Special Issue 2014 • Volume 31 • Number 1 • www.nature.nps.gov/ParkScience

PARK Science

Integrating Research and Resource Management in the National Parks

National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science
Office of Education and Outreach

BIOLOGICAL DIVERSITY: DISCOVERY, SCIENCE, AND MANAGEMENT

IN THIS ISSUE

Synthetic biology, data management, health benefits of biodiversity, and other features

Bioblitz science and outreach

All-Taxa Biodiversity Inventories

Surveying for nonvascular plants and invertebrates, including pollinators

Cultural sites and biodiversity

PARKScience
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Volume 31 • Number 1 • Special Issue 2014
www.nature.nps.gov/ParkScience
ISSN 0735–9462

Published by
U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Office of Education and Outreach
Lakewood, Colorado

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

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

Sample style for article citation
Leong, K. M., and G. T. Kyle. 2014. Engaging park stewards through biodiversity discovery: Social outcomes of participation in bioblitzes. Park Science 31(1):106–111.

Printed on recycled paper.

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 in summer or winter. The publication serves a broad audience of national park and protected area managers and scientists and provides for 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 presented in nontechnical language. 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

Seek, and you will find

THIS INSIGHTFUL MESSAGE HAS GUIDED PEOPLE ON LIFE'S JOURNEY for millennia, and more recently it has undoubtedly led visitors to national parks in search of restoration, health, and well-being. It is also relevant to the study of biological diversity, the theme of this issue of *Park Science* and a subject of great importance to the future of national parks.

All life-forms, from the smallest virus to the largest marine mammal, help define, regulate, and maintain park ecosystems. Understanding the functions of these organisms—the roles they play in the production of soils, provisioning of water, storage and recycling of nutrients, breakdown of pollution, and many other ecological services—is at the core of our task in the National Park Service to preserve parks unimpaired for the enjoyment of future generations.

The story of biodiversity in national parks is part discovery, part science, and part management, and we touch on all three areas in this issue. A series of articles describes the trend in parks to conduct activities devoted to the discovery of biodiversity. When we commit time and resources to the search for life, we find species that are new to parks and new to science, and we deepen our understanding of familiar species. How we manage the information that comes from this endeavor and incorporate it into park decision making is equally important and is also discussed in several articles.

Much of the science related to biodiversity study is the same today as it has been traditionally, though the pool of taxonomists we rely on to make identifications is shrinking. Additionally, our focus has shifted to invertebrates, nonvascular plants, and other less studied taxa and how we organize our fieldwork, subjects we explore in several articles. Techniques for collecting, processing, and documenting species and communicating about biodiversity are progressing with the help of academic and conservation partners and volunteers. Data analysis now makes it possible to predict locations for species of conservation interest, and synthetic biology has emerged as a means to create novel yet likely controversial alternatives to remedy species restoration and control problems.

In total we share more than 40 articles describing work to explore, understand, and integrate knowledge of biological diversity in national parks. I invite you to read the stories, weigh our progress, and contemplate next steps. You may even find something of value that you didn't know you were looking for.

—Jeff Selleck, Editor

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

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 all articles, and subscription management.

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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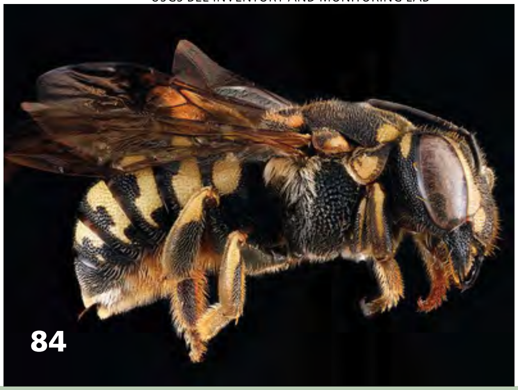

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UPCOMING ISSUES

Winter 2014–2015
Seasonal issue. March release.
Contributor's deadline: 15 November

Spring 2015
Seasonal issue. June release.
Contributor's deadline: 15 February

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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NPS/KATE CULLEN

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Commentary

A bold strategy for biodiversity conservation

By Elaine F. Leslie

Scientists know we must protect species because they are working parts of our life-support system.

—Paul Ehrlich

AS WE EDGE CLOSER TO THE centennial of the National Park Service (NPS) in 2016, there is much to celebrate—science and stewardship have a far more prominent role in park management than at any time in NPS history—yet there is reason for concern. The diversity of native species, including the genetic material they contain, the natural processes with which they are critically intertwined, and the corridors by way of which they move, are declining at a historically unprecedented rate. We are losing our national natural heritage—its species richness, role and function, and the beauty and cultural connection a biodiverse landscape provides in our environment. We must acknowledge that biodiversity not only is at the foundation of our health and well-being, but also that there are cultural and historical relationships to the biological connection that we just cannot afford to lose. We must act.

National parks and other protected areas are critical preserves of biodiversity in the face of increasing global changes; however, they tend to be managed largely as isolated islands within boundaries of human construct. Scientific consensus cautions that land managers plan for extensively connected ecosystems across broad spaces and that we ensure the restoration of those ecosystems and their keystone species. Given the alarming rate at which we are losing biodiverse ecosystems and the services they provide, we must step up our conservation efforts by increasing the number and size of protected natural areas where feasible and improving coordination among already designated protected areas such as our national parks and refuges. As biodiversity is also a potent frontier for discovery, we must tend to its welfare through the knowledge that comes from ongoing research and then apply it to our restoration and conservation efforts. The National Park Service, therefore, is committed to playing a leadership role in a strategy that will benefit biodiversity conservation across the national landscape, inclusive of local benefits at the park and community level.

In taking this national approach, the National Park Service hopes to cultivate and nurture a support network—a community of practice—among our employees, our park neighbors, our partners, and the American public. This will encourage parks to fully develop their capabilities, to learn from each other's experiences and expertise, work out best practices for biodiversity conservation and stewardship, ensure the collection and use of high-quality data, and coordinate information management and sharing. Ultimately, this approach will magnify and leverage the returns of individual parks' efforts, while incorporating this approach into our daily and long-term planning efforts.

For these activities to be successful, the education, interpretation, science, and curatorial communities must also work together to provide support, share their expertise, and leverage funds from local, regional, national, and international partners. In particular, we need to develop persuasive and compelling awareness messages that help us all to better understand the importance of biodiversity and to encourage the conserving of the integral components of Earth's biological portfolio—those that affect our daily lives in the food we eat and the clothes we wear. The messages should strive to engage the American public to protect and conserve biodiversity not just in parks, but also in their own backyards because they *want* to, not because they *have* to.

No framework for biodiversity stewardship would be successful if it were not also sustainable. Climate change issues must be considered and we must ensure the sustainable use of ecosystems and their biodiversity not only within our parks, but beyond our park boundaries.

Implementing such a strategy is ambitious to be sure. It must engage our youth, needs to be scientifically credible, and has to be simply yet passionately communicated. Our goal is for diverse ecological communities to persevere even when a species is lost to a disturbance and upsets the continuity of a living network or ecosystem. The system

We must step up our conservation efforts by increasing the number and size of protected natural areas where feasible and by improving coordination among already designated protected areas such as our national parks and refuges.

will be able to survive because the more complex it is and the more interconnectedness it has, the more resilient it will be.

Over the past decade the National Park Service has invested substantially in Service-wide and park capacity building for biodiversity conservation and discovery through multiple programs. These include the National Park Service–National Geographic Society annual "BioBlitzes," the activities of the Inventory and Monitoring Program, and the more than 100 parks that have held biodiversity and citizen science events over the course of the last two years through the Director's Call to Action initiative.

Across the United States, biodiversity awareness is becoming a common framework for community education and action. The National Park Service is perfectly positioned to build upon this leadership role to further develop the capacity for a wide array of federal science, stewardship, education and outreach, and expanded partnerships toward a national ethic of biodiversity conservation. This is an inclusive and integrative approach to community and park relationships and engagement on this issue.

Advancing conservation while ensuring that past investments in park research and resource management stay potent requires synergies far beyond those that exist currently in the Service or even the United States. We need to transform nature conservation altogether. Postage stamp protection must be replaced by a whole systems approach—continental conservation—with its inherent focus on landscape-level connectivity and the health and diversity of species. Through a coordinated approach at this broad scale, no matter where our national parks and protected areas dot the world map, together we can ensure that our work bestows healthy, vital components upon our national natural heritage and legacy, with biological integrity remaining intact for future generations. It starts with one park at a time, thinking big, acting boldly.

These are reasons to celebrate!

About the author

Elaine F. Leslie *is chief of the NPS Biological Resource Management Division in Fort Collins, Colorado. The division has the responsibility of providing technical expertise to parks in support of the management and protection of native species and related ecological processes throughout the National Park System. She can be reached at elaine_leslie@nps.gov.*

Getting Started

The language of biodiversity: A glossary

Consolidated from several sources by Greg Eckert and Glenn E. Plumb

As described in this issue of *Park Science*, national parks undertake many different kinds of biodiversity discovery and conservation activities that bring together various public groups, such as professionals and students from the formal education and science sectors; representatives from local, state, tribal, and federal governments and agencies; nongovernment organizations, including the private for-profit and not-for-profit sectors; and the overall citizenry. An aspiration of this undertaking is developing a common shared comprehension of and passion for biodiversity discovery and conservation. For most people, learning a new language is indeed challenging, though personal experience and passion can engender conditions of flexibility conducive to absorption of new words, syntax, and meaning. Knowing even a few words of a new language can be meaningful for eventual linguistic fluency. The following terms, used in this edition, and short descriptions are but an illustrative share of the exciting and powerful language of biodiversity!

Adaptation: Any morphological, physiological, sensory, developmental, and behavioral change in a character that enhances survival and reproductive success of an organism. Typically adaptation focuses on the process of genetic change within a population resulting from natural selection, whereby the average state of a character becomes better suited to some feature of the environment.

All-Taxa Biodiversity Inventory (ATBI): Intense inventory to identify all species of all taxa within a geographic area.

Bioblitz: Short-term (usually 24- to 48-hour) event that brings together professional species specialists and the public to sample biodiversity in a particular area.

Biodiversity: Full variety of organisms at all levels of biological organization, including the genetic, species, and ecosystem levels.

Biome: Major regional ecological community characterized by distinctive life-forms and principal plant (terrestrial biomes) or animal (marine biomes) species.

Bioregion: Geographic area whose limits are defined by natural features such as topography, biological attributes, and environmental processes rather than by political boundaries.

Biota: All of the species in a place.

Biotope: Large regional area with relatively uniform environmental conditions and consistent assemblages of populations of animals and plants.

Citizen science: Research science that engages the public in the scientific process, including training in methods and analysis, formulation of research questions, collecting data, and interpreting results.

Ecology: The study of the interrelationships among living organisms and their environment. Ecology is the study of patterns, networks, balances, and cycles rather than of the straightforward causes and effects studied in chemistry and physics.

Ecoregion: Area of general similarity in ecosystems and in the type, quality, and quantity of environmental conditions such as climate, landforms, hydrology, soils, and communities of plants and animals.

Ecosystem: Community of organisms and their physical environment interacting as a cohesive whole.

Ecotone: Boundary or transitional zone between adjacent ecosystems or biomes.

Endemic: Native to, and restricted to, a particular geographic region.

Genome: The total genetic constitution of an organism.

Habitat: The locality, site, and particular type of local environment occupied by an organism; its "address" or place where conditions are right for its survival.

Island biogeography: A theory affirming that the number of species inhabiting an island is a function of island area and distance from the mainland and is determined by the relationship between immigration and extinction.

Keystone species: A species that through food web or nutrient cycle position has a "disproportionate effect on the persistence of other species" and determines the composition of a biological community.

Niche: An organism's lifestyle; distinguished from habitat, an organism's place.

NPSpecies: Database, maintained by the National Park Service, of park species records, accessible Service-wide and by the public.

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Recommended readings in biodiversity

By Glenn E. Plumb

The glossary of E. O. Wilson's 1992 book, *The Diversity of Life*, identified more than 200 key terms and notable individuals important to a cogent discussion and understanding of the evolution of biodiversity. By 2008 the glossary of Chivian and Bernstein's *Sustaining Life: How Human Health Depends on Biodiversity* (see McNeely et al. 2008 and Pimm et al. 2008 for the reference) conveyed recent growth in biodiversity science through its more than 1,600 important terms and concepts. The commentary by Plumb et al. in this volume (see pages 14–16) also discusses the extent to which scientific narrative about biodiversity has proliferated in recent years. Within this growing scientific literature, the following recommended readings represent a very small, though satisfying, selection that may be of interest to the readers of *Park Science*, and address basic concepts and principles, syntheses and integrated states of knowledge, nexuses with evolution, and specific considerations across different ecosystem types.

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Phenology: Timing of seasonal or periodic biological events, generally tightly coupled to climate, such as flowering and migration.

Phenotype: The physical expression (outward appearance) of a trait of an organism, which may be the result of genetics, environment, or an interaction of the two.

Population: A group of organisms of one species, occupying a defined area, and usually isolated from other similar groups. The National Park Service typically manages populations of a species, not the whole species.

Range: All of the habitat areas where a species is usually found.

Species: Groups of individual organisms that can interbreed, resulting in fertile offspring. (Advances in analytical technologies have allowed other concepts to emerge, but they are beyond the scope of this glossary.)

Species richness vs. species diversity: Species richness is the actual number of different species in an area. Species diversity is an indirect measure that also takes into account the frequency of occurrence of species (e.g., rare vs. common).

Subspecies: A group of interbreeding natural populations different taxonomically and with respect to gene pool characteristics, often isolated geographically from other such groups within a biological species.

Taxon (pl. taxa): Unit or category used in the biological system for classifying related organisms. Taxa are ranked in descending order from kingdom to subspecies and include groups such as phyla, families, genera, and species.

Taxonomic working group (TWiG): Self-organized group of taxonomists and other scientists with particular expertise and interest in specific taxa.

Taxonomy: The theory and practice of describing and naming organisms and classifying them into hierarchical series of groups that emphasize their phylogenetic, and now genetic, interrelationships. Evolution now drives taxonomy, emphasizing "descent with modification"; that is, life-forms evolve in family trees.

Voucher: Representative specimen of an organism used to confirm a species' identity in a biological study. Vouchers are usually entire preserved specimens, though they may consist of photos, sound recordings, or tissue.

About the authors

Greg Eckert *is restoration ecologist and* ***Glenn E. Plumb*** *is chief wildlife biologist with the NPS Biological Resource Management Division in Fort Collins, Colorado. Correspondence can be directed to the editor at jeff_selleck@nps.gov.*

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"READINGS" CONTINUED FROM PAGE 8

Wamer, R. M. 2014. Conserving marine biodiversity in areas beyond national jurisdiction: Co-evolution and interaction with the law of the sea. Frontiers in Marine Science 1:6. doi:10.3389/fmars.2014.00006. Accessed 17 July 2014 at http://journal.frontiersin.org/Journal/10.3389/fmars.2014.00006/full.

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About the author

Glenn E. Plumb *is chief wildlife biologist with the NPS Biological Resource Management Division in Fort Collins, Colorado. He was working as a cattle ranch manager for The Nature Conservancy when, in 1988, he first read E. O. Wilson's* Biodiversity. *He has worked for the National Park Service since 1993 in "wild life" biodiversity conservation. He can be reached at glenn_plumb@nps.gov.*

PS

National parks and biodiversity discovery

By the editor

THE MAP ON PAGES 12–13 locates national parks that have undertaken biological diversity discovery research and monitoring work since around 1996. Many of these activities were funded, organized, and carried out by the parks and their partners, and many involved public participation. The activities commonly focused on understudied taxa such as insects, fungi, and other groups of invertebrates and nonvascular plants. The information produced by this work augments the systematic and program-funded vertebrate and vascular plant inventories led by the NPS Inventory and Monitoring Program that began in the 1990s.

The map also denotes the types of biodiversity discovery activities conducted. This includes onetime and independent taxonomic investigations. More and more, however, biological survey work is being combined with an opportunity to engage the public in meaningful and satisfying park stewardship experiences. These biologically focused public activities are flexible in scope and design and require special planning. They encompass relatively small and easily managed park inventories focused on particular taxa or habitats, larger-scale collection and festival-style events such as the NPS–National Geographic Society BioBlitzes, the more comprehensive and longer-term All-Taxa Biodiversity Inventories, and coordinated, multipark surveys and related research.

The driving distance between parks and the nearest U.S. city with a population of 250,000 or more is illustrated too. Five of the 119 parks on the map are located in a city of this size and another 49 are within a 100-mile (161 km) drive—a reasonable day trip—of such a city. Thus nearly half of the parks on the map are relatively close to population centers, which underscores the ability of parks to appeal to urban and suburban residents to participate in these types of events.

Developing the map was not without challenges. Criteria for what constitutes biodiversity discovery have not been defined precisely and reporting of these activities varies, complicating the synthesis. Additionally, most of the work has not been fully documented or analyzed from a national perspective. We have chosen to be inclusive[1] because biodiversity discovery is a scalable, cumulative process. Small, onetime, and less formal activities have the potential to inform our knowledge of biodiversity, as do large, coordinated, and repeated events. Plus, participation in citizen science–oriented activities is not limited to taxonomists or other scientists; anyone can take part, make a discovery, and help bring meaning to an observation. Nevertheless, we may have overlooked some activities for lack of knowledge, for example breeding bird surveys, Christmas bird counts, and less publicized inventories.

We summarize the biodiversity discovery activities for each of the parks shown on the map at http://www.nature.nps.gov/ParkScience/index.cfm?ArticleID=653. The parks on the list are cross-referenced with the map grid for ease of location. We invite you to review this online list and improve it by sharing news of your park's biodiversity discovery activities that we missed, adding detail to those that are sparse, and clarifying misinterpretations. To log your input please write to editor Jeff Selleck at jeff_selleck@nps.gov.

The story of biodiversity discovery in our national parks is exciting and continues to unfold. Small and large parks across the National Park System increasingly are taking part in these scientific activities that capture the public's imagination and enthusiasm. Moreover, urban and suburban residents are participating in biological surveys and biodiversity conservation, concepts typically associated with textbooks and more remote parks.

The graph on page 13 illustrates that these events have proliferated since the first bioblitz was held at Kenilworth Park and Aquatic Gardens in Washington, D.C., in 1996, and particularly since the NPS Call to Action item 7: "Next Generation Stewards" was announced in 2011. Numbering 109 in the last four years, biodiversity discovery activities are increasing our knowledge of park biota and providing educational and park bonding experiences for a multitude of volunteers and park visitors.

