < 0.001$) and *Salicornia maritima* (Wilcoxon rank-sum Z = 8.24, $p < 0.00$) was significantly higher in mechanical removal plots than in control plots (table 2, next page).

Halophyte abundance (both mature and seedling) was not significantly correlated with distance from wrack line (Spearman's $r_s = 0.21$, $p < 0.11$). Plots where halophytes were present averaged 15.0 ft (4.6 m) in distance from seed source populations. However, halophyte presence was not significantly different ($p = 0.83$) with regard to distance from already established seed source populations or open pathways for seed dispersal.

Halophyte (mature and seedling) diversity

Halophyte plant diversity was significantly higher in halophyte-dominated areas than in *Phragmites*-dominated areas of Hatches Harbor in 2008, 2009, and 2008 and 2009 combined (fig. 6, page 47). Diversity was significantly higher in plots from which *Phragmites* was mechanically removed than in control plots (Wilcoxon rank-sum Z = 2.94, $p < 0.001$) (fig. 7, page 47). Diversity was not significantly correlated with distance from wrack line in 2008 (Spearman's $r_s = 0.01$, $p = 0.59$), 2009 (Spearman's $r_s = 0.04$, $p = 0.33$), or 2008 and 2009 combined (Spearman's $r_s = 0.06$, $p = 0.64$).

Discussion

We observed few halophytes, either mature plants or seedlings, in undisturbed (i.e., noncleared) *Phragmites*-dominated areas upslope from where wrack accumulates. In contrast, we observed a greater abundance and diversity (particularly in annuals) in

Table 2. Mean (± SE) abundance of halophyte species in control (C) and mechanically removed (MR) plots in the restricted marsh at Hatches Harbor

		2008				2009				2008 + 2009			
Common Name	**Scientific Name**	**C**	**(SE)**	**MR**	**(SE)**	**C**	**(SE)**	**MR**	**(SE)**	**C**	**(SE)**	**MR**	**(SE)**
salt marsh hay	*Spartina patens*	406	198	380	231	268	156	255	167	340	127	309	137
slender glasswort	*Salicornia maritima*	0	0	36	13	<1	0	24	10	<1	0	29	8
seepweed	*Suaeda* sp.	2	2	6	3	1	1	6	3	2	1	6	2
Virginia glasswort	*Salicornia depressa*	0	5	6	0	4	0	8	0	2	3	7	0
common threesquare	*Schoenoplectus pungens*	0	0	2	2	0	3	1	2	0	2	2	2
salt marsh cordgrass	*Spartina alterniflora*	5	0	<1	0	0	0	1	0	3	0	1	0
marsh spikegrass	*Distichlis spicata*	0	0	0	1	0	0	1	1	0	0	<1	1
sea lavender	*Limonium carolinianum*	0	0	<1	0	0	0	<1	0	0	0	<1	0
salt sandspurry	*Spergularia salina*	0	0	0	0	0	0	<1	1	0	0	<1	0
spear saltbush	*Atriplex patula*	0	0	0	0	0	0	0	0	0	0	0	0
eastern baccharis	*Baccharis halimifolia*	9	9	0	0	3	2	0	0	6	5	0	0
All species		**422**	**202**	**430**	**230**	**277**	**156**	**377**	**182**	**353**	**129**	**400**	**142**

Note: Halophyte abundance is measured by stems per plot (stems/10.76 ft² [1.00/m²]). The most abundant halophyte in *Phragmites*-dominated areas, *Spartina patens*, was found in slightly fewer numbers in mechanically removed plots, not indicating much change from areas cleared of *Phragmites*. However, whereas a significant increase of most annuals was noticed in response to removed *Phragmites*, control plots with standing *Phragmites* saw very few annuals.

plots from which we mechanically removed *Phragmites*. When we looked at annual and perennial halophytes separately, we found that the abundance of the perennial *Spartina* grasses actually declined slightly in plots where *Phragmites* was removed, whereas the annual halophytes experienced modest gains in abundance. The annual halophytes *Salicornia maritima* and *Suaeda* spp. responded favorably to *Phragmites* cutting, growing among the majority (66%) of cleared plots but in only 7% of neighboring control plots. We observed fewer perennial halophyte species (e.g., *Spartina*) in areas kept clear of *Phragmites*, likely because of differences in germination or seed dispersal characteristics between annual and perennial halophyte species. Annual plants such as *Salicornia* spp. produce small, round seeds as opposed to the seeds of *Spartina* spp., which are much larger and oblong with sharp ends. The latter tend to disperse less easily (Rand 2000). Once established, many perennial salt-marsh species, like *Spartina* grasses, also spread through vegetative growth.

The *Phragmites* stands at Hatches Harbor also contain patchy, isolated populations of halophytes dominated by *Spartina patens* and wrack piles; thus, we hypothesized that these "halophyte islands" might provide seeds to *Phragmites*-dominated areas devoid of these species. However, we observed no significant correlation between halophyte germination and distance from these potential seed sources, likely because seeds from potential seed sources could not disperse through the surrounding *Phragmites* stems.

Clearing *Phragmites* has the potential to enhance dispersal and germination from an existing seed bank (Smith 2007). The majority of the *Phragmites* plots we cleared at Hatches Harbor were isolated from adjacent halophyte communities—that is, they were not connected to these areas by tidal channels or clearings through which halophyte seeds could be dispersed. Monitoring these plots gave us an opportunity to observe whether the existing seed bank would respond favorably to increased light and soil temperature when *Phragmites* is removed (Smith 2007). We observed that halophyte abundance and diversity increased in these cut plots. However, seedling density in these plots was still only about 50% of the average plant density in halophyte-dominated areas of the marsh (average 400 seedlings versus 827 seedlings per plot). Further, halophyte seedlings germinated in only 30% of cleared plots. Either growing conditions were unfavorable for seed germination or viable seeds were not present in those areas. The few seeds that did germinate in cleared plots likely germinated from the extant seed bank because of increased light levels and temperatures at the soil surface following *Phragmites* removal.