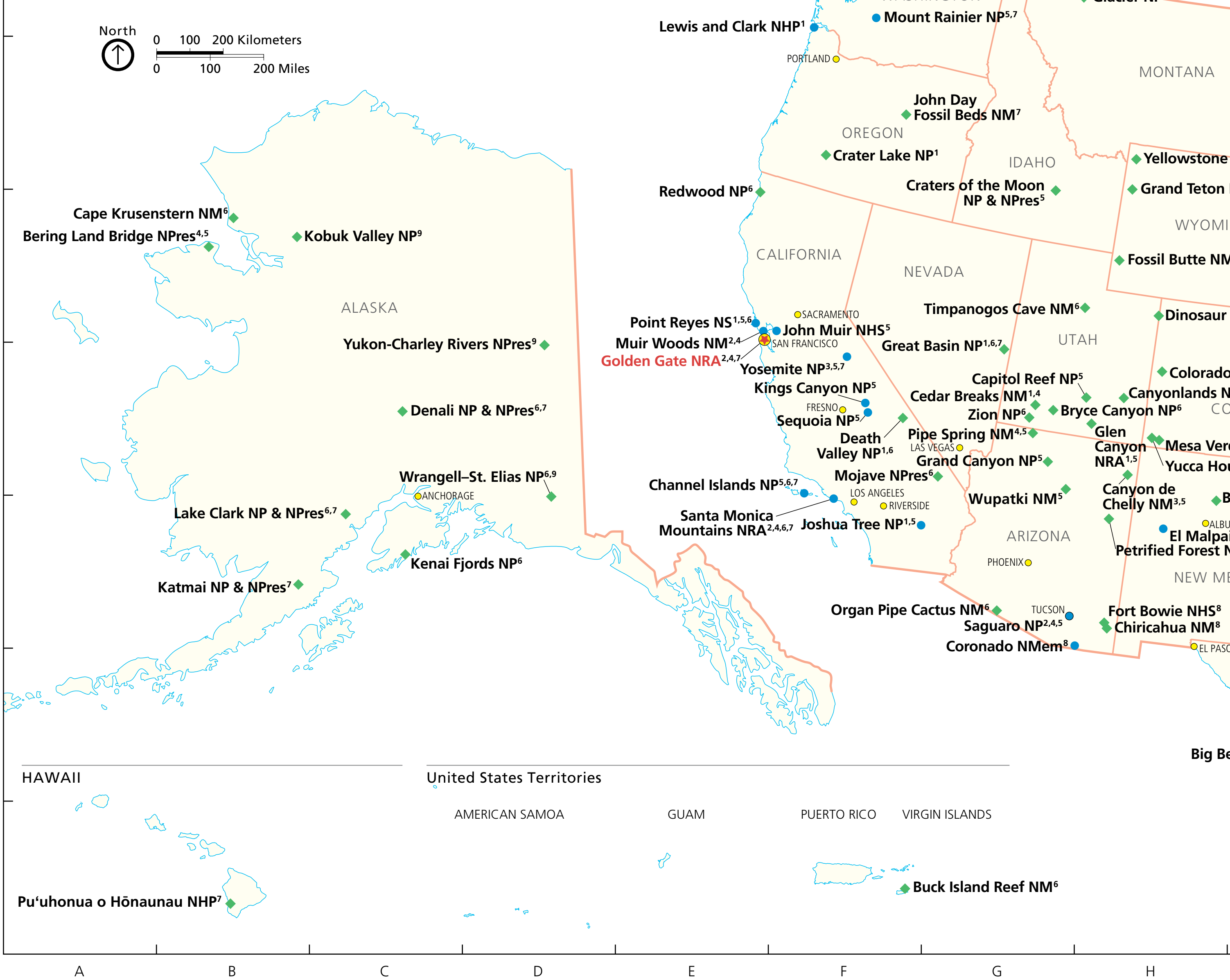
In biodiversity discovery, a rich and dynamic enterprise is taking shape in our parks, and with continued focus and resources, there is potential to do more. For the onetime, independent, or less formal inventories an opportunity exists to build on the information they produced and put it into a broader, more complete context by planning follow-up activities that address knowledge gaps and involve the public. Parks that have already carried out an activity can add to their knowledge of park biota and increase their public outreach by tweaking and repeating the events. Parks that have yet to get involved can draw from the considerable experience of those that have already done so and design an activity that meets their needs and matches their goals.

Biodiversity discovery is a concept in shared stewardship, and it seems to be working. If the trend continues, particularly after the NPS centennial celebration in 2016, it would not be surprising to see another 50–100 national parks plan and carry out a biodiversity discovery event over the next 5–10 years. Considering the recent growth in this enterprise and the potential for more, we may well want to revisit this topic in *Park Science* around that time to continue to gauge our progress.

1 Fifteen parks have plans for a "bat blitz," "paleoblitz," or camera-based activity later this year. Likewise, four additional parks plan to carry out dragonfly larvae sampling in October 2014. They are not shown on the map.

CONTINUE TO MAP

National Parks and Biodiversity Discovery 1996–2014



Legend

★ Urban Park (5)*

● Park Relatively Near City (49)†

◆ More Distant Park (67)‡

○/● City Nearest Park (38)§ *

*Located in a city with a population of 250,000 or more. NPS considers Ocmulgee NM to be an urban park, though it is not in a city of this size.

† Within a 100-mile drive of a city with a population of 250,000 or more.

‡ More than a 100-mile drive away from a city with a population of 250,000 or more.

§ City nearest park(s) with a population of 250,000 or more. Locations approximate.

Abbreviations

EHP	Ecological and Historic Preserve
Mem	Memorial
NB	National Battlefield
NBP	National Battlefield Park
NHP	National Historical Park
NHR	National Historical Reserve
NHS	National Historic Site
NL	National Lakeshore
NM	National Monument
NMem	National Memorial
NP	National Park
NPPA	National Park for the Performing Arts
NPres	National Preserve
NRA	National Recreation Area
NRRA	National River and Recreation Area
NS	National Seashore
NSR	National Scenic Riverway(s)
Pres	Preserve
SRR	Scenic and Recreational River

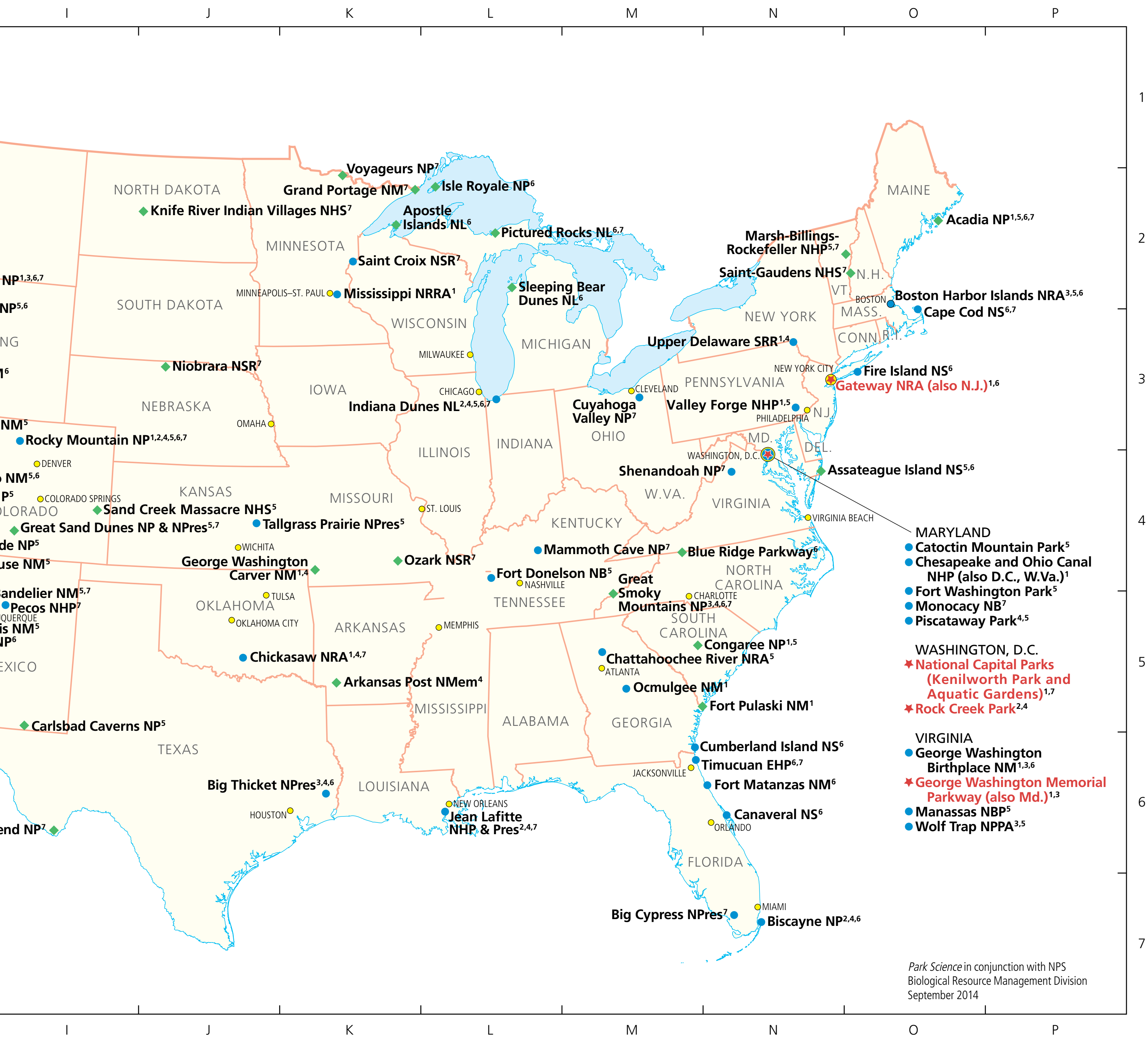
Note: To review the listing of biodiversity discovery activities that informed production of this map please visit www.nature.nps.gov/ParkScience/index.cfm?ArticleID=677??.

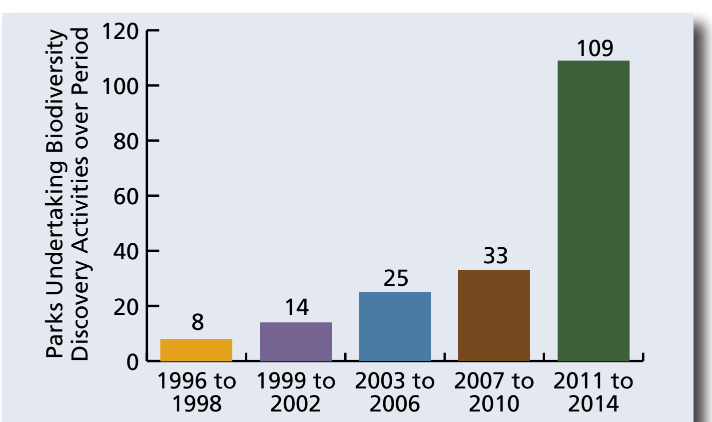
Activity Types

[1] Bioblitz(es) (focal taxa/habitat or general)
[2] NPS–National Geographic Society BioBlitz
[3] All-Taxa Biodiversity Inventory
[4] Educational programs, biodiversity fair
[5] Other (count, survey, monitoring, photographic/ digital documentation, observation, training)

Multipark projects

[6] Pollinator inventory (native bees)
[7] Environmental mercury in dragonfly larvae
[8] Automated camera/photo sampling (mammals)
[9] Acoustic monitoring of wood frogs to determine breeding phenology





(Graph) Since the advent of the bioblitz in 1996, national parks, their partners, and the public have planned and carried out biological diversity discovery activities with increasing frequency. The graph illustrates growth in this type of research and stewardship work over five periods in the last 19 years, particularly since 2011. That year the National Park Service set numerous goals to be achieved by 2016, the NPS centennial, including a challenge to conduct biodiversity discovery activities in at least 100 parks, at least 5 of which are located in an urban area.

Biodiversity Discovery Activities 1996–2014

Map Supplement

This list summarizes biodiversity discovery activities undertaken by national parks from around 1996 to 2014. It was developed in conjunction with and provides detail to the map and synthesis article on pages 11–13. Parks are cross-referenced with the map grid by letter and number for ease of location. Activity types are indicated according to the categories listed in the legend. We recognize that some listings may be incomplete or inaccurate. We invite you to help improve this list by sharing news of your park's biodiversity discovery activities that we missed, adding detail to those that are sparse, and clarifying misinterpretations. To log your input please write to editor Jeff Selleck at jeff_selleck@nps.gov.

Legend

Park Name (Map Location)
- Year(s) | Activity Type | Focal Taxa/Habitats | Participation | Highlights

Individual Park Projects

[1] Bioblitz(es) (focal taxa/habitat or general)
[2] NPS–National Geographic Society BioBlitz
[3] All-Taxa Biodiversity Inventory
[4] Educational programs, biodiversity fair
[5] Other (count, survey, monitoring, photographic/digital documentation, observation, training)

Multipark Projects

[6] 2013–2014 | multipark pollinator inventory | native bees | scientists from NPS, USGS, Harvard University | 46 parks | ~685 species
[7] 2013–2014 | multipark environmental mercury study | dragonfly larvae | ~300 citizen scientists | 700 larvae collected in 6 odonate families
[8] 2013–2014 | multipark six-week automated photographic sampling, educational programs | mammals | I&M network, U.S. Fish and Wildlife Service, Student Conservation Association interns, public | 30 species
[9] 2012–2014 | breeding phenology through acoustic monitoring | wood frogs | Alaska Region, citizen scientists, student intern

Acadia NP (O2)[6,7]
- 2003–2014[1] | annual 24 hr targeted taxa bioblitzes | ants, aquatic insects, beetles, butterflies, flies, macrofungi, moths, spiders, true bugs, other insects | amateur entomologists and mycologists, school groups, public, academic institutions, state government, naturalist organization | 20 species of butterflies, 300 species of moths, 226 species of aquatic insects
- ongoing[5] | hawk migration observation | volunteers in conjunction with Cornell Lab of Ornithology

Apostle Islands NL (K2)[6]

Arkansas Post NMem (K5)
- 2012–2013[4] | biodiversity fair | mammals, herpetofauna, nighttime species | I&M network scientists, public

Assateague Island NS (N4)[6]
- 2012[5] | science field day/survey | marsh and bay biota, mole crabs, water quality | educators, schoolchildren

Bandelier NM (H5)[7]
- 1992–2014[5] | surveys, monitoring | ground-dwelling arthropods: beetles, crickets/grasshoppers, selected true bugs, spiders and other arachnids; species-habitat associations and shifts because of climate change | 300 species | University of New Mexico

Bering Land Bridge NPres (B3)
- 2013[4,5] | science engagement through videography | loons | high school students, educational and nongovernmental partners

Big Bend NP (I6)[7]

Big Cypress NPres (N7)[7]

Big Thicket NPres (K6)[6]
- 2006–2014[3,4] | ATBI, educational fairs and programs, seminars | amphibians, aquatic true bugs and ectoparasites, butterflies and moths, fishes, fungi, lichens, mussels, orchids, pseudoscorpions, slime molds, tardigrades, terrestrial arthropods, vascular and nonvascular plants | professional scientists, public, students | 2,761 species, 103 new to park, 1 (crayfish) new to science

Biscayne NP (N7)[6]
- 2010[2,4] | large, 24 hr bioblitz and fair (NPS-NGS) | marine species focus | with National Geographic Society, scientists, educators, public | 824 species tallied, 324 new listings for park

Blue Ridge Parkway (M4)[6]

Boston Harbor Islands NRA (O2)[6]
- 2013–2014[5] | 4.5 hr pilot photo voucher bioblitz | flora and fauna | 13 public | 248 photo insect observations; 52 species, 23 new for Thompson Island
- 2005–2010[3] | ATBI | invertebrates, intertidal species, mammals | entomologists, professional and citizen scientists, high school students, academic partners | 1,777 species

Bryce Canyon NP (G4)[6]

Buck Island Reef NM (F7)[6]

Canaveral NS (N6)[6]

Canyon de Chelly NM (H4)
- 2005–2007[3,5] | inventories, ATBI | arthropods and other taxa | inventories of three habitats: mixed conifer forest, pinyon-juniper woods along canyon rim, riparian woodlands | volunteers, schoolchildren, professional scientists

Canyonlands NP (G4)
- [5] | survey | insects | entomologist

Cape Cod NS (O2/3)[6,7]

Cape Krusenstern NM (B3)[6]

Capitol Reef NP (H4)
- 1998–2005[5] | inventories | rare plants | NPS, BLM, and other agencies; Canon USA grant

Carlsbad Caverns NP
- 2006–ongoing[5] | survey | moths | lepidopterist

Catoctin Mountain Park (N4)
- 2008–2013[5] | inventories | bees (93 species), damselflies and dragonflies (28 species), ground-beetles (103 species) | contractors | two odonates of conservation concern, 42 bees new to county, 1 bee new to Maryland, park insect list expanded from 364 to 588 species

Cedar Breaks NM (G4)
- 2013–2014[1,4] | weekend "bioblast" | bat, bird, bug surveys | live identifications only, no specimens collected; educational fair to celebrate biodiversity at 10,000 feet; public participation; local universities, retired entomologist

Channel Islands NP (F4)[6,7]
- 2009–2014[5] | inventories | ants, beetles, lichens | local taxonomists, in cooperation with The Nature Conservancy

Chattahoochee River NRA (M5)
- 2011[5] | inventory | pollinators (bees) | principal investigator, academic and federal partners | 8 species new to state, 1 new to science

Chesapeake and Ohio Canal NHP (N4)
- 2014[1] | bioblitz | invasive species
- 2006[1] | 30 hr bioblitz | algae, amphibians, arachnids, bryophytes, fungi, insects, reptiles, select flowering plants, slime molds | with The Nature Conservancy

Chickasaw NRA (J5)[7]
- 2011[1,4] | 24 hr bioblitz, educational programs | 800 species | 40 scientists

Chiricahua NM (H5)[8]

Colorado NM (H4)[6]
- multiple years[5,6] | survey | insects | university researcher

Congaree NP (M5)
- 1995–present[1] | ~1 hr training followed by 3–4 hr guided observation | birds, butterflies, moths | naturalist partners, citizen scientists (average 75 per year)
- 2006–2007[1] | spiderblitz, three 3 hr sessions | arachnids | professional scientist, public
- [5] | survey | freshwater mussels | professional scientists, conservation partner volunteers

Coronado NMem (GH5)[8]

Crater Lake NP (F2)
- 2014[1] | 24 hr bioblitz | moths and butterflies | entomologists, public

Craters of the Moon NM and NPres (G2/3)
- 2014[5] | inventory | pikas and natural sounds | citizen scientists

Cumberland Island NS (M6)[6]

Cuyahoga Valley NP (M3)[7]

Death Valley NP (F4)[6]
- 2007–2008[1] | bioblitz | invertebrates | taxonomists, school groups

Denali NP and NPres (C4)[6,7]

Dinosaur NM (H3)
- multiple years[5] | survey | insects, other arthropods | entomologist

Ebey's Landing NHR (F1)
- 2004[5] | monthly collecting forays (April, May, June, September) | vascular plants | professional and amateur botanists, public

El Malpais NM (H5)
- 2007–2008[5] | ATBI | cave arthropods, bats, and other vertebrates | university researcher through CESU | 59 arthropods, 3 bats, 3 other vertebrates; many arthropod species new to science

Fire Island NS (O3)[6]

Fort Bowie NHS (H5)[8]

Fort Donelson NB (L4)
- 2013–2014[5] | targeted inventories, various techniques | plants and all animal species: photography; owls: audio calling; bats: echolocation recording; nighttime biota: infrared photography and night-vision scopes; bioluminescent species: UV illumination and high-intensity chemical lighting | volunteers, citizen scientists

Fort Matanzas NM (N6)[6]

Fort Pulaski NM (N5)
- 2013[1] | 12 hr bioblitz | nonnative plants | park staff, 27 public (high school students, area naturalists) | new exotic species identified

Fort Washington Park (N4)
- ongoing[5] | video and direct observation monitoring | bald eagles | citizen scientists

Fossil Butte NM (H3)[6]

Gateway NRA (N3)[6]
- 2007–2008,[1] 2010[1] | bioblitzes, ATBI | all taxa, 3 focal areas | scientists, 50 preregistered public

George Washington Birthplace NM (N4)[6]
- 2007–2009,[1,3] 2012[1,3] | bioblitzes, ATBI | arthropods, including terrestrial and aquatic insects, birds, fungi, vascular and nonvascular plants | professional and amateur scientists, partners, schools | 377 arthropod species identified

George Washington Carver NM (K4)
- 2013[1,4] | bioblitz | aquatic and terrestrial invertebrates, small mammals, vascular plants, water mites | 4 professional scientists, 20 volunteers; 15 attended a related educational program | 141 species, 89 of which were new to park

George Washington Memorial Parkway (N4)
- 2006–2014[1,3] | 30 hr bioblitz, ATBI | algae, amphibians, arachnids, bryophytes, fungi, insects (including microwasps), reptiles, select flowering plants, slime molds | students, 59 citizen naturalists, academic institutions, museum | 378 genera (comprising 377 species) of insects

Glacier NP (H1)[6]
- ongoing[5] | focal taxa inventories | butterflies, diatoms, ferns, mayflies, mollusks, mycobacteria, vascular plants