In a recent seed bank study, Boyle (2011) found little halophyte germination in sediments collected from *Phragmites*-dominated

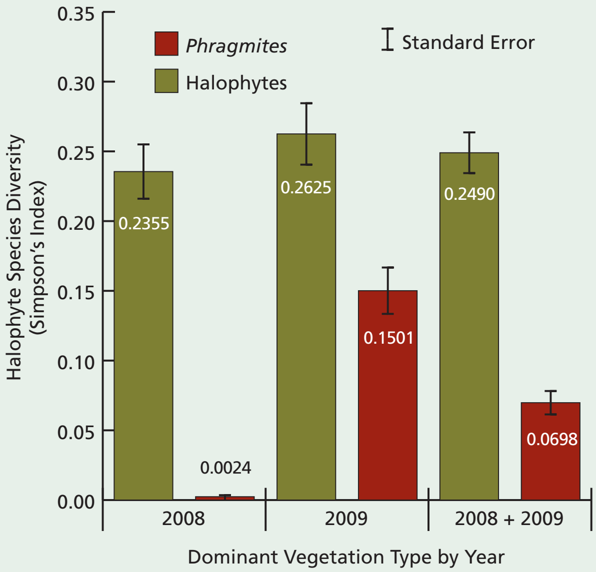


Figure 6. Mean (±SE) halophyte diversity (Simpson's index) was significantly higher in areas dominated by halophytes than in areas dominated by *Phragmites* in Hatches Harbor in 2008, 2009, and 2008 and 2009 combined. The dominant vegetation types are halophyte-dominated areas, defined as lying between the tidal creek and wrack line, and *Phragmites*-dominated areas, the section of marsh that runs from the wrack line to the upland edge of the marsh.

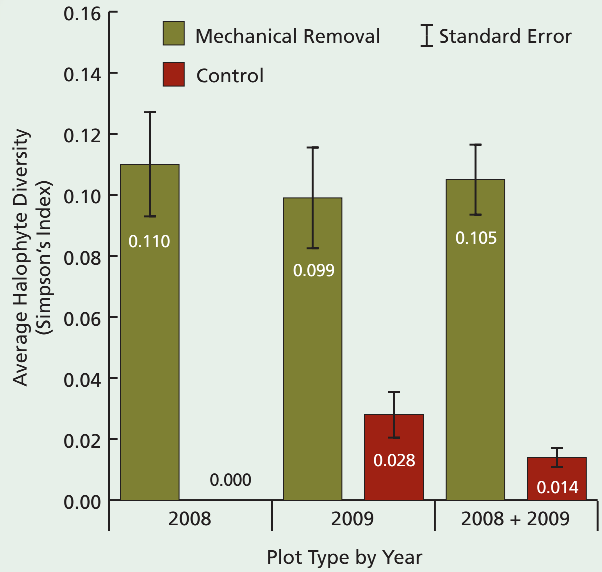


Figure 7. Mean (±SE) halophyte diversity (Simpson's index) was significantly higher in mechanically removed *Phragmites* plots than in control plots in Hatches Harbor for 2008, 2009, and 2008 and 2009 combined. Zero Simpson's diversity was recorded in control plots of 2008 because only one halophyte species was present at any given time.

areas of Hatches Harbor, suggesting that there may be few viable seeds in dense *Phragmites* stands. These findings, combined with our observation that halophyte seed germination from the seed bank in cleared plots occurs but is minimal, suggest that managers may need to cut *Phragmites* from large areas of the marsh to see substantial halophyte germination and reestablishment. In fact, cleared pathways that connect any artificial openings with existing halophyte vegetation would reduce impediments to dispersal into these areas and enhance seed supply to *Phragmites* zones. Boyle (2011) observed that transplanted mature plugs of *Spartina patens* had very high (99.5%) survivorship after one year in *Phragmites*-dominated areas of Hatches Harbor, suggesting that halophytes can persist in *Phragmites* stands if they are able to establish and reach maturity. Thus, sowing seeds collected directly into areas where *Phragmites* is cleared may increase seedling abundance substantially.

In addition to seed dispersal limitations, recruitment of halophyte taxa into *Phragmites* stands is likely inhibited by direct competition with *Phragmites* plants. We found no correlation between mature or seedling halophyte abundance and distance from the wrack line, suggesting that competition and obstructed seed dispersal severely limit halophyte expansion into *Phragmites*-dominated areas. *Phragmites* forms dense root mats, covers soil surfaces with leaf and shoot litter, casts shade, and alters the physicochemical conditions of the soil, making growing conditions for other species difficult (Minchinton et al. 2006). Very few noncleared *Phragmites* plots at our study site supported any halophytes at all. Given the limitations to seed dispersal and the dominance of Phragmites at this site, halophyte seeds deposited on bare soil surfaces completely devoid of *Phragmites*, or where *Phragmites* is mechanically cleared and connected with halophyte communities, will have the best chance of germinating.

Conclusions and management suggestions

Management of *Phragmites* at Hatches Harbor and other similarly affected sites in the National Park System could accelerate the process of vegetation restoration by (1) allowing halophyte seeds to disperse more easily, and (2) improving conditions for seed germination. At some salt-marsh sites, burning may not be an effective management tool to create clearings and conduits for seed dispersal because of public concern or insufficient fuel continuity. Burning also may destroy the resident seed bank (Boyle 2011). Creating new tidal channels, along with mechanical removal of *Phragmites*, could provide conduits for seed dispersal and result in increased halophyte establishment from incoming seed and from the existing seed bank. Alternatively, active seeding and transplanting of salt-marsh taxa to areas cleared of *Phragmites* (or areas naturally clear but that do not receive halophyte seeds because of limits on dispersal) may enhance establishment. Repeated clearing of *Phragmites* may be needed to create optimal conditions for seed dispersal, germination, and seedling establishment. The use of herbicides may be particularly effective in keeping areas clear of dense *Phragmites* for longer periods of time. Once stable native halophyte populations are established, clearing *Phragmites* may no longer be necessary, assuming that salinities in the restored marsh are high enough to limit *Phragmites* encroachment. The most effective adaptive management efforts will likely depend on land use history and local site conditions, including the proximity of established halophyte communities that serve as seed sources.

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PS

Improving National Park Service partnerships: A gap analysis of external partners

By Melissa S. Weddell, Rich Fedorchak, and Brett A. Wright

Abstract

Partnerships between public agencies and nonprofit organizations, corporations, and private businesses are a growing trend, and consequently the nature of these partnerships has become more complex. With this expansive role for partnerships comes the need for the National Park Service and its partners to be knowledgeable of NPS policies and to possess a variety of management skills if they and stakeholders are to work together optimally. In 2005 the National Park Service and Clemson University entered into a cooperative agreement to determine partnership training and development priorities for NPS employees (phase I) and NPS partners (phase II). Both phases used online surveys to obtain baseline data regarding knowledge, skills, and abilities, as well as partnership attitudes, that identified existing and future training needs of employees and partners associated with NPS partnership work. This article reports on the second phase of the partnership study, administered in spring 2010 to NPS partners, including but not limited to friends groups (alliances, associates, clubs, conservancies, foundations, societies, and trusts) and cooperating associations across the United States.

Key words

collaboration, gap analysis, parks, partnerships, stewardship, training

PARTNERSHIPS BETWEEN PUBLIC AGENCIES AND NON-profit organizations, corporations, and private businesses are not a new phenomenon. The National Park Service has been involved in partnerships since its creation in 1916 when, for example, it involved the railroads and the hotel industry in providing transportation, meals, and accommodations for the first park visitors. Since then the size and scope of partnerships engaged in by public agencies have grown and the nature of these partnerships has become more complex. Today many park managers regard partnerships as a strategy for more effective park management because they can help expand the range of services a park can offer. They also increase public support by enhancing opportunities for park visitors to learn about and participate in park management and help build a sense of community pride (Vaske et al. 1995).

With this expansive role for partnerships comes the need for NPS managers to be knowledgeable of NPS policies and to possess a variety of management skills if they and stakeholders are to work together optimally. In an interview published on the NPS Web site http://www.nps.gov/partnerships/, National Park Service Director Jon Jarvis explained his view that "partnership skills are a core competency." He continued, "Our employees must be able to find and welcome partners, to reach common ground, and leverage each other's skills and resources." Thus partnership management is a core competency that can help to carry out the NPS mission and deliver public service at a higher level. The challenge is to more effectively grow this competency by building on past partnership successes and developing new capacity for enhanced partnership management Service-wide. However, very little effort has been made to study, understand, and manage partnerships in a proactive manner.

Earlier study and latest work

In 2005 the National Park Service and Clemson University entered into a cooperative agreement to determine partnership training and development priorities for NPS employees (phase I) and NPS partners (phase II). Both phases used online surveys to obtain baseline data regarding knowledge, skills, and abilities, as well as partnership attitudes, that identified existing and future training needs of employees and partners associated with NPS partnership work. We analyzed data about employee and partner perceptions of the importance and preparedness of specific competencies in the performance of their jobs. We then applied a gap analysis to study perceived differences (i.e., a gap) in preparation for, and importance of, specific competencies deemed to be pertinent to their ability to engage in partnerships.

For phase I of the study Weddell et al. (2009) assessed partnership competencies that delineated the importance and performance of active NPS employees regarding partnership activities and identified gaps in training to perform these critical competencies at satisfactory levels. This phase was initiated in fall 2006 through a survey of 18,224 NPS employees. We found that almost two-thirds of respondents reported that their past experiences working with partnerships were rewarding and productive (61.2%); however, another 16% reported that their experience had been difficult, frustrating, and not very productive. More than 60% reported currently being engaged in one or more partnerships. Respondents reported being involved in an average of seven partnerships over the past five years.

According to the phase I study, some of the largest gaps respondents reported in training were (1) the ability to collaborate with philanthropic and grant-making entities; (2) understanding NPS partnership construction requirements; (3) the ability to establish organizational structures that nurture and manage partnerships; (4) the ability to plan effectively for the commitments needed to build a successful partnership (including the knowledge of techniques used to resolve conflicts, grievances, and confrontations); and (5) working effectively with the Department of the Interior's Office of the Solicitor to develop and manage agreements.

Respondents felt that partnership constraints included the lack of a reward structure to engage in partnerships, complex accountability requirements, differing budgeting practices among stakeholders, and challenges of finding flexibility within NPS rules and regulations. Respondents reported that motivations to partner included (1) giving others a better understanding of one's own park, the National Park Service, or its mission; (2) more constructive and less adversarial relationships with stakeholders; (3) better coordination of policies and practices; and (4) leading to better management decisions.

This article reports on the second phase of the partnership study, administered in spring 2010 to all NPS partners, including but not limited to friends groups (alliances, associates, clubs, conservancies, foundations, societies, and trusts) and cooperating associations. We selected a total of 274 NPS partner leaders to participate in the study and asked them to forward the survey on to other employees in their organizations.

The purposes of this research were (1) to describe and discuss the assessment of partnership training gaps identified among partners of the National Park Service, (2) to analyze the gaps NPS partners perceived in their abilities to conduct partnerships successfully, and (3) to report partners' attitudes toward engaging in partnerships with the National Park Service, including motivations and constraints.

Methods

Survey instrument

We initially developed our phase I Web-based survey based on a thorough review of the partnership literature in various fields of study and discussions with NPS management personnel. We took care to identify those variables found to influence partnership behavior by examining previous studies, in terms of both motivations and perceived constraints. Moreover, an exhaustive list of employee competencies pertaining to partnerships was developed by NPS professionals, reviewed by a team of researchers, and then incorporated into the instrument. For phase II the survey was reevaluated, refined, and shortened by researchers and professionals in the field for distribution to NPS partners.