Glen Canyon NRA (H4)
- 2009[1] | bioblitz | animals, plants | professional and amateur scientists | with The Nature Conservancy
- 2004[5] | surveys | amphibians, arthropods, reptiles, small mammals, vascular and nonvascular plants | professional scientists

Golden Gate NRA (E3)[7]
- 2014[2,4] | large, 24 hr bioblitz and fair (NPS-NGS) | all taxa | with National Geographic Society

Grand Canyon NP (G4)
- 2007[5] | inventory | ground-dwelling arthropods | professional scientist
- 1999–2004[5] | surveys | aquatic annelids | park staff, professional scientists, public

BIODIVERSITY DISCOVERY ACTIVITIES 1996–2014 (CONTINUED)

- ~2004[5] | surveys | amphibians, arthropods, reptiles, small mammals, vascular and nonvascular plants | professional scientists
- 2001–2003[5] | inventory | terrestrial and riparian invertebrates | professional scientist | 1,127 taxa collected

Grand Portage NM (K2)[7]

Grand Teton NP (H2/3)[6]
- 2004[5] | surveys

Great Basin NP (G4)[6,7]
- 2009,[1] 2011–2013[1] | annual 24 hr targeted taxa bioblitzes | arachnids (2 orders and several families new to park, white cave mite may be new to science), bees and wasps (65 species), beetles, flies (47 families, 19 species new to park) | professional and amateur scientists, public, volunteers | average 60 participants per year

Great Sand Dunes NP and NPres (I4)[7]
- [5] | survey | insects | entomologist

Great Smoky Mountains NP (M4/5)[6,7]
- 1998–present[3,4] | ATBI, grant-funded projects involving TWiGs, bioblitzes, educational programs, workshops | ~130 focal taxa projects over 17 years, including algae, annelids (including oligochaeta), ants, aphids, aquatic bugs, bacteria (hemlock, plant, soil, waterborne), beetles (leaf, long-horned, wood), butterflies, cave and karst biota, crickets, diatoms, dry cliff plants, elk stomach biota, ferns and fern viruses, fish, flies (biting, bloodsucking, crane-, horse-, moth-, tephritid), flat worms, forest litter, freshwater invertebrates, fungi and microfungi (including pyrenomycetes), grasshoppers, hemlock insects, homoptera, hymenoptera (including wasps), insect viruses, internal bird parasites, leeches, lichens, microspore parasites, mosquitoes, moths (clearwing, micro-, noctuidae, owl-), pauropoda, planthoppers/leafhoppers, pollinators, slime molds (including myxomycetes), soil mites, spiders, springtails, stream microbes, tardigrades, thysanoptera, tree-canopy life, vascular plants, violets, viruses (plant), waterborne spores, water mites | partner-led, long-term study; researchers; volunteers; student participation through research learning center; public events | 18,038 species total; 7,636 species new to park, 923 new to science | 400+ participants in 2013

Indiana Dunes NL (L3)[6,7]
- ongoing[5] | monitoring, counts | birds, plants of concern | 21 citizens, area naturalists | 52 bird species tallied
- 2009[2,4] | large, 24 hr bioblitz and fair (NPS-NGS) | all taxa | with National Geographic Society | more than 1,200 species tallied

Isle Royale NP (L2)[6]

Jean Lafitte NHP and Pres (L6)[7]
- 2013[2,4] | large, 24 hr bioblitz and fair (NPS-NGS) | all taxa | 458 species tallied | with National Geographic Society, 1,500 adults, 1,500 children, 100 scientists | Louisiana milk snake, mud minnow

John Day Fossil Beds NM (F2)[7]

John Muir NHS (E3)
- 2011–2013[5] | phenology monitoring | 50 high school students

Joshua Tree NP (FG5)
- 2011–2013[1] | 36 hr "biodiversity hunts" | terrestrial, aquatic, and aerial insects at park oases | university taxonomists and students, local naturalists, public education programs | range of 40–105 citizen scientists/event | new families, genera, and species to park
- 1994–present[5] | checklist updates, counts, inventories, surveys | amphibians, breeding birds, butterflies, lichens, mammals, including bats and rodents, reptiles, terrestrial arthropods, including insects, vascular plants | park staff, academic institutions
- 1968–present[5] | Christmas bird count | National Audubon Society
- 1991,[5] 1993,[5] 1999–2001[5] | surveys | bats | UCLA, Bat Conservation Int'l

Katmai NP and NPres (B5)[7]

Kenai Fjords NP (C5)[6]

Kings Canyon NP (F4)
- 2014 | inventory[5] | DNA analysis of harvestmen (arachnid)
- ongoing[5] | Christmas bird count
- 2002–2004[5] | inventory | cave invertebrates | contractor | about 30 new species (combined with those reported for Sequoia NP)
- [5] | roadside acoustic surveys | bats

Knife River Indian Villages NHS (J2)[7]

Kobuk Valley NP (B3)[9]

Lake Clark NP and NPres (C5)[6,7]

Lewis and Clark NHP (F1)
- 2012[1] | bioblitz | macroinvertebrates | 300 participants

Mammoth Cave NP (L4)[7]

Manassas NBP (N4)
- 1995–2014[5] | annual breeding bird surveys | birds, grasslands, shrublands | local Audubon chapter | designation as Important Bird Area, 10 species of regional conservation concern; butterflies, bees, plants also documented

Marsh-Billings-Rockefeller NHP (N/O2)[7]
- 2013–2014[5] | Atlas of Life field day, pilot digital documentation | bees, birds, moths, plants | 40 workshop/program participants | 90 observations/photographs by smartphone submitted to iNaturalist

Mesa Verde NP (H4)
- 1999–2007[5] | invertebrates and other arthropods | university entomologists | state range extensions, pinned collection
- inventory[5] | spiders | fire-burned areas | museum partner
- inventory[5] | ground-dwelling arthropods, spiders | comparison of burned and unburned pinyon-juniper forest | graduate student

Mississippi NRRA (K2)
- 2011–2013[1] | annual 24 hr focal-area bioblitzes | birds, fish, fungi, insects, mammals, plants | 100 participants in 2013, local university and museum | 322 species in 2013

Mojave NPres (G4)[6]

Monocacy NB (N4)[7]

Mount Rainier NP (F1)[7]
- 2004–2007[5] | annual forays at different park locations | vascular plants | botanists, public
- survey[5] | caddisflies, mayflies, stoneflies | entomologist

Muir Woods NM (E3)
- 2014[2,4] | large, 24 hr bioblitz and fair (NPS-NGS) | diverse taxa | with National Geographic Society

National Capital Parks (Kenilworth Park and Aquatic Gardens) (N4)[7]
- 1996[1] | 24 hr bioblitz | NPS and USGS scientists

Niobrara NSR (J3)[7]

North Cascades NP (F1)[6,7]
- ongoing[5] | inventories | insects, lichens | independent researchers
- 2002–2007[5] | annual forays at different park locations | vascular plants | botanists, public

Ocmulgee NM (M5)
- 2013[1] | 2-day butterfly bioblitz | 480 participants | butterflies (28 species), dragonflies (5 species) | field identifications only (i.e., specimens not collected)

Olympic NP (F1)[7]
- 2008[3] | ATBI | fungi, insects, lichens, liverworts, microbes, mosses, spiders | before large-scale Elwha watershed restoration | park staff, academic institutions

Organ Pipe Cactus NM (G5)[6]

Ozark NSR (K4)[7]

Pecos NHP (I5)[7]

Petrified Forest NP (G5)[6]

Pictured Rocks NL (L2)[6,7]

Pipe Spring NM (G4)
- 2011–2012[4,5] | surveys, educational programs | bats, especially migratory species | academic partner | 18 species identified, 600 public participants

Piscataway Park (N4)
- 2013–2014[4,5] | videography, educational programs | bald eagles

Point Reyes NS (E3)[6]
- 2002–2014[1,5] | 24 hr bioblitzes, counts, forays, grants, 2- to 3-day inventories | algae, benthic invertebrates, crabs, diatoms, eelgrass, fish, fungi, intertidal biota, invasive species, lichens, mollusks, oysters, phytoplankton, sea squirts, shellfish, stream butterflies | taxonomists, students, 15–100 public and scientists per year depending on event

Puʻuhonua o Hōnaunau NHP (B7)[7]

Redwood NP (E2/3)[6]

Rock Creek Park (N4)
- 2007[2,4] | large 24 hr bioblitz and fair (NPS-NGS) | amphibians, aquatic insects, birds, fish, fungi, mammals, microbes, plants, reptiles, and terrestrial invertebrates (including insects) | with National Geographic Society | more than 650 species tallied

Rocky Mountain NP (I3)[6,7]
- 2012[2,4] | large, 24 hr bioblitz and fair (NPS-NGS) | all taxa | with National Geographic Society, 5,000 public, schoolchildren, scientists, partners | 490 species total, 138 new to park (including 2 mammals)
- 2008–2009[1] | 2-day mycoblitz | fungi | professional and citizen scientists, local naturalist organization
- 2008–2009[5] | waterblitz | water sampling at 168 and 140 park locations, respectively | scientists, public
- survey[5] | caddisflies, mayflies, stoneflies | entomologist

Saguaro NP (G5)
- 2012–2014[5] | student monitoring of 10,000 saguaro cacti and other plants and animals
- 2011[2,4] | large, 24 hr bioblitz and fair (NPS-NGS) | all taxa | with National Geographic Society, 5,500 public, schoolchildren, scientists, partners | 859 species tallied, 400 new to park, 1 may be new to science

Saint Croix NSR (K2)[7]

Saint-Gaudens NHS (O2)[7]

San Juan Island NHP (F1)[6]
- 2014[1] | 2-day bioblitz | all taxa | students to help run event

Sand Creek Massacre NHS (I4)
- [5] | survey | insects | entomologist

Santa Monica Mountains NRA (F5)[6,7]
- 2009–2014[4] | annual biodiversity festival (1.5 days) | 2,000 people
- 2008[2,4] | large, 24 hr bioblitz and fair (NPS-NGS) | all taxa | with National Geographic Society, 2,000 public, schoolchildren, scientists, partners | more than 1,700 species tallied

Sequoia NP (F4)
- 2014[5] | inventory | DNA analysis of harvestmen (insect)
- ongoing[5] | Christmas bird count
- 2002–2004[5] | inventory | cave invertebrates | contractor | about 30 new species (combined with those reported for Kings Canyon NP)
- [5] | roadside acoustic surveys | bats

Shenandoah NP (N4)[7]

Sleeping Bear Dunes NL (L2)[6]

Tallgrass Prairie NPres (J4)
- 2009–2013[5] | annual count | butterflies | 70 participants | 2013: 50 species (3,070 specimens), 5 species new to park

Timpanogos Cave NM (H3)[6]

Timucuan EHP (M6)[6,7]

Upper Delaware SRR (N3)
- 2013–2014[1,4] | 24 hr bioblitz | all taxa | 2013: 50 scientists, amateur naturalists, 25 volunteers, 250 educational program attendees | 1,024 species in 2013

Valley Forge NHP (N3)
- 2014[1,5] | "Summer of Bugs" (two 24 hr bioblitzes and a summer-long "photoblitz") | terrestrial invertebrates | university partner with public participation | catalog bugs present in two seasons; includes macrophotography workshop and use of iNaturalist to log photos
- 2009[5] | "Crayfish Corps" | inventory and manual removal of nonnative rusty crayfish | volunteers from schools, summer camps, corporate groups, conservation organizations, families, park neighbors | native-to-nonnative crayfish ratio is 4:1
- 2003[5] | inventory | crayfish | 1 undescribed species and 1 new to state

Voyageurs NP (K2)[7]

Wolf Trap NPPA (N4)
- 2013[3,5] | photo inventory, ATBI | birds, insects (including pollinators: bees, butterflies, moths), plants | volunteer and federal biologist, professional and volunteer naturalists, public, local naturalist organizations | 100 bird species, thousands of photo insect and plant observations

Wrangell–St. Elias NP (D4/5)[6,9]

Wupatki NM (G4)
- 2012–ongoing[5] | ATBI cave arthropods, bats, and other vertebrates | university researcher through CESU | 1 bat and at least 2 arthropod species new to science

Yellowstone NP (H2)[6,7]
- 2009[1] | 24 hr bioblitz, public event | various taxa | taxonomic working groups, public
- 2007–2009[1,3] | aquatic molecular ATBI | aquatic DNA of Yellowstone Lake, various taxa | largest study of environmental DNA: 7 billion base pairs of DNA sequenced | academic institutions

Yosemite NP (F4)[7]
- 2007–2014[3] | ATBI with annual targeted taxa and habitats | bryophytes, caves, cliff lichens, high-elevation lakes | park staff, taxonomists, contractor, American Alpine Club | 500 lichen species new to park, some new to Sierra Nevada and North America, a few new to science; more than 300 bryophyte species identified
- 2004–2010[5] | inventory | vertebrates | park, academic, and federal scientists | repeat of early 1900s Grinnell Survey
- 2002–2004[5] | inventory | cave invertebrates | contractor | 1 new species

Yucca House NM (H4)
- 1 year[5] | survey | insects | entomologist

Yukon-Charley Rivers NPres (D3/4)[9]

Zion NP (G4)[6]

Invited Features

COMMENTARY

Biodiversity and national parks: What's relevance got to do with it?

By Glenn Plumb, Edward O. Wilson, Sally Plumb, and Paula J. Ehrlich

RECENTLY, THE DIRECTOR OF the National Park Service (NPS) asked the National Park System Advisory Board Science Committee to answer three questions: What should be the goals of resource management in the National Park Service? What policies for resource management are necessary to achieve these goals? What actions are required to implement these policies? Broad in scope and implication, these questions and their answers are intended to help chart the course of NPS resource stewardship. This dialogue generated a call "to steward NPS resources for continuous change that is not yet fully understood, in order to preserve ecological integrity and cultural and historical authenticity, provide visitors with transformative experiences, and form the core of a national conservation land- and seascape" (National Park System Advisory Board 2012). Within this context, the next century for the National Park Service will be influenced by a combination of system-level drivers and stressors such as advancement of climate and land use change, responses to such changes, and how stakeholders perceive the agency's relevance. This essay considers not the relevance of biodiversity, but rather the relevance of the National Park Service as seen through the lens of participants in national park biodiversity discovery and conservation experiences. Simply put, without relevance, the National Park Service will have a difficult time championing meaningful biodiversity conservation.

Discovery matters

What connects national parks, biodiversity, and relevance? The public perception of the centenary National Park Service is increasingly focused on the nation's biodiversity, though this vocabulary is not yet universally practiced. Technically, biodiversity is the diversity of life across the ecosystem, species, and genetic levels. Personally, only the most inattentive of park visitors do not find themselves taking a short breath in wonder and delight when first encountering a park's diversity of life: majestic trees, expansive prairie, tender wildflowers, teeming wild fish, charismatic wild predators and prey, a hatch of the salmon fly, marine mammals, migratory birds and butterflies on their long journeys, cold-blooded amphibians and reptiles, coral reefs, and the colorful extremophiles of acidic hot springs. The diversity of life lives on in its full exuberance, we intend and hope.

We believe that old and young alike who experience biodiversity fully at the level of species in a national park are more likely to believe in the importance of conserving life in general, and to actively become a current- or next-generation steward. The power of biodiversity discovery in such moments is becoming central to the perceived transcendence of national parks. One needs only see the light of discovery in a child's eyes at a park bioblitz to become a believer in the value of living nature. Such transformative experiences of discovery can be tightly coupled with the diversity of life that has been entrusted to the National Park Service. Think about it. *The diversity of life that has been entrusted*. Think about it again. Think about the great archetypal stories of journeys of discovery and of being entrusted with the diversity of life. Biodiversity is not an asset or a currency simply to be carefully packaged for passage through a purported Anthropocene. For the National Park Service and its visitors and stakeholders, biodiversity discovery and conservation are the journey. Exhilarating.

Words matter

Let's take a step back from the edge of the profound, draw a short breath, and think about our current state of affairs. Just as of old, we continue to record and pass along our rules, accomplishments, aspirations, and paths through written narrative. In the past three decades, the scientific and nonscientific narrative about our growing understanding and anxiety about the ecological consequences of the accelerating loss of biodiversity, especially at the species level, has exploded globally. From this emerging understanding of the ecological centrality of biodiversity in the human condition, this discussion has expanded to include the aesthetic, ethical, sociological, and economic consequences of the loss of diversity of life. Distinctly, Nobel Peace Prize–winner Eric Chivian and colleague Aaron Bernstein (2008) undertook the first

Biodiversity is not an asset or a currency simply to be carefully packaged for passage through a purported Anthropocene. For the National Park Service and its visitors and stakeholders, biodiversity discovery and conservation are the journey.

in-depth synthesis of the fundamental and profound relationships between biodiversity and human health. Though we face many challenges to improving the human condition, conservation of the diversity of life remains within our collective capacity. Conceivable.

Words are important. Certain words speak volumes when used, and are poignant by their absence. Relevance can indeed become biased by a deft turn of phrase. Notwithstanding the rapidly growing global interest in biodiversity, a quiet reading of NPS Management Policies (2006) reveals that "biodiversity" or "diversity" is not to be found in the table of contents or glossary, and is mentioned obliquely only four times amidst this 170-page tome. Intriguing.

Despite this lack of specific biodiversity guidance, the business of biodiversity conservation takes place day to day in national parks through a wide array of resource protection and management, including restoration of native species and ecosystems, control of invasive species, integrated pest management, and inventory and monitoring. The National Park Service is actively engaged in the business of protecting a wide range of habitats, such as prairie, tundra, ocean, mountains, forest, desert, rivers, islands, reefs, mangroves, and coastal wetlands; conserving ecological processes such as predation, competition, and disturbance; preserving large-scale marvels such as migration and dispersal; and providing for genetically diverse *wild life* populations.

Who cares matters

In addition to this foundational work of protection, the National Park Service advances biodiversity conservation by raising awareness through effective engagement of our citizens. As global threats increase, national parks are becoming critical reserves of biodiversity. Yet current societal trends include the disconnection of youth from nature and low park visitation by minority groups and underrepresented communities. If something is not seen as relevant, it is not considered important.

We suggest that public education and involvement in biodiversity discovery at our national parks are vital to conserving our national biodiversity for the future. Biodiversity discovery in national parks, for example via a public bioblitz, has proven to generate transformative visitor experiences that both educate and inspire through direct public involvement in the discovery of living organisms in the parks, of which it is estimated that 80–90% remain unknown. Because biodiversity discovery activities often require only excited minds and willing hands, they appeal to children and nonscientists as much as they do to experts in the subject matter. The NPS Call to Action item 7, "Next Generation Stewards," envisions a new generation of citizen scientists and future stewards of our parks through societal involvement in fun and educational biodiversity discovery activities and has challenged park staffs to conduct such activities in at least 100 parks from 2011 to 2016. Parks can thereby develop new, engaging relationships with diverse audiences, especially children, in the discovery of life in our parks. In the past 16 years, biodiversity discovery activities in parks have identified approximately 21,500 species new to park species lists, and have provided hands-on science experiences for more than 39,000 people of diverse ages, races, and backgrounds (NPS 2014). The scientific gains from biodiversity discovery are incalculable, species specialists will tell you. Public involvement and education can also be catalytic, yielding an exponential increase in awareness of and motivation for stewardship of biodiversity. Imagine the number 39,000 with a few more zeroes.

Consider, for example, the middle school student from Connecticut who attended the 2013 NPS–National Geographic Society BioBlitz at Jean Lafitte National Historical Park and Preserve in Louisiana (see sidebar on page 17). He became so inspired by the experience that he subsequently coordinated a bioblitz that engaged his entire school. As stated by one of his teachers, "City kids who live in some of the most crime-ridden and drug-ridden housing projects in the Northeast, and who need to appear 'tough' so they can survive, are now talking biodiversity."