The phase II survey instrument consisted of four sections, totaling 118 items. The first section included two identical batteries of 28 competencies depicting knowledge, skills, and abilities (KSA) regarding entering into partnerships with external organizations. In the first section, respondents were asked to rate the *importance* of each KSA in the conduct of their present job. The same set of questions in the first section was repeated and respondents rated their level of *preparedness* to perform each competency. The second section included four questions about partnership experience with outside organizations. Respondents were asked how many partnerships they were involved with in the five previous years, then were asked about their past, present, and future views of the role of partnerships working with the National Park Service. The third section asked respondents to indicate their level of agreement or disagreement with 16 statements regarding specific motivations and constraints to partnerships found in the literature (Gray 1989; Huxham 2003).

Data analyses

We performed a gap analysis to identify "training gap scores," which were identified for each individual by calculating the difference between preparation (P) and importance (I) scores for each competency. A negative gap score indicated an area in which professionals felt ill-prepared relative to the importance of the competency. A positive gap score indicated the reverse was true; in this case respondents' perception of preparation exceeded the importance they assigned to a particular competency. These gap interpretations suggest partnership competencies that have implications for future education and training of NPS partnering organizations.

Results and discussion

Survey respondent characteristics

The average respondent was 52 years old, white (95%), female (54%), and had attended college (77%). They reported working in partnership with the National Park Service for an average of 12 years. Respondents represented all NPS partnership organization types, including friends groups (27%), cooperating associations (40%), national heritage areas (18%), field institutes or field schools (5%), trail organizations (5%), and the remainder comprising combined friends groups and cooperating associations (5%).

Today many park managers regard partnerships as a strategy for more effective park management because they can help expand the range of services a park can offer.

Partnership training gaps

The largest gap respondents reported involved the "knowledge of NPS policies and legal and reporting requirements for nonprofit partners" (−1.18) (see table 1, next page). Other reported gaps were ability to work effectively with the NPS contracting and procurement process to develop and manage agreements (−0.94); understanding of federal and state laws regarding nonprofit/not-for-profit organizations and reporting requirements (−0.84); understanding the "political realities" both nationally and locally where partnerships take place (−0.71); knowledge of the concepts, policies, and practices related to donations and fund-raising partnerships in the NPS (−0.69); ability to effectively plan for the commitments needed to build a successful partnership (e.g., staff time and skills, possible financial commitments, and other resources) (−0.54); and ensuring that innovative partnerships are encouraged while operating within governmental regulatory boundaries (−0.53).

Past, present, and future partnership behaviors and intent

Two-thirds of respondents reported that their past experiences working with the National Park Service were rewarding and productive (76%); however, another 18% reported that their experiences had been difficult, frustrating, and not very productive. Almost half of respondents (49%) reported currently being engaged in one primary partnership with the National Park Service, serving a single park or unit, while almost a quarter (21%) reported being engaged in multiple partnerships, programs, or projects, serving multiple parks or units. The overwhelming majority of respondents indicated they intended to (1) remain engaged in one or more NPS partnerships because it is a primary way that their organization will fulfill its mission in the future (42%) or (2) expand or grow their NPS partnerships because they believe it is a better way for their organization to fulfill its mission in the future (53%).

Partnership attitudes

Partnership motivation statements with the highest agreement (1 = strongly disagree, and 7 = strongly agree) are presented in table 2 (page 53) and include the following: partnerships lead to greater innovation and effectiveness (6.20); partnerships with others (public, private, not-for-profit, or government organizations) can lead to better management decisions (6.04); partnerships give other organizations a better understanding of their partner's organization and its mission (5.87); partnerships improve communications among organizations, making it easier to deal with problems (5.80); partnerships expand one's own organization's capacity for leadership because decisions are influenced by people with different perspectives (5.77); partnerships allow the pooling of resources, thus saving time and money for each partner (5.16); and partnerships result in better coordination of policies and practices of multiple stakeholders (5.10).

Partnership constraint statements with the highest-level agreement are also summarized in table 2 and deal primarily with policies and governmental regulations: one is frequently challenged to find flexibility within the National Park Service's rules and policies regarding partnering (4.67); and as accountability requirements within the Park Service increase, they make partnering increasingly complex and difficult (4.57).

Implications and conclusions

Partner organizations are a cornerstone of the National Park Service and help sustain park programs. Understanding perceptions, attitudes, and competencies needed for partner organizations to work in concert with the National Park Service is crucial for long-term partnership viability. Outside partners overwhelmingly agreed that partnerships lead to greater innovation and effectiveness as well as better management decisions. Moreover, 76% of respondents reported their past experiences working with the National Park Service were rewarding and productive. The major constraints were centered on navigating complex regulations and accountability requirements, findings that are similar to those of the phase I study that surveyed NPS employees.

These perceived impediments are often at the federal level, and therefore partnership regulations may need to be reexamined to decrease frustrations among NPS employees and outside partners. Additionally, the National Park Service can address these problems by continuing to offer training programs that focus on understanding the legal requirements and best practices for managing partnerships, specifically for developing agency/bureau agreements, improving communication and collaboration skills, building consensus, and evolving leadership.

Table 1. Partnership competencies with the greatest P-I* gaps

Competencies*	Mean Importance[1]	Mean Preparation[1]	Mean P-I Gap
Knowledge of NPS policies and legal and reporting requirements for nonprofit partners	6.07	4.89	–1.18
Ability to work effectively with the NPS contracting and procurement process to develop and manage agreements	5.18	4.24	–0.94
Understanding of federal and state laws regarding nonprofit/not-for-profit organizations and reporting requirements	6.12	5.28	–0.84
Understanding the "political realities" both nationally and locally where partnerships take place	6.12	5.41	–0.71
Knowledge of interpretive and educational program development in partnership with the NPS	5.7	5	–0.7
Knowledge of the concepts, policies, and practices related to donations and fund-raising partnerships in the NPS	5.66	4.97	–0.69
Demonstrate methods to ensure that NPS work units' and your organization's culture can move the NPS mission forward	6.02	5.34	–0.68
Ability to manage partnerships effectively to achieve your organization's and NPS missions	6.33	5.76	–0.57
Knowledge of negotiating skills and techniques to find mutually acceptable solutions	6.3	5.74	–0.56
Ability to communicate strategic goals, performance expectations, and collaborative work necessary to reach common goals	6.18	5.62	–0.56
Effective communication, listening, and interpersonal skills	6.76	6.21	–0.55
Ability to effectively plan for the commitments needed to build a successful partnership (e.g., staff time and skills, possible financial commitments, and other resources)	5.95	5.41	–0.54
Ensure that innovative partnerships are encouraged while operating within governmental regulatory boundaries	6.08	5.55	–0.53
Ability to work with and through others in achieving a citizen-focused, seamless network of parks, historical places, and open spaces	5.7	5.2	–0.5

**Note*: The P-I Gap is a diagnostic statistic based on the function between the importance of a competency and the preparation to perform that competency. Caution must be used in interpreting this statistic since a large gap could conceivably include a measure that is not high in importance, and therefore not worthy of training resources.

[1]Where 1 = strongly disagree, 7 = strongly agree

The major constraints were centered on navigating complex regulations and accountability requirements.

The National Park Service currently offers a variety of partnership training courses for employees and collaborators to assist in partnership development and management, and this research provides valuable baseline data to help understand the partnership culture. Results from both phases of this study are helping staff of the NPS Mather and Albright training centers to better understand the relationship between the Park Service and its many partners. In fall 2005, the National Park Service hired a training manager specifically for partnerships and collaborative work. Based on the competency gaps revealed in this and the 2007 study, the National Park Service has focused its attention on developing curricula (online and residential training, job aids and templates, regional workshops, webinars, and resource lists) to assist NPS employees and partners in forging and sustaining strong NPS partnerships. Further partnership research can continue to guide the training process as the partnership culture changes and adapts to future challenges.

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Table 2. Strength of selected partnership motivations and constraints

Partnership Motivations	1	2	3	4	5	6	7	Mean[1]
Partnerships lead to greater innovation and effectiveness	0	0	1.2	8.3	9.5	31	50	6.20
Partnerships with others (public, private, not-for-profit, or government organizations) can lead to better management decisions	1.2	0	2.4	9.6	9.6	31.3	45.8	6.04
Partnerships give others a better understanding of my organization and its mission	0	0	7.2	9.6	15.7	24.1	43.4	5.87
Partnerships improve communications among organizations, making it easier to deal with problems	0	0	4.8	11.9	16.7	32.1	34.5	5.80
Partnerships expand my organization's capacity for leadership because decisions are influenced by people with different perspectives	2.4	0	2.4	13.1	11.9	35.7	34.5	5.77
Partnerships result in more constructive, less adversarial attitudes among stakeholders	0	6.2	11.1	13.6	8.6	28.4	32.1	5.38
Partnerships allow the pooling of resources, thus saving time and money for each partner	1.2	7.2	9.6	12	20.5	25.3	24.1	5.16
Partnerships result in better coordination of policies/practices of multiple stakeholders	0	4.9	8.5	20.7	19.5	30.5	15.9	5.10
Partnership Constraints	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Mean[1]**
I am frequently challenged to find flexibility within the NPS's rules and policies regarding partnering	6.2	9.9	11.1	16	17.3	19.8	19.8	4.67
As accountability requirements within the NPS increase, it makes partnering increasingly complex and difficult	3.7	12.2	9.8	18.3	25.6	14.6	15.9	4.57
Partnerships with the NPS lead to a power struggle among the participants	13.3	26.5	12.0	21.7	8.4	9.6	8.4	3.48
Entering into partnerships with the NPS is just too difficult because of governmental bureaucratic processes and regulations	17.1	22	12.2	14.6	18.3	12.2	3.7	3.46
I am uncomfortable with the mistrust that accompanies establishing and maintaining partnerships	26.5	31.3	10.8	18.1	9.6	2.4	1.2	2.65

[1]Where 7 = strongly agree, 1 = strongly disagree

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A system-wide assessment of night resources and night recreation in the U.S. national parks: A case for expanded definitions

By Brandi L. Smith and Jeffrey C. Hallo

Abstract

Degradation of the night environment by light pollution poses a threat to the viability of nighttime outdoor recreation activities, experiences, and related resources in parks and protected areas (PPAs). The terms "night resources" and "night recreation" are often narrowly defined by PPAs, considering only the night sky or stargazing. These definitions may omit a wide range of other night-dependent resources or recreation activities, possibly resulting in a decreased ability of PPAs to protect and promote them. This article examines the range of night recreation activities offered by U.S. national and state parks through Web site analysis and uses this to propose more complete definitions of "night resources" and "night recreation." The article then assesses the prevalence and characteristics of night recreation activities in U.S. National Park System units (n = 315) through a mail survey. Results reveal that a diversity of night recreation activities are represented across National Park System units and that visitors participate in night recreation activities to a substantial degree. These findings support the call for more complete recognition of night resources to best protect them while providing for visitor enjoyment. Further implications and future research directions are discussed.

Key words

light pollution, night recreation, night resources, night sky, outdoor recreation

THE NIGHTTIME ENVIRONMENT HAS HISTORICALLY IN-cluded darkness in outdoor settings, brightened only to the degree that celestial objects and human-sourced light allowed. Human-caused lighting has increased in intensity and use over the last several decades, producing what is known as light pollution, or nuisance lighting. It is estimated that nearly 99% of the world's skies are now deemed light-polluted, and the severity and extent of light pollution are expected to increase substantially (Cinzano 2001; fig. 1). A key trait of nuisance lighting is that it shines where it is not wanted (Brons et al. 2008), creating light trespass, or is deemed problematic in some other way. The U.S. National Park Service (NPS) has documented light pollution up to 200 miles (322 km) from its source in the form of sky glow: the orange or milky-gray glow characteristic of many metropolitan areas at night. Remote locations that have few or no nuisance light sources of their own can be affected by distant light sources via sky glow.