Participation in biodiversity discovery can be life-changing in unexpected ways. Contemplate, for instance, students from inner-city Los Angeles who were bused to the 2008 NPS–National Geographic Society BioBlitz at Santa Monica Mountains National Recreation Area. Before a single species had been identified, a bigger discovery was made: these children were *seeing the ocean* for the first time. Extrapolate this handful of children to the millions of people who have not yet experienced a national park and who have little understanding of the importance

One needs only see the light of discovery in a child's eyes at a park bioblitz to become a believer in the value of living nature.

of biodiversity in their lives, health, and well-being. They need to experience the ocean to appreciate the fish; they need untamed spaces to attach importance to wild life.

Partners matter

The overarching enterprise of biodiversity conservation is beyond the scope of any single entity. Preservation of biodiversity and our natural heritage needs to take place not only in our national parks but also in our citizens' hearts and minds. We believe that the NPS mission to pass on park resources unimpaired for the enjoyment of future generations, along with the array of implications from the loss of biological diversity, requires the Park Service to undertake leadership and teamwork at spatial scales larger than parks, and in step with partners who may share in this mission. Capturing the public's mind and soul means engaging people wherever they are, whether it be in national parks, vital private natural areas, or their own backyards. Parks are embedded in larger regional and continental landscapes (National Park System Advisory Board 2012), and thus we propose that partnerships with organizations that are working to protect and restore at-risk species and ecosystem biodiversity on private lands are vital to the National Park Service mission. Nonprofits such as the E. O. Wilson Biodiversity Foundation (www.eowilsonfoundation.org), Encyclopedia of Life (www.eol.org), and Discover Life in America (www.dlia.org) are building much-needed capacity for biodiversity discovery and conservation; they can act as conveners, anchoring a driving focus on the importance of biodiversity field research and education, and the use of our parks as classrooms for learning, involvement, and caring. By working together to build a broad and authentic grassroots community of people who have a deep and personal experience of nature—who explore and participate in the *science* of biodiversity and the *practice* of global biodiversity conservation—we can encourage a public citizenry who understands how the complex and intricate web of biodiversity supports the fabric of our lives and who, through that knowledge, begins to seed this understanding into our cultural DNA and the way we engage with the living world.

Purpose matters

How to serve both humanity and the rest of life is the great challenge of the modern era. That is the reality of the natural world we are trying to save in national parks and other reserves. These final sanctuaries are our transcendent heritage and we will be wise to hold on to them. We can enjoy surviving fragments of nature in various ways and measures. Let us all first take constant pleasure from the surprise, mystery, awe, wholeness, and redemption they offer. Deeper still, let us hold on to a sense of the eternal, which is latent in wildlands. These special places provide hope for the immortality of life as a whole, freed of human cares and intervention (Wilson 2014).

In the not too distant future, we will look back and recognize that sometime near the transition to the 21st century, biodiversity became one of the defining characteristics of the American experience. For the National Park Service mission, for national park relevance, and perhaps for the insights herein, it is imperative for the National Park Service, without hesitation, to undertake leadership and commit to the enduring journey of *biodiversity discovery and conservation* with our stakeholders and partners, along with all the accompanying aspirations and consequences.

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About the authors

Glenn Plumb *(glenn_plumb@nps.gov) is chief wildlife biologist with the National Park Service, Biological Resource Management Division, Fort Collins, Colorado.* ***Edward O. Wilson*** *(wilson@oeb.harvard.edu) is with the Harvard University Museum of Comparative Zoology, Cambridge, Massachusetts.* ***Sally Plumb*** *(sally_plumb@nps.gov) is biodiversity coordinator, National Park Service, Biological Resource Management Division, Fort Collins, Colorado.* ***Paula J. Ehrlich*** *(pehrlich@eowilsonfoundation.org) is president and chief executive officer of the E. O. Wilson Biodiversity Foundation, Durham, North Carolina.*

PS

PROFILE

Ben Clark, Biodiversity Youth Ambassador

By Sally Plumb

THROUGH POURING RAIN in the redwood forest at Muir Woods National Monument, 14-year-old Ben Clark is grinning from ear to ear. He is participating in a predatory beetle inventory during the 2014 National Park Service–National Geographic Society (NGS) BioBlitz at the parks geographically associated with Golden Gate National Recreation Area (California).

Ben is an NPS Biodiversity Youth Ambassador. Initiated in 2010, the ambassador program has the mission of cultivating youth leadership that inspires next-generation environmental stewards in schools and communities. To date, five ambassadors have been selected by the host parks of the NPS-NGS BioBlitzes, while a sixth, Ben, was selected by the Natural Resource Stewardship and Science Directorate.

Ben's interest in biodiversity began during the 2011 Rocky Mountain National Park BioBlitz. While looking for amphibians in an alpine pond, Ben found a damselfly larva and learned that it was not native to the area. He became fascinated with the question of how it came to be there. In Ben's words, "It was that one little fly that opened my eyes to biodiversity."

Since that time, Ben's work to further biodiversity awareness has been inspiring. While attending the 2013 bioblitz at Jean Lafitte National Historical Park and Preserve in Louisiana, he was selected as an interviewee in a minidocumentary by the E. O. Wilson Biodiversity Foundation, Inspired by Nature (http://eowilsonfoundation.org/nps-biodiversity-youth-ambassadors/). At his school, St. Ann Academy, Ben helped implement a schoolwide bioblitz at a local estuary, with an accompanying biodiversity festival featuring exhibits on the biodiversity of 38 national parks. This growing awareness of biodiversity resulted in 42 students, parents, and teachers traveling from Ben's home community of Bridgeport, Connecticut, to participate in the Golden Gate BioBlitz. Ben was recently selected as an "Everyday Young Hero" by Youth Service America, an organization that engages young people to change the world and that sponsors Global Youth Service Day, the largest volunteer event in the world.

Sally Plumb: Why is biodiversity important?

Ben Clark: Biodiversity is important because it is the life and world we live in. So the more we learn and discover about biodiversity, the better we can improve the quality of human life.

SP: Why is it so important for youth today to connect with nature?

BC: "Youth" means the next generation, so if we can get them excited and enthusiastic about learning and conserving biodiversity, the better we can conserve it and the better we can control what we're doing.

SP: You've participated in several bioblitzes. Which was your favorite and why?

BC: My favorite bioblitz was the 2014 Golden Gate BioBlitz because when I was there, I learned more about how the ecosystem and the organisms in the ecosystem interact with each other to sustain the environment. And I found that really fascinating and really interesting—and I really liked learning about that.

DAWN PILOTTI, ST. ANN ACADEMY

Ben Clark collects a patent-leather beetle at the 2013 NPS-NGS BioBlitz at Jean Lafitte National Historical Park and Preserve.

SP: As a Biodiversity Youth Ambassador, what have you done to promote interest and awareness of biodiversity?

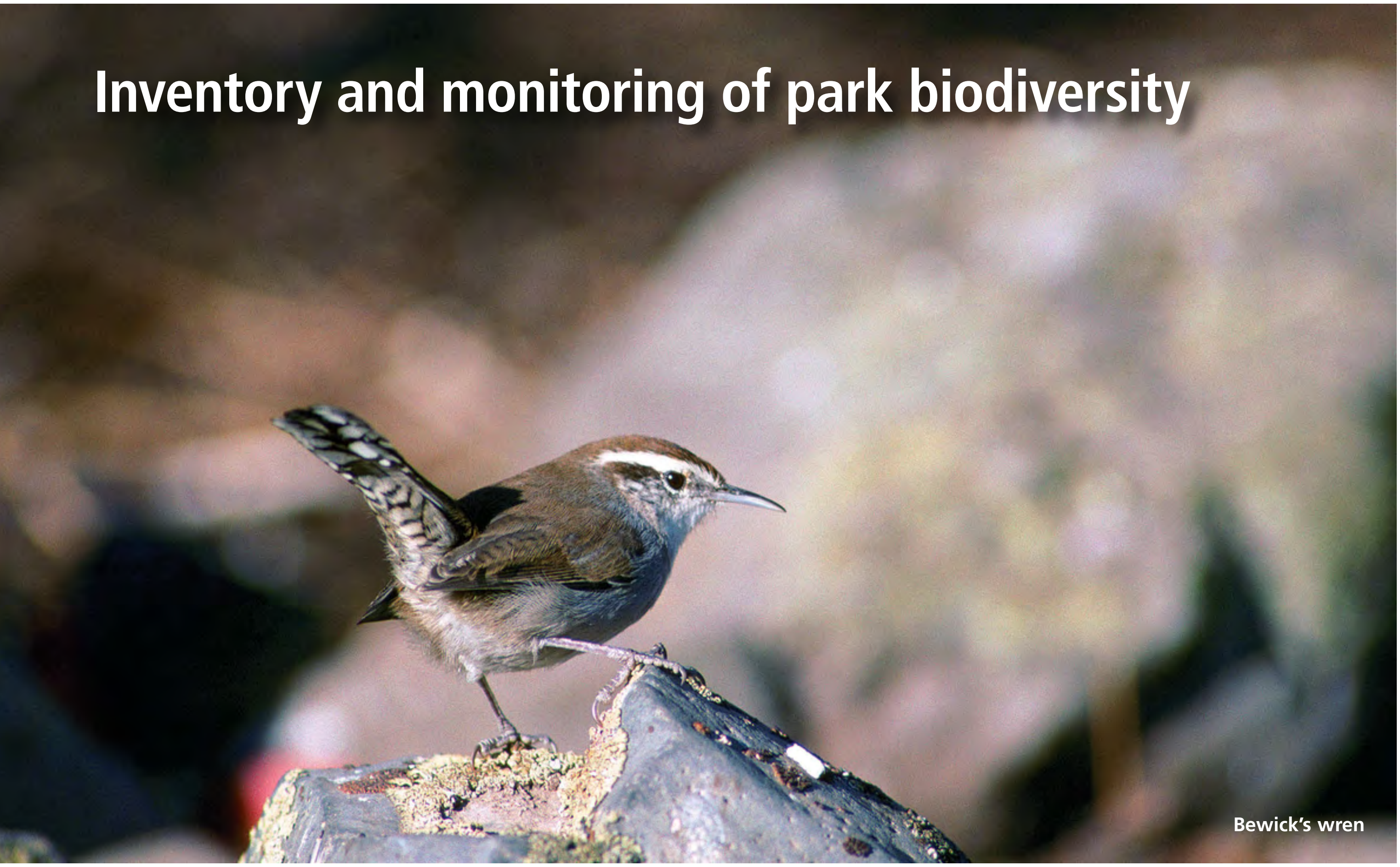
BC: As a Biodiversity Youth Ambassador, my friends and teachers and I organized a school bioblitz to promote youth involvement in biodiversity and to get youth excited about it. Change begins with one. At home in Connecticut, there are now 250 students waiting for the second annual school bioblitz. Just imagine how many people can be inspired by 250 students!

About the author

Sally Plumb *(sally_plumb@nps.gov) is biodiversity coordinator, National Park Service, Biological Resource Management Division, Fort Collins, Colorado. She can be reached at sally_plumb@nps.gov.*

PS

Inventory and monitoring of park biodiversity



USFWS/DAVE MENKE; NCTC IMAGE LIBRARY

Bewick's wren

By William Monahan and Kirsten Gallo

THE NPS INVENTORY AND Monitoring Program (I&M) was established in 1992 to develop a scientific understanding of the physical, chemical, and biological elements and processes of park ecosystems that shape the overall "health" or condition of park resources occurring in more than 270 national parks. The primary purpose of the program is to deliver to parks the science needed to manage their natural resources, beginning with 12 basic inventories (https://science.nature.nps.gov/im/inventory/index.cfm):

- Natural resource bibliography (IRMA Data Store)
- Base cartography
- Air quality
- Air quality–related values
- Climate
- Geologic resources
- Soil resources
- Water body location and classification (including wells)
- Baseline water quality
- Vegetation (vascular plants)
- Species lists (NPSpecies)
- Species occurrence and distribution of vascular plants, birds, mammals, fish, amphibians, and reptiles

While certain inventories such as baseline water quality (benthic macroinvertebrates), vegetation, and species lists directly inform our understanding of biodiversity in parks, others, such as climate, geology, and soils, are central to understanding the environments and processes that have led to diversification. Thus, both the biotic and abiotic components of the 12 natural resource inventories contribute to our growing body of knowledge of park biodiversity.

The inventories have shaped our understanding of biodiversity and facilitated its discovery in parks across the country. The Kahuku plant inventory at Hawaii Volcanoes National Park discovered a total of 455 vascular plant species, including 5 endangered species and 26 locally rare, native species. During vegetation mapping at the Blue Ridge Parkway (North Carolina and Virginia), 75 distinct plant communities were documented within the park, of which 24 are considered globally rare and

THIS IMAGE WAS PREPARED BY ELLEN EDMONSON AND HUGH CHRISP AS PART OF THE 1927–1940 NEW YORK BIOLOGICAL SURVEY CONDUCTED BY THE CONSERVATION DEPARTMENT (THE PREDECESSOR TO TODAY'S NEW YORK STATE DEPARTMENT OF ENVIRONMENTAL CONSERVATION). PERMISSION FOR ITS USE IS GRANTED BY THE NEW YORK STATE DEPARTMENT OF ENVIRONMENTAL CONSERVATION.

Bridle shiner

7 are considered globally imperiled. Herpetological surveys at Sleeping Bear Dunes National Lakeshore (Michigan) revealed 4 new species of reptiles and amphibians. At Delaware Water Gap National Recreation Area (Pennsylvania and New Jersey) and Upper Delaware Scenic and Recreational River (Pennsylvania and New York), several species of fishes that were previously considered to be rare or uncertain are now known to be relatively widespread in the two parks, and another very rare species (the bridle shiner, *Notropis bifrenatus;* see photo) was discovered at several new sites. A bird species thought to be extirpated from Chickamauga and Chattanooga National Military Park in Georgia and Tennessee (Bewick's wren, *Thryomanes bewickii*) was (re)discovered breeding, providing the first such evidence in the region since the early 1980s. At Craters of the Moon National Monument and Preserve (Idaho), pika (*Ochotona princeps*) were detected at several historical (recolonized) and many new locations.

Monitoring and biodiversity

Our knowledge and understanding of park biodiversity continue to grow beyond the inventories through long-term monitoring that tracks the health of park resources. More than 30 major categories of natural resources and indicators are monitored nationally by the I&M Program. Monitoring results routinely include the documentation of new species and, in some cases, rediscovery of species we thought were lost. For example, bird monitoring in the Southwest adds, on average, five new species of birds to park species lists each year. Two species of bats and a lady-slipper orchid, all listed as critically imperiled by NatureServe, were documented in Big South Fork National River and Recreation Area (Tennessee and Kentucky). Two species not seen in parks in more than 30 years have been documented through monitoring: spadefoot toad in Yellowstone National Park (Wyoming, Montana, and Idaho) and a freshwater sponge in Rock Creek Park (Washington, D.C.). Species identification for the sponge is pending.

Monitoring has helped document changes in biodiversity and why the changes have occurred. For example, stream monitoring conducted by the Rocky Mountain I&M Network and other collaborative stream sampling efforts in and around Glacier National Park (Montana) have resulted in the discovery of 26 new-to-science species of diatoms from Waterton-Glacier International Peace Park. Diatoms are important bioindicators that reflect water quality conditions. The Great Lakes I&M Network sampled about 60 sites across network parks. Results show that many of the lakes, especially those that are shallow, are experiencing rapid changes in diatom species composition. Sediment cores collected from at least one lake in most of this network's parks reflect water quality conditions for the past 150–200 years. Biological changes from the 1970s to 1980s, as reflected by diatom composition, are best explained by changes in climate rather than land use. Water temperature monitoring will help determine the extent to which climate change is driving changes in diatoms and water quality.

By focusing on the highest-priority measurements of park resource condition, I&M results and findings provide early warning of situations that require management intervention. This contribution to management is attainable without a fully comprehensive understanding of park biodiversity because species have interactions and dependencies both within and among park ecosystems. National Park Service and National Geographic Society BioBlitzes thus complement the Inventory and Monitoring Program by expanding our knowledge of the biological resources in parks. For example, nonvascular plants and invertebrates are two groups of taxa considered by bioblitzes that have not been systematically inventoried. Bioblitzes can help parks understand the diversity, distribution, and abundance of these taxa, along with others such as fungi and microbes. Knowledge gained through park bioblitzes adds to our inventories and, as with all science, bioblitzes help identify and highlight questions for future study. NPSpecies is the centralized NPS resource for archiving and curating these observations in support of future science.

About the authors

William Monahan *is an ecologist with the NPS Inventory and Monitoring Division in Fort Collins, Colorado.* ***Kirsten Gallo*** *is chief of the NPS Inventory and Monitoring Division in Fort Collins, Colorado. They can be reached at bill_monahan@nps.gov and kirsten_gallo@nps.gov.*

Data management for National Park Service–National Geographic Society BioBlitzes

Evolving biodiversity documentation

By Peter Budde and Simon Kingston

THE NATIONAL PARK SERVICE (NPS) and the National Geographic Society (NGS) have cohosted eight annual national park bioblitzes since their inception in 2007. Over time the methods and tools used to manage data from these events have evolved. Spreadsheets may have given way to smartphones and other mobile devices, but one constant has been the use of NPSpecies (https://irma.nps.gov/App/Species/Welcome), the centralized data application that documents the occurrence and status of species in national parks. NPSpecies provides a baseline of the species known to occur in a park and reflects the new knowledge gained from bioblitzes and other forms of scientific inquiry.

Information stored and managed in NPSpecies satisfies a fundamental purpose of the National Park Service to protect and maintain biological diversity in parks. Park managers, interpreters, planners, and scientists need basic information about species occurring in parks as a basis for making decisions and for working with the public, other agencies, and the scientific community.

Data management for NPS-NGS BioBlitzes occurs in three distinct stages: the pre-bioblitz buildup, the rush of activity during the bioblitz itself, and the post-bioblitz follow-up (fig. 1). Each stage has its own set of activities, but common themes are links to NPSpecies and quality assurance (QA) and quality control (QC) steps that are taken to ensure the most reliable data possible are recorded and made available.

Bioblitz

A bioblitz is commonly a 24-hour event in which teams of volunteer scientists, families, students, teachers, and other community members work together to find and identify as many species of plants, animals, microbes, fungi, and other organisms as possible. The National Geographic Society is helping conduct a bioblitz in a different national park each year during the decade leading up to the U.S. National Park Service centennial in 2016.[1]

[1] http://www.nationalgeographic.com/explorers/projects/bioblitz/.

The buildup (pre-bioblitz)

Preparation for managing data at an NPS-NGS BioBlitz involves determining the local contact (typically the Inventory and Monitoring Network data manager), designing field data sheets (fig. 2, page 22), eliciting the types of questions park staff would like to be able to answer as a result of the event, designing and developing the data entry and reporting application, and writing procedures and workflows to be used during the bioblitz.

Bioblitz events provide an opportunity for more than the enhancement of a park's NPSpecies inventory. The buildup to an NPS-NGS BioBlitz requires coordination by invited scientists who have been identified as being able to increase the understanding of often lesser-known taxonomic groups. Additionally, more than 3,000 people, including more than 1,500 schoolchildren, typically participate in a bioblitz and the concurrent biodiversity festival.

NPSpecies

The goal of NPSpecies is to be the authoritative source of species that occur in a park; however, many park species lists were last updated and reviewed during a certification process that occurred several years ago. Before the bioblitz, in order to make sure that a park's species list reflects the current state of knowledge for organisms that occur in a park, species records from inventories, incidental observations, and research activities must be reviewed and added. In addition, the taxonomic nomenclature often needs to be updated to reflect the latest science. Once this is complete, the final step is to update the records to indicate how certain the park is that an organism occurs in the park.