The National Park Service has a small team of scientists dedicated to addressing what it calls "natural lightscapes." The Night Skies Team (NST) uses science and technology to better understand the impact of anthropogenic light on the view of the celestial sky and to develop management recommendations for protection of these nighttime resources. Since its inception in 1999, the NST has expanded its scope to address the cultural, historical, ecological, and experiential (i.e., recreational) value of the night in the national parks. National Park Service management policies paralleled this change and in 2001 incorporated discussion of ecological and cultural values of natural lightscapes (natural resources and values found in the absence of human-caused light). Yet the bulk of nighttime stewardship remains focused on the celestial view and stargazing. This narrow bias may be a result of the decades of outreach by professional and amateur astronomers or the appearance of other park-related efforts and organizations. For example, the Starlight Initiative, the International Union for Conservation of Nature's (IUCN) World Commission on Protected Areas, and the International Dark-sky Association remain focused on the view of the sky, whether on scientific, aesthetic, or cultural grounds.

A consequence of this institutional narrow focus is that a park manager may dismiss or minimize the value of the nighttime environment if the desire for stargazing is low, and overlook the wide range of other recreational activities that are linked to a naturally dark nighttime environment. Additionally, the fraction of the public that enjoys stargazing per se is likely smaller than the fraction that enjoys other nighttime recreational activities. Nighttime recreation may include other activities such as nocturnal species observation, historical or cultural learning, night fishing, camping, and night hiking (fig. 2). Night resources include nocturnal flora and fauna (fig. 3), the relative quiet of the night, and a natural dark environment. No accepted definitions of night recreation or night resources exist. This is problematic because an incompletely or incorrectly defined activity or resource cannot be properly managed, protected, or fully appreciated.

Empirical examinations of night resources—other than the night sky—and night recreation are just beginning to occur from a social science perspective. A need exists to better understand the diversity of activities, experience opportunities, and use levels of night recreation in PPAs. This article presents (1) a census of night recreation activities offered in U.S. national and state parks; (2) proposed, expanded, and formalized definitions of *night recreation* and *night resources*; and (3) an assessment of opportunities, access to, and visitor participation in night recreation activities in the U.S. National Park System.

Methods

Census of night recreation and expanded definitions
Because of the narrow, incomplete, and informal definitions of night recreation and night resources, a census of night activities offered in national (n = 392) and state park (n = 3,500) units with Web sites was conducted as a preliminary step. We visited and searched each park unit Web site by exploring the site systematically (i.e., home page, visitor activities information, activity calendars) and using specific search terms (i.e., night, dark, star, moon, and nocturnal). We assumed that Web site content and calendar listings of activities and educational programs were current and accurate. The census included both national and state parks to enhance the breadth of investigation of potential forms of night recreation and night resources. For each Web site visited, we recorded night-dependent or night-related recreation activities. This list then served as the basis for more complete definitions and examinations of night recreation and night resources.

Night opportunities and activities in the national parks
Based on the census, we created a paper-based questionnaire to assess the opportunities for, access to, and visitor participation in night recreation activities in the National Park System. Also, the questionnaire allowed the activities identified through the Web site census to be examined for validity and completeness. We sent questionnaires to superintendents (or equivalent) of the national park units. The researchers included only those parks solely managed by the National Park Service. This yielded a final study population of 390 national park units.

We distributed questionnaires using a modified Dillman (2007) approach. This approach involved an initial mailing with the questionnaire and a cover letter, followed by a postcard reminder to nonrespondents, a second mailing of the questionnaire and a modified cover letter to nonrespondents, and a final contact by telephone. The cover letter and questionnaire contained a definition of night recreation and night resources (presented later in this article) and a request that the survey be forwarded to the park employee who the superintendent felt would best be able to answer the questions. Parks were asked to complete the survey even if they did not consider themselves a "night park" to ensure a complete assessment of night activities in the national parks.

NASA'S EARTH OBSERVATORY

Figure 1. City lights in the United States, based on data from 2012.

BRANDI SMITH

Figure 2. Camping is just one of 15 common types of night recreation that occurs in parks.

BENJAMIN DERGE, WIKIPEDIA COMMONS

Figure 3. Bioluminescent fungi are both natural and cultural night resources. Foxfire, created by such fungus, is a part of Appalachian folklore.

In the questionnaire, respondents were asked to indicate whether their park is ever open during dark hours. This question was intended to assess the number of parks that potentially could offer night activities or that may use night resources for visitor enjoyment. Additionally, the number of parks whose information facilities, such as visitor centers, are ever open during dark hours was captured. We then asked respondents whether the listed night resource activities occurred in their park and whether visitors could engage in the activity on their own or as part of a park program. Respondents were also able to indicate whether an activity is prohibited in their park. Finally, respondents were asked to note the number of both campers/lodgers and other nighttime visitors in their park.

Results

Census of night recreation and defining night resources
The census of night activities yielded 15 night-dependent or night-related recreation activities or categories of activities (table 1). This broad range of night activities is evidence that night resources and night activities go beyond the night sky and stargazing and supports the need for more comprehensive definitions of the terms "night resources" and "night recreation." We note that no definition of these terms or concepts is given or implied in the 2006 NPS *Management Policies*, and the term "lightscape" used in this document is a limited and vague concept described as "natural resources and values that exist in the absence of human-caused light" (NPS 2006, p. 57). Based on the variety of night resource activities found in our census of Web sites, we propose that the terms "night resources" and "night recreation" be more comprehensively defined as follows:

> Night resources: "anything that either enhances the visitor experience after sunset (including safety measures, recreational opportunities, and interpretive programs), or that is most active or prominent at night, including animals, plants, and features of the night sky."

> Night recreation: "any recreational activity occurring after sunset, including camping."

Night opportunities and activities in the national parks
A total of 313 National Park System units returned completed questionnaires (table 2), yielding a response rate of 80.3%. Of those, 80.2% (251 units) indicated that their park is open at least sometimes after sunset. Just over 54% of respondents indicated that information facilities in their park, such as visitor centers, are ever open to visitors at night.