QA/QC

In order to prevent errors from making their way into species lists from bioblitz-collected data, we take several quality assurance steps. This includes crafting a standardized field data sheet for use by

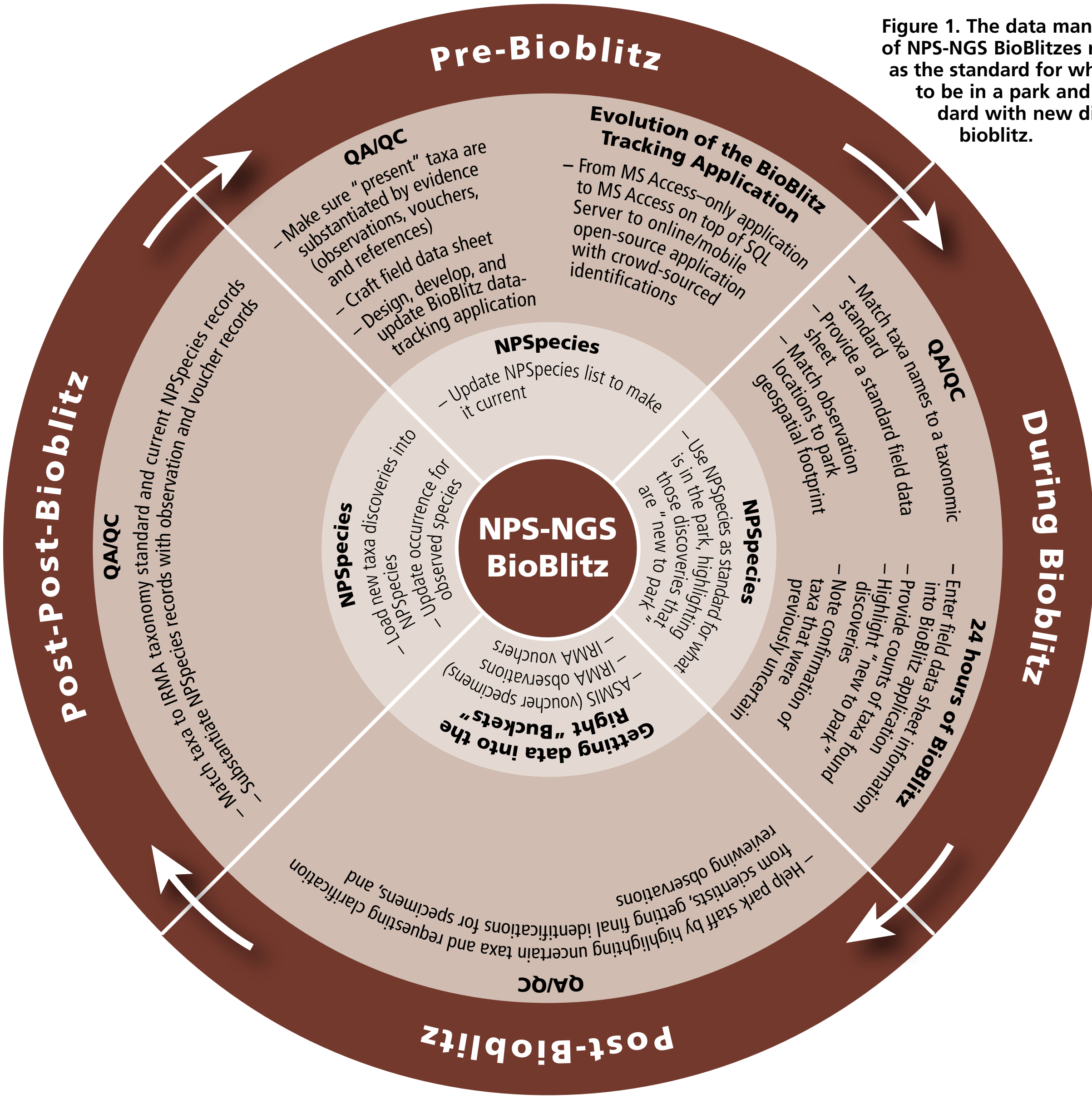


Figure 1. The data management life cycle of NPS-NGS BioBlitzes relies on NPSpecies as the standard for what species are known to be in a park and updates that standard with new discoveries after the bioblitz.

all registered scientists, standardizing the taxonomy for all species lists, and requiring that species marked as "present" in a park are substantiated by evidence (e.g., voucher specimens or detailed observations). At this stage we also decide upon the observation-tracking method to be used, and further design and develop it as necessary. Once we have developed a field data sheet and decided on an observation-tracking method, we draft standard operating procedures, including detailed instructions, for their use.

Evolution of the bioblitz observation-tracking tools

Getting started (2007)

Bioblitz participants used paper data sheets to note observations made in the field, which were then entered into an electronic spreadsheet. After transferring the data, the paper data sheets were discarded, making it impossible to check entries. The NPSpecies list was not used as a source for correct spelling of species names.

Getting relational (2008–2009)

Though the paper data sheets continued to be used in the field, we recognized the importance of the original field records and began to retain them following bioblitzes. Also, a participating network data manager developed a relational desktop database that replaced the spreadsheets and removed the need to reenter survey team information for every

2014 Golden Gate National Recreation Area BioBlitz Field Datasheet

Turn in completed datasheets to your Scientist Check-In Location, or: Crissy Center, 1199 East Beach, Presidio San Francisco, CA 94129. If found, please call 415-426-5110

Inventory Leader Information
(1) Name **(2) Primary Taxa:**
(3) iNaturalist Username: **(4) Phone (during BioBlitz):** **(5) Email:**

(6a) Records added to iNaturalist in the field? All / Some / None **(6b) Account Used for Data Entry (Username):**

(7) Date of Observations: ☐ March 28, 2014 ☐ March 29, 2014 **(8) Time Searching:** From __ : __ AM / PM To __ : __ AM / PM

(9) Inventory Location: *BAKER CRISSY ELPO FOFU GIAC LANDS LOBOS MAHE Marine MORI MUBE MUWO PRSF-NW RANCHO*
Other:____________

(10) Location Description/Habitat Type:

(11) Sampling Method:

(12) Species Information	Qty. Obs.	Coordinates		Evidence		Comments
	actual # or est. # (≤25, ≤100, >100)	☐ Geographic, WGS84 (decimal degrees)† ☐ UTM Zone 10, NAD83 (meters) † decimal degrees preferred		enter all that apply: Observed Photo Specimen Audio rec.	if P, S, or A enter specimen ID / photo no. / audio file name	(include alternate names of species)
Scientific (preferred) or Common Name		X (easting, longitude)	Y (northing, latitude)			
1.						
2.						
3.						
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11.						

Figure 2. Standardized field data sheets ensure consistency of information collected during a bioblitz, capturing the who (inventory leader), what (species information), where (inventory location and coordinates), when (date of observations), and how (sampling method) of biodiversity discovery.

observation. Database forms allowed users to navigate through a menu system to look up official taxonomic names associated with the NPSpecies list for each park. By controlling these "pick lists" we avoided spelling errors and more easily saw when new species were added. Based on these improvements, we were able to provide counts of the number of different species found by taxonomic category (e.g., mammals, birds, vascular plants) during the bioblitz.

Tighter coupling with NPSpecies (2010–2011)

Field data sheets evolved to include a unique identification number displayed on each sheet, which made information easier to trace back to a team leader and easier to find in the database. Data managers scanned the field data sheets in order to make it easy for data entry technicians to review the original entries and to create digital records. The database application was split into two parts: a simplified data entry tool that closely resembled the field data sheet and a more complex reporting tool. The reporting tool was based on a desktop NPSpecies application developed in 2005, allowing for even closer tie-in to the updated NPSpecies list for the park. New reports could be created, including a "Tree of Life" report, which interpretive staff have used to highlight extant and extinct species. Overall, these procedures facilitated tighter coupling with NPSpecies.

Going enterprise and getting social (2012–2013)

We continued to use paper field data sheets. The desktop database, however, was migrated to a higher-powered database system, which provided greater capacity for multiuser editing and better protection against accidental data loss. We designed a custom, menu-driven user interface that allowed bioblitz volunteers to enter the field data into the database. Naturalists then reviewed, matched, and corrected scientific and common names and an administrator ran count reports. For the first time, Internet-based observation tools came into use, as Project Noah (www.projectnoah.org) observations from citizen scientists were imported into the bioblitz database and counted.

Going mobile (2014)

Paper field data sheets continued to be used in 2014 at the Golden Gate National Recreation Area bioblitz. In addition, we adopted the iNaturalist mobile application, which allowed citizens and scientists alike to contribute observations using their mobile devices. Rather than NPS staff designing and developing a database application for recording observations at the bioblitz, this time we selected an existing Web-based citizen science platform, iNaturalist (www.iNaturalist.org), to be the data repository. Staff worked to develop requirements for modifications to iNaturalist in order to make it compatible with the needs of the bioblitz. Investments in this observation tool not only allowed for greater participation by individuals who were not able to attend the 24-hour biodiversity discovery event, but also created a persistent resource for the park and citizens to continue to contribute species observations after the bioblitz.

> Out of the 972 species identified at Biscayne National Park's bioblitz in 2010, 473 (49%) of the park total were found to be new to the official park species list.

The rush (during bioblitz)

Bioblitzes typically run from Friday morning through Saturday afternoon and usually start off slowly for data management, as it takes a while for data sheets to arrive from the field. By the end of the day on Friday and especially on Saturday morning, things are hopping. Once groups start to return from the field, the data management team kicks into action, entering field data sheet information into

> Field guidebooks and access to authoritative Internet resources such as the Integrated Taxonomic Information System (ITIS) are critical in refining species observations during a bioblitz. These resources are used to correct misspellings and other common errors.

the bioblitz application, downloading and associating photos with the field records, and providing reports, such as counts of distinct species observed, to the bioblitz communication staff.

NPSpecies

By comparing species entered from the field data sheets with the computer-based NPSpecies list, we are able to highlight species that are new to a park and note when a previously uncertain species occurrence is confirmed. For example, out of the 972 species identified at Biscayne National Park's bioblitz in 2010, 473 (49%) of the park total were new to the official park species list.

QA/QC

NPSpecies serves as the source for scientific and common names when entering species from field data sheets, helping to prevent spelling errors. If a name is not found on the park's NPSpecies list, then a standardized taxonomy "lookup" or query of the database is used. If a name does not appear in the standardized taxonomy search results, then science volunteers try to validate the name with a recognized authority and follow up with field scientists. Field guidebooks and access to authoritative Internet resources such as the Integrated Taxonomic Information System (ITIS) are critical in refining species observations during a bioblitz. These resources are used to correct misspellings and other common errors.

The unique identification number on each field data sheet is entered into the bioblitz database and saved into the scanned data sheet filename, making it easy to trace records from collection and entry to reporting. Data management volunteers also evaluate observation locations to be sure that they are within park boundaries.

The follow-up (post-bioblitz)

In the days and even years following a bioblitz, data management staff finalize data entry into NPS data systems, such as the Interior Collections Management System (ICMS), the Integrated Resource Management Applications (IRMA) Voucher system, and the IRMA Observations application.

NPSpecies

New species discoveries are added to the park's species list, updating the state of knowledge of what organisms occur in the park. Occurrence status is changed to "Present in Park" for species that were previously uncertain.

QA/QC

Data management staff work with park staff to finalize identification of specimens and review questionable identifications before adding these records to NPS data systems. They also work to ensure that NPSpecies records are substantiated with links to observations and vouchers.

Conclusion

The methods used to record species observations during National Park Service–National Geographic Society BioBlitzes have changed over time as new technologies have become available. The recent bioblitz at Golden Gate National Recreation Area in March of this year used an open-source, Web-based application that allowed contributions by citizens using applications on mobile devices. It also permitted crowd sourcing of identifications—that is, soliciting help from the online community of users.

As the technology used to document species observations at bioblitzes continues to evolve, NPSpecies remains the constant the National Park Service uses to communicate the depth of biodiversity in the parks. NPSpecies serves as the baseline for what species are known to occur in a park. It is used for quality assurance during a bioblitz to ensure that legitimate species names are associated with observations and to highlight discoveries of species that are new to a park. Finally, NPSpecies is updated after a bioblitz to reflect the new state of knowledge of what species are known to occur in a park.

About the authors

Peter Budde *is chief of the Restoration and Adaptation Branch, Biological Resource Management Division, Fort Collins, Colorado.* ***Simon Kingston*** *is a data manager with the NPS Inventory and Monitoring Division in Fort Collins, Colorado. They can be reached at peter_budde@nps.gov and simon_kingston@nps.gov.*

PS

Benefits of biodiversity to human health and well-being

By Danielle Buttke, Diana Allen, and Chuck Higgins

OLMSTED NATIONAL HISTORIC SITE/JOEL VEAK

THE NATIONAL PARK SYSTEM hosts some of the most diverse resources found anywhere on the planet. Parks host more variety in plant and animal organisms than almost any other land use (Flynn et al. 2009). Parks also curate our nation's cultural diversity, including landscapes, values, aesthetics, stories and belief systems, science, and knowledge. This variation among plants and animals, including cultural variation in humans, is called biodiversity (WHO 2014). Biodiversity is profoundly important to the health and sustainability of all species, including our own, regardless of where we live, work, or play. Biodiversity gives resilience—from the microbes that contribute to the formation of the human biome to the genes that help us adapt to stress in the environment—supports all forms of livelihoods, may help regulate disease, and is necessary for physical, mental, and spiritual health and social well-being.

Biodiversity can be explored in a number of emerging movements and schools of thought that are changing how we value and care for nature. Edward O. Wilson defined the term "biophilia," in his 1984 book of the same title, as the natural and instinctive bond humans have to other living things. Biophilia means that human affiliations with other life are deeply rooted in our biology and necessary for our well-being. An increasing amount of science supports this theory, and several very successful and prominent science and social movements have developed based on this science. The One Health movement promotes interdisciplinary approaches recognizing the interconnectedness of human, animal, and environmental health, and has been embraced by the veterinary, medical, and scientific communities as a way to promote and protect the health of all species and the environment on which all depend. The Healthy Parks Healthy People movement was initiated by Parks Victoria, Australia, in 2000, and has subsequently been institutionalized by the National Park Service to protect and promote the sum total of cultural and natural resources entrusted to our care (including park environments, park facilities, and programs) collectively, as health resources. In 2012 the U.S. National Park Service sponsored a Healthy Parks Healthy People motion that was adopted by the International Union for Conservation of Nature (IUCN) and its members, including government and nongovernmental organizations and scientists, to "protect the Earth's two most important assets—nature and people" and "to promote the benefits of enhancing healthy ecosystems and human health and well-being synergistically." As stated in the "Revisiting Leopold" report, this interconnectedness between human well-being and nature could have significant management and stewardship implications for parks, and there is need to examine and promote this science as an additional avenue to benefit parks and biodiversity (NPSAB 2012). This report was created following a request from NPS Director Jarvis and is intended to act as a guide for natural resource goals, policy, and action within the National Park Service.

Figure 1 (facing page). Exposure to biodiversity in nature has multiple benefits to both mental and physical health at any age.

Human dependence on biodiversity extends beyond the food we eat, the air we breathe, and the water we drink (fig. 1). This dependence has been classified into four main services—provisioning, regulating, cultural, and supporting—and each is essential to human health (Millennium Ecosystem Assessment 2005). In this article we examine four ways in which biodiversity benefits human health and include examples of how parks contribute to this emerging science and understanding.

Provisioning services

Humans depend upon biodiversity for survival, such as for the foods we eat, medicines we use to stay healthy, and materials we wear or use to build our homes. These services are the tangible products or items that we and other species consume for survival. Although this may be less obvious to the average American who purchases supermarket food from a select few grain and livestock species, a large variety of organisms maintain human consumption needs. Historically, this variety was much greater, but even today, wildlife serves as an important protein and iron source for much of the developing world, and botanical products serve as the base for both modern and traditional medicines. For example, 118 of the 150 most commonly used drugs are based on natural sources (ESA 1997).

Natural resources are not typically harvested from national parks for consumptive purposes aside from selected grazing and hunting provisions; however, park vegetation provides oxygen and removes and stores tremendous amounts of carbon dioxide, and snowmelt from national parks provides a significant source of municipal water to many major cities. The Tuolumne River system in Yosemite National Park provides water to more than 2.5 million people in the San Francisco Bay area.

Regulating services

Our dependence upon biodiversity, however, goes far beyond simple consumption of resources. Biodiversity influences how disease occurs in an individual or population, how the local climate is able to support life, and how resilient an area will be against flooding or a catastrophic storm. Regulating services are the processes that renew resources and ensure

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a functional, habitable environment. These include the well-known ecosystem services of cleaning air and water, as well as the less well-understood services of climate modification, immune and brain function modulation (from symbiotic bacteria, the human "microbiome"), and modulation of infectious disease. Many regulating services are currently being studied for their benefits to human health, and science continues to identify new ways in which humans depend on other organisms to modulate our internal and external environment.

Scientists have learned a great deal about the regulating services of biodiversity by studying the human health impacts of ecosystem alteration and degradation (Myers et al. 2013). Human-made dams and irrigation projects have been linked to increases in vector-borne diseases such as malaria, leishmaniasis, and schistosomiasis (see Myers et al. 2013 for review). Deforestation and human encroachment into wildlife habitat have been associated with the emergence of several zoonotic diseases, including HIV and ebola (Hahn et al. 2000; Ostfeld 2009). Direct correlations between increased incidence of several infectious diseases, including Lyme, Chagas', West Nile virus, and hantavirus, and decreasing mammalian or avian species diversity also demonstrate the protective, regulating service of biodiversity (see Ostfeld and Keesing 2012 for review).

The biodiversity in parks serves many of these regulating services, whether it be flood mitigation from parks with swamps and floodplains, disease-regulating services of predators and other wildlife species that reside in parks, or clean air and water. Park research also is leading the way to learning more about the regulating services of biodiversity: a study from Channel Islands National Park suggests that an increase in species richness, in particular predators, can decrease the prevalence of hantavirus in deer mouse populations and thereby decrease human disease risk (Orrock et al. 2011).

Climate change is expected to increase the importance of regulating ecosystem services (Nelson et al. 2013). Wetlands, marshes, and riparian areas mitigate floods, filter water, and can mitigate damage from natural disasters such as hurricanes, which are predicted to occur with increasing intensity and frequency as global temperature rises. Many vector-borne diseases are already increasing in prevalence and expanding their geographic range because of climate change, and wildfires are becoming more frequent and more severe (Nelson et al. 2013). Regulating ecosystem services are increasingly important means to adapt to and dampen negative effects of climate change.

Cultural services

Our dependence on biodiversity also includes cultural services that promote health for individuals, communities, and society. Cultural services include inspiration, education, recreation, aesthetics, traditional knowledge, and opportunities for scientific discovery and are derived from interaction with or exposure to biodiversity (Millennium Ecosystem Assessment 2005). Cultural services deliver health-promoting benefits of biodiversity and sustain the relationship of people with nature that is necessary to support life (Frumkin 2001; Abraham et al. 2010).

Nature experience has been found to have a positive impact on physiological and psychological health. Research has shown that contact with nature improves cognitive function and relieves stress (Gladwell et al. 2013). Further, nature experience has been associated with higher levels of physical activity, lower levels of mortality and chronic disease, improved self-esteem, and improved immune function (Gladwell et al. 2013; Nieuwenhuijsen et al. 2014; Karjalainen et al. 2010; Maller et al. 2006; Barton and Pretty 2010; Pretty et al. 2005; Thompson Coon et al. 2011). People living in biodiverse natural areas are less prone to allergies and other chronic inflammatory diseases than people living in landscapes of lawns and concrete (Hanski et al. 2012).

The incidence of depression and anxiety, as well as asthma/COPD, diabetes, and coronary heart disease, has been found to be significantly reduced for people living with more green space (10% or more than the average) within a 1 km (0.6 mi) radius (Maas et al. 2009).

Participation in outdoor recreation provides a range of potential benefits. These include health improvement from physical activity, spiritual well-being, an increase in self-esteem, mental restoration, and an appreciation for the natural environment (Buchner and Gobster 2007; Frumkin 2001; Hartig 1993; Hoener et al. 2010; McCurdy et al. 2010; Kaplan and Kaplan 1989; Kaczynski and Henderson 2007; Leahy et al. 2009). There is also evidence indicating that exercise conducted in outdoor settings or green space may be of more value to mental health, physical performance, and motivation to maintain exercise adherence than exercise conducted in other settings (Logan and Selhub 2012).

The emotional and cognitive dimension involved in the experience of nature is another area of scientific investigation that demonstrates the restorative value of nature and its importance to people's well-being. The presence of water, trees, and grass has been found to help people to relax and renew, and to reduce aggression (Kuo and Sullivan 2001). The restorative benefits of urban green spaces and their soundscapes were identified in one study as the top three reasons for visiting an urban park in Amsterdam, Netherlands: "to relax," "to listen and observe nature," and "to escape from the city" (Chiesura 2004). People with a strong sense of connection to nature report more happiness than those who are less connected. A high degree of nature relatedness is also associated with more environmentally protective behavior (Nisbet 2013; Zelenski and Nisbet 2014). The beneficial physiological effects of nature experience are also being discovered. A variety of studies have shown that spending time walking or contemplating in a forest setting is associated with lower cortisol (a stress hormone), lower blood pressure and pulse rate, and increased heart rate variability (Li et al. 2008; Logan and Selhub 2012). Visits to forest settings have been shown to improve immune responses and the production of anti-cancer proteins (Li and Kawada 2011). Individuals exposed to nature experience decreased recovery times post-illness or -operation and a decreased need for analgesia compared with those with no nature exposure (Depledge et al. 2011).

Access to nature is also closely linked to individual and community health. Evidence is mounting that proximity to parks and other green spaces has benefits for health and health-related behavior, especially of urban residents, and aids in reducing health disparities among populations (Richardson and Parker 2011; Wells and Evans 2003). Communities with more green spaces report a higher sense of connectivity, increased cohesion, and lower crime rates (reviewed in Largo-Wight 2011). Conversely, environmental degradation is associated with poor mental health, including depression and a loss of sense of place (Speldewinde et al. 2009). Residents of greener areas experience greater mental health than those who live in or relocate to areas with less green space (Alcock et al. 2014). This effect was reversible if individuals moved again to areas with more green space.

Supporting services

Supporting services are the ways in which biodiversity provides the building blocks for life. Supporting services are necessary for all other ecosystem services to exist. These include primary production (i.e., photosynthesis and chemosynthesis) of new organic matter, cycling of nutrients necessary for life, and pollination. Without this constant creative process, life would quickly grind to a halt. Primary productivity is a key determinant of biodiversity (Rosenzweig 1995), meaning that plants and animals alike are dependent upon this supporting service for survival. Humans may be the best example of this, as humans are estimated to use or co-opt 40% of all net primary productivity (Vitousek et al. 1986).

Conclusions

Biodiversity is important and should be conserved for its values and benefits to human health and well-being. Increased understanding of these health benefits may improve public support for conservation. As land use change and other anthropogenic disturbances to ecosystems impact biodiversity, we continue to learn more about how much humans depend upon the natural world and biodiversity for their well-being. Fortunately, the National Park Service is well positioned to raise understanding and appreciation of the values and benefits of biodiversity to protect and preserve our two most vital resources: nature and people.

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About the authors

Danielle Buttke *is the One Health coordinator for the National Park Service, a joint position between the Wildlife Health Branch, Biological Resource Management Division, and the Office of Public Health, and can be reached at danielle_buttke@nps.gov.* ***Diana Allen*** *is chief of the NPS Healthy Parks Healthy People program. She can be reached at diana_allen@nps.gov.* ***Chuck Higgins*** *is director of the Office of Public Health for the National Park Service.*

PS

IUCN World Parks Conference to address values and benefits of biodiversity

The World Parks Congress will meet in Sydney, Australia, November 12–19 to focus global attention on the values and benefits of parks and protected areas, including biodiversity. This once-in-a-decade event celebrates achievements of conservation policy and practice of the past decade and launches new policy initiatives for the future. Park and protected area professionals, partners, and allies will consider opportunities to create and maintain connected ecosystems that can best halt the loss of biodiversity, adapt to climate change, provide for human health, and secure food supplies and freshwater sources. The conference aims to involve governments, businesses, and citizens in taking action to marshal the most promising solutions to achieve a healthy and sustainable planet.

Recorded sessions of the conference will be available at http://worldparkscongress.org. You can also join in an initiative to reach millions of youth and inspire connections to nature through a campaign called “No Walls” on Facebook and Twitter at www.facebook.com/nowallsinfo and www.twitter.com/nowallsouthere.

—Diana Allen (diana_allen@nps.gov), Chief, NPS Healthy Parks Healthy People Program

EMERGING SCIENCE

Synthetic biology offers extraordinary opportunities and challenges for conservation

By Kent H. Redford

HUMANS HAVE ALWAYS sought to reshape nature to meet their needs: taming fire, domesticating animals and plants, building dams and nuclear power plants, and shaping and reshaping nature in countless other ways. We have been largely interested in how humans benefit from our actions with little attention to how nature is affected. To be sure, our species has affected nature in many significant ways such that historical extinction rates far exceed those in the geologic past. For example, on average, humans appropriate about 25% of potential net primary terrestrial productivity, mostly from agricultural land use and harvests (Haberl et al. 2007); we use more than half of all accessible freshwater; we apply more ammonia and nitrate than are fixed naturally in all terrestrial ecosystems; and we are changing the atmosphere through the dramatically increased production of methane and carbon dioxide (Crutzen 2002). Clearly humans are the dominant ecological and evolutionary force on the planet (Palumbi 2001).

The Anthropocene, the geological epoch we have entered, is named for this pervasive impact humans are having on the earth. But the impacts are not just pervasive; they are also increasingly novel. Humans are breaching boundaries that have held throughout human evolution. Species have been moved purposefully and accidentally, resulting in new ecosystems; climate change is threatening to produce a set of novel climates; species boundaries are being breached as humans move genes about; and organisms are being created that incorporate machines and electronics as part of their bodies.

Synthetic biology arrives

Part of this new age of human impacts is the developing field of synthetic biology, or "synbio." Synthetic biology is a hybrid of engineering and biology with an emphasis on reliably and predictably engineering the genomes of living cells to produce goods and services of use to humans. There is no universally agreed-upon definition of synthetic biology but one that is commonly referred to is (1) the design and construction of new biological parts, devices, and systems and (2) the redesign of existing natural biological systems for useful purposes (syntheticbiology.org).

Key elements of synbio in the field are (1) its engineering approach to natural systems (designing and fabricating "components" and "systems" using standardized and automated processes; (2) an emphasis on novelty: fabricating parts and systems that do not exist in the natural world (or redesigning and fabricating those that do); and (3) doing so to address human needs (ECNH 2010; Presidential Commission for the Study of Bioethical Issues 2010). Synthetic biology can be applied to a broad range of fields, including food production, new materials and manufacturing, waste processing and water purification, ecological restoration, and human health (see http://www.parliament.uk/mps-lords-and-offices/offices/bicameral/post/post-events/future-environmental-impacts-of-synthetic-biology/).

Synthetic biology is a rapidly developing field because of the rapid decrease in the cost of reading and writing DNA. Technologies that enable the manipulation of DNA are changing at a rate faster than the developments that led to cell phones and today's computers, suggesting that we could see in synthetic biology a rate of change faster than that in the last decade of smartphone and associated technologies (Carlson 2013). Billions of dollars are being invested annually in synthetic biology; developments of novel applications or improvements of existing ones emerge weekly. For example, only recently we read an announcement of the creation of the first custom, synthetic chromosome using synthetic biology tools (Mosendz 2014).

The practice of synthetic biology

Media coverage about the future that synthetic biology will enable has included a great deal of hype, but significant scientific advances show some of the potential that synthetic biology may bring. Trees have had their genomes altered so that they are easier to process for pulp; vanilla and other flavorings are now being produced in factories by algae and bacteria; ACT, the most significant drug used in treating malaria, no longer must be grown from the *Artemisia annua* plant but is produced in factories by yeast; bacteria have been reprogrammed to construct electronic and optical materials; and a new species of fruit fly has been created specifically by altering the genes responsible for its reproduction. There are thousands of other fronts across which synthetic biology is pursued, from fuels and medicines to foods and the reanimation of extinct species.

Unlike that of many other technologies, the philosophy underlying synbio development, as practiced at least in the United States and Europe, is open access, with new techniques and approaches being put into the public domain. Associated with this philosophy is widespread experimentation with synbio by community labs, teams of undergraduates, and now even high school students. Community labs are set up by interested synthetic biologists and made available for a nominal fee to anyone who is interested in experimenting with the new technologies (see diybio.org). The easy accessibility of equipment and genetic sequences (many can be ordered over the Internet) has extended the practice of synbio to students in high school, college, and graduate school. A great deal of synbio work is being done in university and commercial labs, but this is a technology that is open to many segments of society, including do-it-yourself biologists.

Despite all the work on and investment in synbio, next to no attention has been given to the relationship between this emerging field and conservation. Synthetic biologists have formed collaborations to look at the implications of their work for the social sciences, law, and arts and humanities (Marris and Rose 2012), but not with the protected area community or any other type of conservationist. This lack of engagement is equally stark from the conservation side, as the conservation and global change communities have paid virtually no attention to synthetic biology. These two fields are taking steps, though only in small ways, to talk to each other. A recent Wildlife Conservation Society meeting held in 2013 brought together the two groups (Redford et al. 2013; Redford et al. 2014), and some follow-up discussion on the intersection of the two communities is beginning to take place.

And what about biodiversity?

Synthetic biology may have a range of potential negative impacts on biodiversity: novel organisms may escape containment and cause negative impacts on natural ecosystems; land conversion for crops that were developed using synthetic biology may cause immediate, direct effects on species, ecosystems, and protected areas; and complex secondary effects on society and economy may also result (e.g., land conversion by people displaced or impoverished by first-order changes). Of equal significance, synthetic biology could provide conservationists with more effective methods of conservation, including the creation of biological tools that could help to gather and process field samples affordably or monitor for the presence of particular threats. Synthetic biology could be used to restore lost genetic variation to extant but diminished and threatened populations. Or it could be used to engineer microorganisms to create approaches to solving intractable problems facing humans, including providing clean water, restoring degraded lands, and developing better medicines—outcomes that might also have positive effects for conservation.

The two fields have a great deal to discuss:

- How should conservationists think about the novel species being developed by synthetic biologists?
- How will these species interact with existing species and ecosystems?
- Will or could these new technologies be used to re-create extinct species—a process called “de-extinction?” (The Long Now Foundation 2014)
- What will it mean if extinction is no longer forever?
- What will happen to our definitions of “natural” when human-made species are created and begin to interact with “natural” species?
- What threats will synbio bring? Will the organisms produced through synbio escape industrial facilities and become invasive? Will high school students purposefully release organisms they made as part of a class? What would happen if engineered organisms developed to fight an invasive disease evolved to attack agriculturally beneficial organisms?
- Conversely, what threats might synbio alleviate? Can it be used to develop solutions to known risks to biodiversity, such as the fungal diseases that threaten many amphibians and bats with extinction (Fisher et al. 2012)? Could we engineer disease resistance into species like the Tasmanian devil that are threatened with extinction because of a highly contagious disease?
- What would happen to the ecosystems into which new life-forms are introduced?
- Will species created through synbio be privately owned? What will this privatization do to conservation efforts?
- What will happen if synbio is used to deliver services more efficiently and at lower cost than “natural” systems?

Finally, synthetic biology organisms could directly affect existing protected ecosystems in a variety of ways by:

- Becoming invasive or otherwise affecting populations of protected species, or disrupting protected ecosystems
- Changing the economic value of land (and hence demand for land) within protected areas (e.g., making crop production possible on land currently regarded as marginal for agriculture and hence allocated as a protected area)
- Changing the way land surrounding protected areas is used and hence affecting species composition in the protected areas because of species immigration or extinction
- Accelerating (or slowing) the rate of ecosystem conversion outside pro-

tected areas and hence the relative importance of existing protected areas (e.g., reducing pressure on habitats like tropical forests and making protected areas less necessary and therefore uneconomic to run)
- Changing demand for products currently illegally harvested from protected areas (e.g., meat, timber, nontimber forest products, illegal drug crops)

Need to engage

We do not know what impacts synthetic biology will have on biodiversity and park-based conservation. Some experts are convinced the effects will be positive and an equal number are convinced they will be catastrophic. What is clear is that the future will feature synbio in many forms. One of synthetic biology's pioneers, George Church, has written glowingly of the promises this new technology will bring, including improving human and animal health, extending the human life span, increasing intelligence, and resurrecting extinct animals, even hominids (Church and Regis 2012).

Inevitably, synthetic biology will proceed in developing new products based on new or modified organisms, despite the frequent calls for more oversight and the desire by some governments to establish regulations specific to this field (AAAS 2012). Institutions to put such restrictions in place simply do not currently exist, so the strong sense by many synthetic biologists of the imperative to create open-source architecture has led to strong calls for self-policing by practitioners. Finally, synthetic biology will not be stopped: investments in the field are huge, the potential applications are numerous, and the technology is accessible to too many.

Conservationists may choose to ignore synthetic biology, but they do so at their own risk and the risk of the natural biodiversity they are devoted to conserving. Synthetic biology is a fact and, because it is being pursued throughout the globe by governments, industries, academics, and individuals, it will be with us for a long time. But given the early stages of its development, this is a key time for the conservation community to engage and try to influence the practice and outcomes.

This scenario creates an opportunity for the National Park Service to begin to engage with the synbio community and the public about the issues raised by synthetic biology. To achieve this engagement, at a minimum the National Park Service needs to understand what is happening in the field of synthetic biology and begin to educate its key constituencies. Better still would be engagement with the synbio community to influence the development of the industry in ways that are at least benign to conservation efforts and at best beneficial to protecting national park resources and values. Perhaps there are intractable—wicked—problems that are facing the National Park Service that could be addressed with synbio solutions. Or the Park Service could consider undergoing a scenario planning exercise related to synthetic biology as it has been doing with climate change.

A sea change?

Despite local successes, conservationists have not been succeeding at their objective of conserving greater biodiversity (Butchart et al. 2010). Numerous measures have been applied to quantify this lack of success, and a general air of despair has settled over the field. The conservation community has been quick to adopt new technologies, including camera trapping or monitoring of wildlife, GPS collars, and environmental DNA capture and analysis. But by and large the community is disinclined to adopt new technologies, saying as one person said to me: "Technology is responsible for getting us into the mess in which we find ourselves. You are crazy to think that technology will do anything but make the situation worse." In the last few years strong voices have demanded a new approach to conservation (e.g., Kareiva and Marvier 2012). But these voices have not talked about truly extraordinary changes—ones like careful and discriminating inclusion of synthetic biology approaches in our conservation toolbox such as discussed above.

The future world will not be a slightly older version of the one we currently inhabit. Rather it will have a significantly altered climate, changed sea levels, novel pests and diseases, nonanalogue ecological communities, and a human population with less interest in conservation. The costs, benefits, and risks of synthetic biology need to be considered against this backdrop, not against a projected version of the world as we now understand it.

Much of conservation is predicated on the core ideals of wilderness and nature. However, recognition of the increasing role humans play in structuring ecosystems and thereby shaping the lives of wild species has led practitioners to realize that human management may be a paradoxical but necessary part of conserving the wild. Synthetic biologists propose to further equip humans to actively and consciously engineer the living world. Aldo Leopold famously said, "To keep every cog and wheel is the first precaution of intelligent tinkering." But what if we could make new cogs and new wheels? What would this mean for our attempts to mend centuries of nonintelligent destruction? The transformed world of 2050 will demand new strategies and new approaches in conservation. Should some of them involve creation of new pieces? Synthetic biology can be incorporated into these as a powerful new tool to face the powerful new challenges facing conservation. It is time to consider such extraordinary measures.

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Synthetic biology and NPS policy

Management application of synthetic biology, whether at the cell, organism, population, or ecosystem level, constitutes human intervention, intervention that at the outset is contrary to policy for most management programs for natural zones of National Park System units. Synthetic biology may be within policy for addressing some problems in cultural zones of parks. Given the growing intensity and rate of change to park biota and ecosystems because of climate change, landscape fragmentation, exotic species, and other factors, park managers may find that application of synthetic biology elements may be an appropriate intervention for solving environmental problems. For example, parks already are using exotic species as biocontrol agents to reduce impacts of other exotic species, and some parks are considering use of cross-species breeding or genetic engineering to help develop blight-resistant chestnut trees to permit restoration to the eastern deciduous forest of the presence and function of the chestnut. In the future, park managers may need to consider whether to construct, or accept the unmanaged development of, novel biological communities to facilitate conservation of rare species at risk of extinction from change-forcing factors. These types of decisions will require determinations of which policy components take precedence over others to facilitate achieving desired park conditions, while recognizing that desired park conditions will constitute the best approximation of what would have been natural in the absence of the human-caused forcing factors.

—John G. Dennis, Deputy Chief Scientist, NPS Natural Resource Stewardship and Science

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About the author

Kent H. Redford *is principal of Archipelago Consulting, located in Portland, Maine. He was previously at the Wildlife Conservation Society headquartered in New York, where he was chief scientist. He has worked with the National Park Service on ecological restoration of bison, migratory species, and most recently on a threatened and endangered species workshop. He can be reached at redfordkh@gmail.com.*

PS

The Bioblitz

Engaging citizens on a large scale in biodiversity discovery

By Sally Plumb

THE NATIONAL PARK SERVICE (NPS) is charged with protecting the biodiversity of its lands and waters, yet the majority of species remain undiscovered, including invertebrates, nonvascular plants, fungi, and microorganisms. This lack of knowledge hampers the protection of living resources from threats such as invasive species, disease, population pressure, and climate change. Indeed, changes induced by these environmental factors will likely appear in the lesser-known animal groups before they are reflected in large, iconic ones.

In an effort to identify life in parks, the National Park Service introduced "Biodiversity Discovery," an initiative that fosters development of activities and events in which members of the public, including professional scientists, park visitors, students, seniors, and children, participate in the discovery of living natural resources.

NPS PHOTO

National Geographic Society's John Francis receives the Ranger Hat Award from National Park Service Director Jon Jarvis at the NPS-NGS BioBlitz at Golden Gate National Recreation Area, March 2014. The award was given in appreciation of National Geographic's long-term and multifaceted collaboration with and support of the National Park Service.

The National Park Service has been engaging in biodiversity discovery since 1996, when a bioblitz was held at Kenilworth Park and Aquatic Gardens in Washington, D.C. The first large-scale biodiversity discovery program, an All-Taxa Biodiversity Inventory, began in Great Smoky Mountains National Park in 1997 through the coordinated efforts of the park and its nonprofit partner, Discover Life in America. Since then, many parks—large, small, urban, wild, naturally or culturally oriented—have initiated their own biodiversity discovery activities. As of 2014, approximately 118 parks have conducted work of varying levels and scopes.

As discussed in depth in the article beginning on page 106, preliminary evaluations of the visitor experience in the large-scale NPS–National Geographic Society BioBlitzes, conducted through a cooperative agreement with Texas A&M University, reveal numerous favorable results:

- Improvement in the quality of the visitor experience through development of direct connections to park resources
- An increase in public awareness and sense of stewardship in park visitors through their engagement in firsthand scientific research
- Increased relevancy and awareness of parks among the nation's youth
- Public education about lesser-known species through educational products, services, and interaction with NPS staff

Host parks of biodiversity discovery events enumerate additional scientific and management benefits:

- More knowledge of species in national parks across the country, allowing for more informed management decisions
- Establishment of baseline knowledge of lesser-known flora and fauna against which changes can be measured
- Increased collaboration with scientists and universities that continues long after the biodiversity discovery effort has concluded
- Establishment of numerous fruitful collaborations with notable partners, such as the E. O. Wilson Biodiversity Foundation, National Park Foundation, Discover Life in America, Encyclopedia of Life, and National Geographic Society

The benefits of biodiversity discovery are so apparent that when the National Park Service announced a Call to Action in 2011, item 7, "Next Generation Stewards," envisioned the creation of a new generation of citizen scientists by conducting biodiversity discovery activities of varying levels and scopes in at least 100 parks by 2016. These activities have a proven track record of contributing to the NPS mission of resource stewardship and the Secretary of the Interior's Youth and Diversity

Initiatives. Also, they mirror the vision of the America's Great Outdoors, Healthy People Healthy Parks, Let's Move, and STEM (science, technology, engineering, and math) initiatives. Moreover, they improve the quality of the visitor experience through development of a direct connection to the resources of the national parks, conserving and restoring our natural resources, working together for the good of our national parks, and encouraging involvement of the American public.