Respondents were asked to indicate which of the 15 previously identified night activities visitors could participate in, under what conditions, and whether visitors engage in these activities (table 3, page 58). Results show that each night resource activity listed occurs and is pursued by visitors in at least one park. Also, each activity was prohibited in at least one park. Night interpretive programming is the most widely offered (n = 210) and pursued (n = 181) night activity. (This difference in the number of parks in which programs are offered versus participated in may be partially due to measurement error—many respondents indicated that an activity is participated in at their park, but did not indicate whether or not visitors could do this activity on their own, as part of a park-facilitated program, or both.) Second to this, night hiking or walking was permitted as a self-facilitated activity in 190 parks, with 179 parks indicating that visitors engage in this activity. We note that a few unlisted activities were indicated by participants: night diving/snorkeling (n = 2), beach fires (n = 1), evening programming (n = 1), drinking with friends (n = 1), evening science lectures (n = 1), Native American spiritual pursuits (n = 1), night docking (n = 1), and using or looking at lighthouses (n = 1).

Respondents were asked to indicate their best estimate of visitors (both lodgers/campers and other nighttime visitors) who use their park at night on an annual basis (table 4, page 59). A majority of respondents did not supply a number, choosing either "Not Applicable" or "Don't Know," or did not respond to the item at all. Of those who did supply a numeric response, 56 (17.9%) estimated that fewer than 500 people camp or lodge in their park in an average year. Likewise, 43 (13.7%) indicated that fewer than 500 nighttime visitors (noncampers/lodgers) use their parks in a given year. Other response ranges were indicated with less frequency, but some parks indicated that hundreds of thousands or millions of visitors either stay in their parks overnight or visit during nighttime hours annually.

Discussion

The majority of national park units responding to the survey reported that they are open during night hours at some point. This figure includes parks that only occasionally grant visitors access during night hours, such as for historical reenactments or holiday programs. However, just over half of responding national park units indicated that information facilities, such as visitor centers, are open during night hours. In these places, nighttime visitors may not have access to information about park resources and may not have the opportunity to interact with park personnel to learn about activities or resources not featured in printed information sources. Therefore, it is likely that nighttime visitors are not given information that would allow them to experience night resources, including simply being made aware of those resources. With the exception of scheduled campfire or evening programs, nighttime visitor use is often allowed but not supported by open facilities, available staff, or readily available information. Parks seldom cre-

Table 1. Night-dependent or light-sensitive night recreation activities recorded in a census of state and national park Web sites

Activity	A Participating Park	Activity Example
Campfires	Patapsco Valley State Park, Md.	Campfire programs with park-sponsored entertainment (i.e., cooking campfire food for audience, storytelling)
Camping	Whitewater State Park, Minn.	Overnight "I Can Camp" program that teaches participants how to set up tents, build campfires, and cook outdoors
Interpretive programs at night	New Bedford Whaling National Historical Park, Mass.	"AHA! Night" (Art, History, Architecture), held throughout the park district in collaboration with the community
Night bike riding	Riverside State Park, Wash.	Nighttime mountain bike riding allowed within park boundaries (self-facilitated)
Night boating, canoeing, kayaking, or rafting	Lake Catherine State Park, Ark.	Full-moon kayak tours
Night concerts or plays	Cape Disappointment State Park, Wash.	"Waikiki Beach concert series" throughout summer months
Night fishing	Bill Burton Fishing Pier State Park, Md.	Fishing from piers specially lit for night fishing
Night hiking or walking	Rocky Mountain National Park, Colo.	"Walk into Twilight" (2 hours, ranger-led), observing sights and sounds of night in the park
Night hunting	Big South Fork National Recreation Area, Tenn.	Self-facilitated hunting of specified game
Night photography	Glacier National Park, Mont.	"Astrophotography of Glacier's Night Sky" (ranger-led)
Night snow skiing or snowshoeing	Voyageurs National Park, Minn.	"Night Light Snowshoe Hike" (ranger-led)
Special night events or festivals	Antietam National Battlefield, Md.	"Civil War Soldier Campfire Program"
Stargazing, star parties, or viewing the Northern Lights	Blackwater Falls State Park, W.Va.	"Astronomy weekend" featuring speakers, workshops, and stargazing parties
Viewing natural, cultural, or historical resources at night	Hawai'i Volcanoes National Park, Hawaii	Identifies "Night Glow" viewing areas for visitors based on current lava flow locations
Wildlife viewing at night (excluding spotlighting)	Congaree National Park, S.C.	"Owl Prowls" (ranger-led)

ate areas intended for stargazing, actively encourage nighttime use of trails, or accommodate nighttime cultural events.

Most respondents did not know the number of nighttime visitors to their park unit. This may reflect a difficulty in counting visitors, but may also suggest that nighttime use of parks and demand on night resources are not well monitored. When provided, estimates of use suggest that night recreation in park units is often low, but some parks reported nighttime visitor use levels that are quite substantial. This variation is likely due to factors such as the night resources that a park contains, the uniqueness of these resources, how they are promoted or used, and the type and number of visitors to a park. Some parks seem more night-focused than others. For example, Golden Gate National Recreation Area has thousands of visitors who come to participate in night concerts and other performances. Other park units may not offer or recognize particular night recreation activities because they have no indication that it would appeal to visitors and have not identified any other reason to offer certain experiences.

Night recreation activities may require facilitation by park personnel and may therefore add to the demand for park personnel in time and cost. Parks may find assistance from outside volunteers or organizations that are aligned with a given activity. For

Table 2. Frequency of survey responses and nonresponses by National Park System designation

Unit Designation	Responses	Non-responses
International Historic Site	1	–
Memorial	5	–
National Battlefield—Site, Park, or Memorial	14	2
National Historic—Site, Park, Preserve, or Reserve	94	31
National Lakeshore	4	–
National Memorial	10	5
National Military Park	5	4
National Monument	67	13
National Park or National Park and Preserve	53	9
National Preserve	3	2
National Recreation Area	12	6
National Reserve	1	–
National River—and Recreation Area, Scenic River, Scenic Riverway, or Wild and Scenic River	12	2
National Scenic Trail	1	1
National Seashore	10	–

Table 3. Frequency of night recreation activity availability and reported visitor participation in the National Park System