Collaboration with the National Geographic Society

The contributions of biodiversity discovery, in terms of scientific gain and public engagement, are essential to the caretaking mission of the National Park Service; hence the Park Service is taking steps to institutionalize these activities and concepts. Measures include partnering with multiple entities to initiate, plan, and execute start-up bioblitzes; mentoring park staff to host subsequent bioblitzes; engaging diverse audiences that include retired scientists, children, volunteers, subject-matter experts, and park visitors in species discovery and identification; and evaluating the experiences of participants in the NPS–National Geographic Society (NGS) BioBlitzes.

The work of the National Geographic Society and its commitment to stewardship of the natural world have served as an exemplary model for collaboration with the National Park Service. John Francis, NGS vice president for Research, Conservation, and Exploration, has been instrumental in initiating and implementing this long-term partnership between the two organizations.

The National Geographic Society has worked tirelessly with the National Park Service to promote the relevance of the outdoors and to educate people about the national parks and their resources. In a couple of years the National Park Service will celebrate its 100th anniversary, with a focus on sustaining our natural treasures in an era that is much different from the one in which the Park Service began. Much is at stake, with perhaps no issue as pressing as the increasing alienation of Americans from the natural world. The partnership with the National Geographic Society has helped to address this challenge by bringing the youth of America into the national parks through collaborative annual "biodiscovery" events.

Each year in the decade leading up to the NPS centennial in 2016, the National Park Service and the National Geographic Society conduct a large-scale "BioBlitz" in a different national park. Goals for these events include accomplishment of a safe and scientifically credible investigation through the combined efforts of scientists, students, and community members; relationship-building with the scientific community; connection of science to technology; enhancement of the relevancy of national parks for participants, especially youth; and increased knowledge of park species.

These two-day events take as much as a year to prepare and plan. Park planning teams are interdivisional and include natural resources, interpretation, public affairs, information technology, safety, law enforcement, and maintenance staff. A dedicated planning team from the National Geographic Society, along with assistance from NPS Natural Resource Science and Stewardship Directorate staff, is also required. The NPS-NGS BioBlitzes are high-profile, well publicized, and thoroughly planned, with attendance by internationally known scientists, entertainers, and speakers; dignitaries from international parks; representation from the highest level of the National Park Service; and coverage by local and national media. Major components are:

- Hundreds of scientific inventories
- Curriculum-based resource education programs
- A biodiversity festival with booths, interactive demonstrations, hands-on activities, entertainment, and speakers
- Increased use of social media
- Involvement of multiple partners
- Selection of a Biodiversity Youth Ambassador (see article on page 17), who represents other youth attending the bioblitz and subsequently continues to foster biodiversity awareness in his or her home community and increase youth engagement in national parks.

Executing a biodiversity discovery effort on this scale is a challenge: logistics are complex, monetary investment is considerable, and safety to humans and to the host park's resources must be ensured. Benefits include obtaining a nearly instantaneous and widespread "snapshot" of species diversity across all taxonomic groups; broad awareness of the host park in surrounding communities; many lasting relationships with scientists, universities, and other partners; and connections with thousands of residents in gateway communities.

Species new to science and to the parks have been discovered during the course of these events and thousands of citizen scientists have participated.

- The 2014 bioblitz at Golden Gate National Recreation Area in California not only opened the door to 9,000 participants, including thousands of youth from diverse and underserved communities, but also revealed 2,700 species.

- The 2013 bioblitz celebrated “bayou” diversity at Jean Lafitte National Historical Park and Preserve in Louisiana.

- The 2012 bioblitz reached new heights at Rocky Mountain National Park in Colorado.

- The 2011 bioblitz was held in Saguaro National Park, with more than 5,000 people combing the eastern and western sides of the park flanking Tucson, Arizona. (See the following article for further information.)

- In 2010, Biscayne National Park, near Miami, Florida, was the first-ever marine bioblitz.

- Volunteers at the 2009 Indiana Dunes National Lakeshore bioblitz turned up more than 1,200 species.

- Six thousand participants discovered more than 1,200 species in the 2008 Santa Monica Mountains National Recreation Area bioblitz in California.

- This series of exciting and innovative bioblitzes began in 2007 at Washington, D.C.’s Rock Creek Park. It engaged 1,000 participants and resulted in the discovery of more than 650 species.

Through this partnership with the National Geographic Society, the National Park Service is increasing the availability of science-based information for making NPS management decisions. Additionally, both organizations are showcasing these national collaborative efforts to discover and conserve natural resources by sharing findings through outreach publications and on interpretive Web pages, and through outreach via different media outlets. With imitation being the truest form of flattery, the NPS-NGS BioBlitzes have served as a model for similar efforts around the world, most notably in Italy, which accomplished its third bioblitz in July 2014. The National Geographic Society continues to be an outstanding partner, visionary, and steward of national park natural resources. Planning has commenced for the 2015 NPS-NGS BioBlitz, taking place 15–16 May at Hawaii Volcanoes National Park, and discussions are under way to determine the location of the 2016 event.

About the author

Sally Plumb *is the NPS biodiversity coordinator and is with the Biological Resource Management Division in Fort Collins, Colorado. She can be reached at sally_plumb@nps.gov.*

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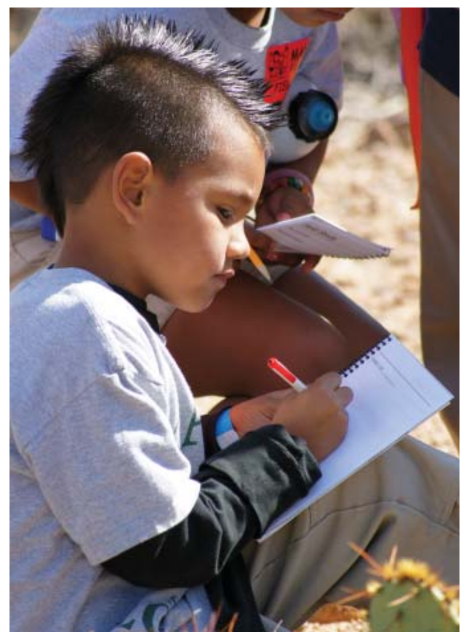

NATIONAL GEOGRAPHIC SOCIETY

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AUDREY KANECOA-MADRID

Saguaro National Park 2011 NPS-NGS BioBlitz!

By Natasha Kline and Don Swann

SAGUARO NATIONAL PARK was an ideal place to host the National Park Service (NPS)–National Geographic Society (NGS) BioBlitz in 2011—not only because of the park's proximity to the rapidly growing city of Tucson, Arizona, but also because of its remarkable biodiversity and legacy of scientific research.

While the park's western Tucson Mountain District highlights the colorful flora of the lower Sonoran Desert, the eastern Rincon Mountain District rises up from the desert, through grassland and woodland, to conifer forests at over 8,600 feet (2,620 m) in elevation. Saguaro's location within the "Sky Island" region of southeastern Arizona, where elements of Mexico's Sierra Madre Occidental and the Rocky Mountains mix with those of the Chihuahuan and Sonoran deserts, creates a stunning landscape of biodiversity. The two disjunct districts of the park lie on opposite sides of Tucson, a diverse southwestern city with nearly one million residents, about 40% Hispanic and 40% under 18 years of age.

Our goals

Despite the park's proximity to Tucson, many local residents have never visited. Conversely, biologists have long recognized the park's distinct and diverse biota, so we already had extensive knowledge of its vertebrates and vascular plants. Thus, our goal was to bring scientists and Tucsonans, particularly those who had never been to the park, together to inventory nonvascular plants, invertebrates, and other little-known "microbiota." We were also determined that the bioblitz would not be a flash in the pan—that is, that the programs and data collected would be followed up on so that this huge effort would create long-term benefits for the park.

How we did it

Saguaro's 2011 bioblitz was all about partnerships. We built on existing ties, especially with the Friends of Saguaro National Park, University of Arizona, and Arizona Sonora Desert Museum, and created many new ones. More than 300 volunteers and literally dozens of groups helped with everything from setting up booths at Base Camp to leading field trips.

The major planning issue for our park, which does not have any road-accessible, large gathering places, was finding appropriate sites for the events and arranging transportation to them. So we created many small events and organized a complex shuttle system to move people from off-site parking to Base Camp and to field sites. Getting schoolchildren safely into the backcountry added logistical complexity that included mule packing and on-site emergency medical technicians. For safety reasons we decided not to conduct the event in summer—when biodiversity is highest but temperatures are scorching—and chose October instead.

Highlights

The 2011 bioblitz was a huge and successful event in terms of outreach and science.

- More than 5,000 participants, including more than 200 scientists and 2,100 schoolchildren, searched the park

(Facing page, clockwise from top. All photos are of the NPS–National Geographic Society BioBlitz in Saguaro National Park, 2011.)

A student shows off the common side-blotched lizard (*Uta stansburiana*) that she added to the count, which totaled more than 40 species of reptiles and amphibians. Inventories were overseen by scientists and all vertebrates captured were quickly photographed and released in place.

A schoolboy takes notes on his field observations. School groups were outfitted with hats, T-shirts, water bottles, and field notebooks provided generously by the Friends of Saguaro National Park.

Schoolchildren from Tucson's Manzo Elementary School display flags they created depicting Sonoran Desert plant and animal species in front of the main stage at Base Camp. Before the bioblitz, the park solicited such flags from the public, including the species' scientific name (in Latin) and common name in English, Spanish, and the language spoken by Tohono O'odham, one of the local Native American tribes.

Some high school students chose to hike the 9-mile, 5,000-foot (1,524 m) climb into the cool pines of the Rincon Mountain Wilderness, where they camped overnight and inventoried birds, mammals, and invertebrates. Here they take a break on Mica Mountain (8,613 feet [2,625 m] in elevation) to spell out "bioblitz" with their bodies.

Students sample aquatic invertebrates from spring-fed bedrock pools, or tinajas, in the park's backcountry. Prior to the 2011 bioblitz the park did not have a formal invertebrate collection. More than 325 species have been documented to date, and the number continues to rise as specimens that are more difficult to identify are cataloged.

for life-forms. Students collected and identified lichens and insects; set up remote wildlife cameras; resurveyed a saguaro study plot established in 1941; and camped in the Rincon Mountains, where they studied butterflies, bryophytes, and birds.

- In the spirit of documenting biodiversity in both districts of the park and in the city of Tucson in between, Dr. J. Michael Fay of the National Geographic Society conducted a "Mini-Transect." He began on the east side of the Rincon Mountains and, accompanied by a succession of park rangers and local biologists, documented every plant species he encountered while traversing the Rincons, crossing Tucson, and hiking into Base Camp, where he kicked off the 2011 bioblitz.

- In the Science Tent, visitors used microscopes to examine local microbiota and discovered life-forms they had previously never heard of, including endophytes (bacteria or fungi that live within vascular plants) and tardigrades. Tardigrades, also called water bears or moss piglets, are microscopic moss-dwelling creatures that constitute their own phylum; they are practically indestructible and surprisingly charming. Scientists discovered new species, too. Several bryophytes (mosses and liverworts) and endophytic fungi documented were new to the park, and some even new to science!

- Citizen scientists took their own photos and posted them on designated Web sites, such as Project Noah (https://www.projectnoah.org/missions/6986014), where they could be tallied.

- When the original count of 859 identified species was revealed on the afternoon of 22 October 2011, we knew it was just the beginning. Scientists continue to identify specimens, and the latest number has grown to 1,106—and we are still counting.

- Not only was the bioblitz about science, it was a celebration of biodiversity and Saguaro National Park that included art exhibits, video production, dance, and a published poetry project.

What we learned

Our goals of getting people into the field and expanding our knowledge of the park's microbiota were met beyond our wildest expectations. Thousands of visitors explored the park in a meaningful, hands-on way and many new species were documented.

As the involvement with our partners deepened, the bioblitz developed a life of its own. Most park staff were too busy to take in more than a sliver of this enormous event. Since then, we have continued to be amazed by new discoveries and experiences from those two days—including new photos, videos, poetry, and art—that teach us and our visitors things about our park that we never knew before.

About the authors

Natasha Kline *(natasha_kline@nps.gov) and* ***Don Swann*** *(don_swann@nps.gov) are both biologists at Saguaro National Park in Tucson, Arizona.*

For more information

Further information on the 2011 bioblitz and the count updates are available on the Saguaro National Park Web site at www.nps.gov/sagu. Here you can also find links to the list of species found; resources and links that participating scientists post about their research; NGS's FieldScope, an online mapping program with observations, photos, and metadata collected during bioblitzes; the National Park Foundation's Electronic Field Trip, a live broadcast for schoolchildren that has reached tens of thousands of kids throughout the United States; photos posted to Flickr and ProjectNoah; a link to published poetry at http://www.spiralorb.net/archives; and media coverage following the bioblitz.

The bioblitz: Good science, good outreach, good fun

By Gretchen M. Baker, Nancy Duncan, Ted Gostomski, Margaret A. Horner, and David Manski

Part contest, part festival, part educational event, and part scientific endeavor, bioblitzes bring together naturalists, professional scientists, and the interested public, who canvass the area over a 24-hour period to find and document all plants and animals.

"WOW! LOOK AT THAT! I never knew that!" The exclamations were coming from a man who, with a small group of people, was participating in a guided bird walk during a bioblitz at a small public park on Lake Superior in northern Wisconsin. The group was walking the road along a stand of red and white pines when a noisy flock of crows drew their attention to the top of one tree in particular.

"Watch that tree," the group leader told them. "Crows make this sort of ruckus when they are mobbing a predator and trying to drive it out of the area. Maybe it will be an owl."

It was June, early afternoon, and the sun was high. The small group watched the tree, occasionally using binoculars to scan the branches. Suddenly, an oblong form took flight from a branch near the top of the tree—a great horned owl (*Bubo virginianus*)—and the crows followed close behind it. The group leader was thrilled to add the owl to the list, and the man was thrilled to learn a little about bird behavior and a trick to finding secretive birds like owls in the middle of the day.

Similarly exciting discoveries are made commonly at any bioblitz. All observations like this are good for science and for the parks where bioblitzes are held, but they are most often exciting because the people making them are citizen scientists spending a day in their local national park and contributing to managers' scientific knowledge of park resources. Some participants may have never been in the park before, and most may have never had an opportunity to spend a day in the field with professional naturalists and to make close personal contact with plants and animals.

What is a bioblitz?

The term "bioblitz" was coined in 1996 by a National Park Service (NPS) employee organizing the first such event at Kenilworth Park and Aquatic Gardens in Washington, D.C. More than half of the 90 participating scientists—who came from federal agencies, the Smithsonian Institution, and area universities—had never been to Kenilworth (Cohn 1996; Droege 1996). Since that first effort, the concept has been used all over the world as a means of gathering and sharing information about plants and animals in parks and other natural areas.

Why host a bioblitz? Park managers may seek to document the presence of rare or understudied taxa, while others may want to establish a baseline of information for a particular piece of land. Some may simply want to introduce people to their local national park. The goals of the event will dictate how it is focused and organized. The searching can be done by professionals, by local volunteers with good naturalist backgrounds, or by a combination of the knowledgeable and the interested. In most cases, a bioblitz is conducted over a 24-hour period, so participants are out in the early morning to inventory songbirds, during the day to catch butterflies and fish and to collect plant specimens, and at night to trap moths or bats or to listen for owls. Because the event is held on a single day, it is not possible to find and document everything, but a bioblitz does give park managers a quick assessment of the plants and animals found in a given area. Plus, it gives participants an opportunity to spend a day outdoors, sharing time with family, friends, or like-minded enthusiasts.

Perhaps the most well-known national park bioblitz is the ongoing All-Taxa Biodiversity Inventory (ATBI) at Great Smoky Mountains (DLiA 2013). The ATBI is a different kind of bioblitz because it is not limited to one day and it has a stated goal of discovering all forms of life in the park. Other well-known bioblitzes are those organized by the National Geographic Society in a different national park each year during the decade leading up to the NPS centennial in 2016 (www

.nationalgeographic.com/explorers/projects/bioblitz/).

We present here examples of bioblitzes from three different parks. Acadia and Great Basin National Parks (in Maine and Nevada, respectively) have conducted 18 bioblitzes between them, each focused on a specific group of organisms. Mississippi National River and Recreation Area (Minnesota) has conducted three bioblitzes, focusing on discrete locations along the riverway. All have used professional scientists to varying degrees, but Acadia is the only one specifically to focus participant recruitment on professionals while allowing casual public participation. All have the purpose of learning more about the park and the life within it.

Acadia National Park bioblitz program

Acadia has conducted annual bioblitzes since 2003, focusing primarily on insects and spiders, but adding mushrooms, algae, and diatoms in some years (table 1). Most events have occurred over one weekend in the summer at the Schoodic Education and Research Center (SERC). Collecting is generally limited to a 24-hour period, with sorting, pinning, and identifying specimens taking the rest of the weekend—and sometimes longer.

Table 1. Focal taxa for the annual bioblitz at Acadia National Park, 2003–2014

Year	Taxon (Taxa)
2003	Ants
2004	Butterflies and moths
2005	Beetles
2006	Flies
2007	Spiders
2008	True bugs
2009	Minor orders of insects, mushrooms
2010	Bees, wasps, ants
2011	Butterflies and moths
2012	Aquatic insects, algae
2013	Beetles and diatoms
2014	Beetles

Event participation is intentionally kept low to ensure financial and operational sustainability. Participants are recruited primarily through the Maine Entomological Society, which also assists with marketing and general oversight of the event. The Maine Forest Service, University of Maine, and University of New Hampshire have also made in-kind contributions of staff time (entomologists) and equipment. The algae and diatom events coincided with professional scientific meetings at which conference participants were given a park research and collecting permit.

Participants are housed and fed at the SERC by the Schoodic Institute, the National Park Service's nonprofit partner that manages and runs programs on campus. Lead taxonomists (usually one or two for each event) are given an honorarium of up to $1,000 for their oversight of the event, teaching participants about the target taxa, completing a summary bioblitz report, identifying specimens, and returning pinned and labeled voucher specimens that are incorporated into the park's museum collection.

Participation by the public is not actively solicited, but no one with a keen interest is turned away. A separate two-hour public education session runs during each bioblitz. Participants learn about the taxa being studied and then are allowed to assist in making collections. Public participants can also watch the bioblitz lab in operation as specimens are identified and cataloged, then meet the scientists involved in the event. Annual attendance varies from 35 to 110, with an average participant return rate of 75%.

Through 2011, collecting was geographically limited to the Schoodic District of the park, which lies approximately 5 miles (8 km) east of Mount Desert Island. In 2012 the main portion of Acadia—Mount Desert Island—was added. Sites that cover the full diversity of habitats within the park are targeted, but participants are also allowed to sample in other areas they choose.

NPS PHOTO/DIANA HUNT

David Manski, former chief of Resource Management at Acadia National Park, watches as a bioblitz volunteer catches moths at a light trap set out during the 2011 Acadia Bioblitz.

All incoming specimens from a single collection event are assigned a "lot" number that is linked to the date, time, location, and method of capture. Lot numbers are unique and not reused in subsequent years. They are handwritten on preprinted labels as the samples are processed so that mounting and labeling can proceed quickly and the collection information can be tracked as identifications are made.

Collection locations are assigned GPS coordinates in the field, or when the specimens are brought in for processing and given their lot number. This information is recorded in a database along with the habitat and host plants where the specimens were taken, the name of the collector, and any pertinent descriptions of the collecting technique. All specimens are then sorted, and at least one representative of each morphospecies (a species established solely on the basis of morphological characteristics) is pinned or placed in an alcohol vial as appropriate with locality labels. Many bioblitz participants assist in sorting and pinning specimens at the SERC laboratory. Experienced entomologists identify the specimens to species or morphospecies, but the lead taxonomist is responsible for proofing and accepting any identifications made by others.