Activity	Specifically Prohibited	Permitted to Do This Activity on Their Own	Permitted to Do Activity as Part of Program	Visitors Engage in This Activity in My Park
Campfires	162 (51.4%)	90 (28.6%)	51 (16.2%)	123 (39.0%)
Camping	165 (52.4%)	97 (30.8%)	37 (11.7%)	132 (42.2%)
Interpretive programs at night	25 (7.9%)	64 (20.3%)	210 (66.7%)	181 (57.5%)
Night bike riding	127 (40.3%)	149 (47.3%)	8 (2.5%)	88 (27.9%)
Night boating, canoeing, kayaking, or rafting	151 (47.9%)	104 (33.0%)	12 (3.8%)	76 (24.1%)
Night concerts or plays	64 (20.3%)	41 (13.0%)	156 (49.5%)	91 (28.9%)
Night fishing	153 (48.6%)	105 (33.3%)	3 (1.0%)	98 (31.1%)
Night hiking or walking	65 (20.6%)	190 (60.3%)	77 (24.4%)	179 (56.8%)
Night hunting	280 (88.9%)	17 (5.4%)	2 (0.6%)	32 (10.9%)
Night photography	56 (17.8%)	193 (61.3%)	51 (16.2%)	153 (48.6%)
Night snow skiing or snowshoeing	108 (34.3%)	112 (35.6%)	16 (5.1%)	74 (23.5%)
Special night events or festivals	25 (7.9%)	53 (16.8%)	209 (66.3%)	143 (45.4%)
Stargazing, starparties, or viewing the Northern Lights	37 (11.7%)	162 (51.4%)	109 (34.6%)	168 (53.3%)
Viewing natural, cultural, or historical resources at night	36 (11.4%)	179 (56.8%)	125 (39.7%)	166 (52.7%)
Wildlife viewing at night (excluding spotlighting)	69 (21.9%)	177 (56.2%)	61 (19.4%)	137 (43.5%)
Other	1 (0.3%)	5 (1.6%)	1 (0.3%)	4 (1.3%)

Note: Frequencies represent the number and percentage of park units responding affirmatively.

example, a park that does not have personnel to facilitate a night hike may find volunteers in a nature-based organization who are able to lead such an activity. Likewise, astronomy groups may be a rich source of assistance for night sky programs.

Respondents were able to indicate whether any of the 15 listed night activities were prohibited in their park unit. Night hunting, camping, and campfires were most often prohibited, reflecting the philosophy and policy of many national parks, a lack of campground facilities, and wildfire threats, respectively. Other night recreation activities may be prohibited because of the inherent dangers of a given park or activity. For example, hiking and walking in parks during daytime hours are permitted in most parks, yet 20% of respondents reported that night hiking and night walks are explicitly prohibited in their park. This may be partially because of increased perceptions of risk (e.g., tripping, hostile wildlife, disorientation) associated with hiking at night. Several parks indicated that night access is limited in an effort to protect their night resources, such as sea turtles that nest at night.

Respondents were also able to indicate whether a given night recreation activity could occur as part of a park program or whether a visitor could engage in the night activity without supervision. Results suggest that a majority of night activities most often occur individually (i.e., "on your own"), rather than with a ranger or as part of a formal program. However, a substantial percentage of activities did occur with a ranger or as part of a park program. This makes sense because many night activities (e.g., nocturnal species observation, astronomy, night concerts/events) require technical expertise, specialized equipment, or knowledge that makes participating in these activities as an individual less feasible. In such cases the park interpretive ranger or performer might be considered a park unit's night resource.

We also note that findings from this study are an incomplete picture of night recreation and night resources because they represent only managers' observations and management policies. Visitors must be polled about their perceptions of night recreation and night resources. It is likely that NPS managers do not have a completely accurate perception of which night recreation activities or related night resources are of value to visitors. Research demonstrates that park managers and visitors often have distinct and divergent attitudes, values, and beliefs (Manning 2011).

In many cases night may not be perceived as a distinct condition but rather as a gradual transition from or to daytime lighting. This may include *crepuscular* periods immediately before, during, or after sunrise or sunset. Likewise, some resources or recreation activities may not be distinctly night-focused, but are influenced heavily by natural light conditions. For example, the bat flight at Carlsbad Caverns National Park (New Mexico) and the sunrise at Haleakalā National Park (Hawaii) are both substantially night-

Table 4. Number of night visitors (annually) reported by units of the National Park System

	Campers and Lodgers		Noncampers/Lodgers	
Quantity	Frequency	Percentage	Frequency	Percentage
Less than 500	56	17.9%	43	13.7%
500 to 999	4	1.3%	9	2.9%
1,000 to 4,999	9	2.9%	11	3.5%
5,000 to 9,999	11	3.5%	4	1.3%
10,000 to 19,999	9	2.9%	5	1.6%
20,000 to 49,999	8	2.6%	3	1.0%
50,000 to 99,999	9	2.9%	1	0.3%
100,000 to 199,999	5	1.6%	1	0.3%
200,000 to 499,999	9	2.9%	9	2.9%
500,000 to 999,999	1	0.3%	1	0.3%
More than 1,000,000	2	0.6%	1	0.3%
Not Applicable	118	37.7%	156	49.8%
Don't Know	46	14.7%	43	13.7%
No Response	25	8.0%	21	6.7%

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Figure 4. Light-dependent resources and recreation are prevalent in many national park units. Photographers' "golden hour" before sunset is just one example, such as in this view of Plum Orchard Mansion's lawn at Cumberland Island National Seashore.

and light-related, but may not occur wholly while the sun is below the horizon. Also, nature photographers often seek out and take advantage of special lighting conditions associated with the "golden hour" that occurs immediately before sunset or after sunrise (fig. 4). Resources and recreation activities such as these may be considered crepuscular resources or recreation activities. Likewise, caving and visiting pre-electricity-era historical structures could be considered light-dependent resources or recreation activities.

Perhaps the most substantial outcomes of the research presented here are the proposed definitions of both night recreation and night resources. Survey results show that these definitions are more inclusive and accurate than those informal and implied definitions that now limit consideration of night in parks to the night sky or night sky viewing. These proposed broadened definitions may enhance recognition of night resources, their use and enjoyment by visitors, and their management.

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