A practical goal is to sort and identify as many specimens as possible on-site during the event when the greatest number of participants can contribute at their relative levels of expertise. However, not all specimens can be identified in this time period. In those cases the lead taxonomist takes the unidentified specimens back to his or her host institution for follow-up work or distribution to other specialists for final identification. For some families or genera there are no specialists available to identify the specimens to the species level, or in some cases even to the genus level. Specimen identifications are entered in the database at the finest level possible, and labeled representative vouchers of all collected species are held at Acadia's Charles Sawtelle Museum. More than 1,600 voucher specimens have been cataloged into Acadia's museum collection.

The bioblitzes have yielded a great deal of information about some otherwise poorly understood biota, including many range extensions and more than 500 new park species records; more than 100 species records are new to the state of Maine. The University of Maine Agricultural and Forest Experiment Station has published a major technical report on the first nine years of bioblitz data (Chandler et al. 2011). There is a lot of regional interest, support, and encouragement for the bioblitz program—everyone wants it to continue—and there is now a cadre of individuals who are enthusiastic about the National Park Service and Acadia.

Wild in the city: Minnesota bioblitz events at Mississippi National River and Recreation Area

One challenge for resource-rich national parks located in urban environments is that they are often overlooked because of the hustle and shine of the cities around them. If managers can make a park experience part of city life, they can open doors for a set of visitors who may not have any other opportunity to catch a glimpse of the natural world around them. Mississippi National River and Recreation Area is one such park.

Mississippi National River and Recreation Area was established in 1988 to recognize and protect the history, industry, and natural resources within and along a 72-mile (116 km) stretch of "working river" that bisects downtown Minneapolis and St. Paul, Minnesota, home to more than 667,000 people. It is also distinct in that it connects a series of city, county, and state parks, which make up most of the landbase of this national park unit.

One way park managers are introducing city residents to their local national park is by working with partners and major sponsors—including the Bell Museum of Natural History (University of Minnesota) and the nonprofit Mississippi River Fund—to hold bioblitzes in different sections of the riverway. This collaboration leads to savings in staff time and expense, while building stronger partnerships. Part contest, part festival, part educational event, and part scientific endeavor, bioblitzes bring together naturalists, professional scientists, and the interested public, who canvass the area over a 24-hour period to find and document all plants and animals.

Rather than roaming all 72 miles of the riverway in search of a particular group of organisms, Mississippi River bioblitzes focus on a particular location. That is how the Bell Museum was doing the bioblitzes before the National Park Service became involved, so the park simply adopted their procedures. In addition, intensive surveys at a single location provide more comprehensive information about species presence and abundance at that place.

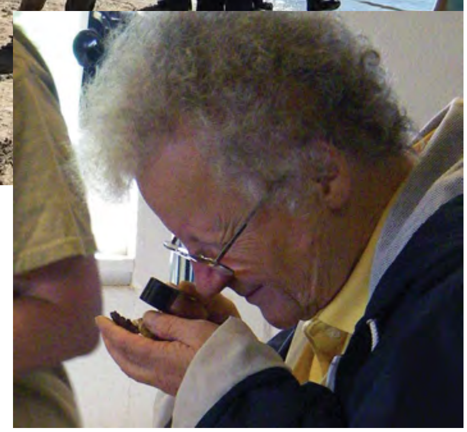
The first bioblitz was held in June 2009 at Crosby Farm Regional Park, the largest natural area (763 acres, or 309 ha) in St. Paul's city park system. More than 100 citizen volunteers and professional scientists participated, along with numerous people who happened to be in the park and stopped by to see what was happening. The survey covered floodplain forest; steep, wooded slopes cloaked mostly in oak forest; and a scattering of wetlands and small lakes. The small lakes serve as nurseries for young fish and other aquatic organisms that move into the main river during floods that connect the two water bodies.

Volunteers tallied 563 species of flora and fauna (table 2), including two species of endangered mollusks (the wartyback, *Quadrula nodulata*, and rock pocketbook, *Arcidens confragosus*); numerous fox snakes (*Elaphe vulpina*), possibly indicating that the area supports a breeding population; and river otters (*Lontra canadensis*), which had been absent from the riverway for some time. A parkwide survey the following year found otters throughout the park's portion of the river, so a long-term research project was initiated to gather basic natural history information. Currently, park and U.S. Geological Survey biologists are working to identify genetic markers they can use to determine the size of the otter population and its genetic diversity within the upper Mississippi River corridor.

The 2011 bioblitz was held at the Katharine Ordway Field Station, owned by Macalester College. Here, volunteers combed through tallgrass prairie; sand gravel prairie; oak savanna and woodland; riparian forests; seasonal and permanent ponds, seeps, and springs; and a backwater lake adjacent to the Mississippi River. Despite intermittent drizzle, this event garnered 611 species at final count.

In 2013 the bioblitz moved to the 92-acre (37 ha) Coldwater Spring site. The National Park Service acquired 29 of those acres in 2010 from the U.S. Bureau of Mines, and in the two years leading up to the bioblitz, a dozen abandoned buildings were demolished and park staff began

NPS PHOTO/TED GOSTOMSKI



NPS PHOTO/TED GOSTOMSKI

(Above) Visitors, park staff, scientists, and volunteers mingle near a temporary aquarium filled with fish collected from the Mississippi River during the 2009 Minnesota bioblitz at Crosby Farm Regional Park in St. Paul, Minnesota. (Right) University of Minnesota entomologist Anna Gerenday uses a hand lens to identify a mushroom species at the 2011 Minnesota bioblitz at the Ordway Field Station.

Table 2. Species counts for select taxa at three bioblitz events along the Mississippi National River and Recreation Area, Minnesota, 2009, 2011, and 2013

Site (acres/hectares)	Taxa										Total Number of Species
	Mammals	Birds	Reptiles	Amphibians	Insects	Plants	Fungi	Fish	Mollusks	Invertebrates (spiders)	
Crosby Farm Regional Park (763/309)	14	80	5	4	~110	241	57	33	19	n.d.	563
Ordway Field Station (300/121)	7	53	5	5	208	192	78	30	4	29	611
Coldwater Spring (92/37)	7	53	3	2	168	217	83	20	n.d.	5 (16)	574

Note: n.d. indicates no data.

restoring the upland area to a mix of oak savanna, wetlands, and prairie.

One hundred volunteers ranging in age from 2 to 90 and with a wide variety of skills and experience assisted bioblitz scientists in documenting the presence of 574 species. Parents commented on how much their kids enjoyed collecting bugs and mammals and seeing the fish that were brought from the river. Even a late-night owl walk was a big hit among casual participants, despite a lack of calling owls. People enjoyed simply being out at night, in the park, savoring the knowledge that these mysterious birds were out there in the dark, even in the city.

Information acquired during the bioblitzes is helping park resource managers in numerous ways. First, there is increasing awareness of what biota are found within the riverway. Several species observed during the 2009 bioblitz were new to the park. That information has led to follow-up studies focusing on fungi, insects, and frogs. Second, the 2013 bioblitz at Coldwater Spring provided excellent baseline data for the property in its first year since site restoration had begun. Park staff plan to hold a bioblitz there every five years to document change in species composition and numbers as restoration of the area continues and plantings mature.

Sampling understudied taxa in Great Basin National Park

What species occur in Great Basin National Park? For many taxa, including plants, mammals, birds, reptiles, and fish, this question has been answered through targeted sampling and data collection since the park's establishment in 1986. However, data on invertebrates—an abundant but understudied taxon—have been incomplete or absent. To help fill this knowledge gap, the park decided to use the bioblitz approach to sample, identify, and catalog invertebrates in the park.

Because of Great Basin's relatively small size (77,000 acres or 31,161 hectares) and remote location (286 miles, or 460 km northeast of Las Vegas), there is a limited pool of subject-matter experts and volunteers interested enough to come to the park and assist with plant and animal surveys. Furthermore, because many areas in the park are difficult to access, a bioblitz focused on different park units or regions was not an option. Therefore, to maximize participation and efficiency, Great Basin staff, as at Acadia, chose to focus their bioblitzes on one order or class of organisms per year.

Park staff were introduced to the bioblitz concept during a program session at the 2009 George Wright Society Conference on Park and Protected Area Management in Portland, Oregon. After returning home, the park established a partnership with Southern Utah University to assist with the first bioblitz at Great Basin.

The primary objectives of the Great Basin bioblitzes are as follows:

- Conduct inventories for taxa not included in the National Park Service Inventory and Monitoring Program
- Determine which invertebrate species are present in the park
- Expand the number of species known to occur in the park
- Collaborate with subject-matter experts from various agencies and universities to strengthen park partnerships
- Engage citizen scientists to help develop park stewards
- Share results to initiate additional studies in the park
- Establish an invertebrate reference collection for park staff and visiting researchers

The park does not have a prioritized list of invertebrates to determine the focal group each year. Instead, the availability of a lead taxonomist helps the park decide how to focus the event. This lead taxonomist is responsible for leading a workshop, demonstrating sampling techniques, identifying specimens to the family level during the event, and providing the expertise, staff, and lab capacity to identify the specimens to the finest taxonomic level by the following year.

The park has now hosted six annual bioblitzes, with a budget ranging from $500 to $7,500 (table 3). The budget covers a stipend for the principal taxonomist, supplies, and salaries of seasonal employees whose time is dedicated to the event. The park was fortunate to have one bioblitz participant, Dr. Ken Kingsley, volunteer to serve as the first taxonomist-in-the-park. Dr. Kingsley spent one week each month during summer 2012 collecting, organizing, and curating the growing invertebrate collection. The Nevada State Entomologist's office has also been an indispensable partner, bringing additional collecting equipment, microscopes, and knowledgeable staff to make each event run smoothly.

Great Basin National Park is generally undersampled for most invertebrate orders, and the bioblitzes provide an opportunity for scientists to apply their knowledge in a beautiful setting where the results will be used. The gathering of scientists at a bioblitz also serves to train graduate students, meet colleagues in the same or a similar field, and share knowledge with park visitors who are eager to learn.

Students and children are always welcome at bioblitzes and have helped collect and sort specimens. A high school teacher from Colorado brought his summer biology class to the 2011 Hymenoptera bioblitz, and they helped collect many additional specimens. Children, with their lower stature and innate curiosity, have helped their parents and scientists find insects and arachnids that otherwise would probably have been missed. In 2013, Dr. Paula Cushing gave a special presentation about arachnids to children, focusing on *Charlotte's Web*. Children (and adults) could touch a real orb-weaver spider, and some children who had always been afraid of spiders suddenly became their advocates.

A potential new species to science (*Acanthetropis* sp. nov.) was documented during the Hymenoptera bioblitz in 2011, and the Arachnid bioblitz documented two orders (Solfugids and Scorpions) that were new to the park. More than 75 families have been added to the park's taxonomic list along with numerous genera and species, providing a more complete species list for the park. Park staff are looking forward to future bioblitzes, and the focal groups are already identified for 2015 (Ephemeroptera, Plecoptera, and Trichoptera—the aquatic insect orders of mayflies, stoneflies, and caddisflies). The information gained from these bioblitzes fosters a greater awareness of the park's biodiversity among both managers and the public. It can also help drive management decisions about where to focus conservation efforts by elucidating locations where more intense sampling and additional research are needed in order to determine species trends.

The diversity of life in our national parks is phenomenal, and the bioblitz has become a popular way of documenting that life and facilitating personal discoveries of it for the visiting public. If every bioblitz has a person who makes as exciting a discovery as a species new to science or even to the park, or who simply learns how to follow the sound of crows to a hidden owl, then the event is a job well done.

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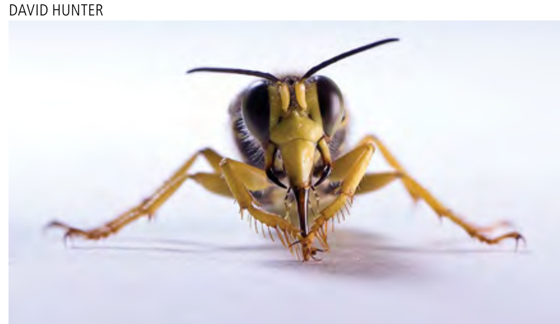
DAVID HUNTER

DAVID HUNTER



(Top) Park Ranger Robb Reinhart points out harvester ants to young participants at the Hymenoptera bioblitz in Great Basin National Park. (Bottom) This wasp was one of 22 species in the Crabronidae family (the most species of any taxa) found during the Great Basin Hymenoptera bioblitz.

Table 3. Summary of bioblitz events held at Great Basin National Park, Nevada, 2009–2015

Year	Order/Class	Common Name	Lead Taxonomist	Participants	Taxa Families Added	Species Added	Notes
2009	Coleoptera	Beetles	Jeff Knight, Nevada State Entomologist	40	9	25+	Organizational support from Southern Utah University
2010	Orthopteroids	Crickets, Grasshoppers, Related	Dr. Andrew Barnum, Dixie State College	25	4	15	Inclement weather
2011	Hymenoptera	Bees, Wasps, Ants	Dr. James Pitts, Utah State University	80	25	100+	First 48-hour event
2012	Diptera	Flies	Dr. Riley Nelson, Brigham Young University	50	15	30+	NPS Biodiversity Coordinator Sally Plumb attends
2013	Arachnids	Spiders, Mites, Ticks, Pseudoscorpions, Solfugids, Scorpions	Dr. Paula Cushing, Denver Museum of Nature and Science	60	>10	30+	Nighttime activities attract significant attendance
2014	Lepidoptera	Butterflies, Moths	Dr. Paul Opler, Colorado State University	60	n/a	200+	New moth species
2015	Ephemeroptera, Plecoptera, Trichoptera	Mayflies, Stoneflies, Caddisflies	To be determined	n/a	n/a	n/a	May/June 2015

BIOBLITZ PROFILES

Ocmulgee National Monument Butterfly Bioblitz

NPS PHOTO

Middle school students pause to photograph a butterfly on the first day of the 2013 Butterfly Bioblitz at Ocmulgee National Monument.

National park
Ocmulgee National Monument, Georgia

Dates
23–24 October 2013

Activity name/type
Butterfly Bioblitz

Methods
Five teams of scientists led groups of community volunteers in the field of this 702-acre (284 ha) park to observe and identify as many species of butterflies as possible over the course of the two-day event. Participants were encouraged to photodocument the butterflies they encountered—no collections were made—and used cameras, binoculars, field guides, and checklists to help make identifications and to record their observations. Students from middle school participated on the first day (see photo), while the general public took part on day two. Participants received a T-shirt, water bottle, and backpack for helping with the event.

Key partners
NPS staff of the Southeast Coast I&M Network, Congaree National Park, and Cumberland Island National Seashore and entomologist Marc Minno, author of *Butterflies Through Binoculars* and *Butterflies of North Carolina, South Carolina, and Georgia*

Participation
480 community volunteers, scientists, and staff

Number of species
40 butterflies and 5 dragonflies

Highlights
Hundreds of photographs of butterflies were submitted to park staff, resulting in identification of 28 species; an additional 12 species were identified by other means. The park set up a children's education area so that the youngest participants could learn about the life cycle of butterflies and get involved in a hands-on crafts program. The event helped raise awareness in the community of the important role butterflies play in park and area ecosystems. The park considered the event a success and has received funding to repeat the activity in August 2014, with hopes of expanding the list of species documented in 2013.

Park contact
Angela Bates (angela_bates@ nps.gov)

George Washington Carver Bioblitz

National park
George Washington Carver National Monument, Missouri

Dates
27–28 September 2013. Similar events are planned for this park on 27 September 2014 and at Buffalo National River on 18 October 2014.

Activity name/type
Bioblitz

Focal taxa/habitats
Aquatic and terrestrial insects, small mammals, water mites

Methods
Staff from the NPS Heartland Inventory and Monitoring Network selected four focus taxa based on understudied groups from previous inventories. Lead scientists selected study protocols with park approval via the NPS Research Permit and Reporting System. Four teams made field collections in various ecosystems using scientific methods. Teams comprised local adult volunteers recruited through public media and university contacts. Team leaders and NPS staff held an orientation meeting to discuss the schedule, methods, data recording, equipment, and safety. Field collections were made from 8 a.m. to noon on Saturday; blacklight traps were set the previous night. Aquatic and terrestrial collections were used for educational purposes Saturday afternoon in the visitor center classroom. Scientists reported taxa count data to the Heartland Network once identifications were complete.

Key partners
Staff from the national monument helped to coordinate the event and provided use of the visitor center, park grounds, and public outreach. Taxonomic team leaders came from Missouri Southern State University, the University of Arkansas, and the NPS Heartland Inventory and Monitoring Network. Team leaders and members volunteered their time.

Participation
Thirty-nine volunteers participated in the event, 4 as leaders and 20 as team members, with an additional 15 visitors participating in the educational program.

Number of species/specimens
More than 1,200 organisms were collected, comprising 141 species, of which 89 were new to the park.

BELOW LEFT: DEREK HENNEN, UNIVERSITY OF ARKANSAS; OTHERS: NPS HEARTLAND NETWORK/HOPE DODD

(Clockwise from top left). Millipede collected in the forest by David Bowles's team. Aquatic invertebrate sample processing at Williams Pond by Kip Heth's team. Small-mammal collecting from prairie by Karen Pulicinski's team. Water mite sample collecting from creeks by Andrea Radwell's team.

Publications
A final report has been published: Hinsey, J. A., and T. M. Johnson. 2014. George Washington Carver National Monument (GWCA) Bioblitz Event–2013. Natural Resource Data Series NPS/HTLN/NRDS–2014/686. National Park Service, Fort Collins, Colorado, USA.

Outcomes
The event was held in conjunction with National Public Lands Day and was well attended by curious visitors, including toddlers and octogenarians. The park considered the event a success in part because it provided an opportunity to involve adults and older students as citizen scientists in the collection of authentic data that will be archived in the NPSpecies database. The park plans to host future bioblitz events based on the favorable outcomes of this initial activity.

Park contacts
Theresa Weiss-Johnson (theresa_weiss-johnson@partner.nps.gov and Jan Hinsey (jan_hinsey@nps.gov)

"PROFILES" CONTINUED FROM PAGE 48

Upper Delaware Bioblitz

National park
Upper Delaware Scenic and Recreational River, Pennsylvania

Dates
28–29 June 2013

Activity name/type
Upper Delaware Bioblitz

Focal taxa
Aquatic macroinvertebrates, birds, fish, fungi, herpetofauna, lichens, mammals, mosses, plants, terrestrial invertebrates

Site
A 64-acre (26 ha) privately owned property mostly in the half-mile-wide wild and scenic river corridor in the northern portion of the park

Methods
Nine taxonomic teams (TWiGs), comprising scientists from the Philadelphia Academy of Natural Sciences, several universities and agencies, students, and volunteers, combed the site to locate and identify taxa, and subsequently to verify certain identifications in the lab. Collection protocols and sampling methods used by each team are described online at http://www.upperdelawarebioblitz.com/science/default.html. The public was invited on Saturday to view the results, talk with team members, and participate in instructive programs (see http://www.upperdelawarebioblitz.com/event/default.html).

Sponsors
Delaware Highlands Conservancy, Delaware Riverkeeper Network, Friends of the Upper Delaware River, Monroe County Conservation District, National Park Service (Natural Resource Stewardship and Science Directorate, Northeast Regional Office, and Washington Office), Norcross Wildlife Foundation (the property owner), Northeast Pennsylvania Audubon Society, Paul and Scott Hunt, Pennsylvania Native Plant Society, Verizon Wireless (for WiFi access), and Wayne County Community Foundation

Key science partners
The Academy of Natural Sciences (Patrick Center for Environmental Research) of Drexel University, Delaware Highlands Mushroom Society, East Stroudsburg University, Pennsylvania Natural Heritage Program, and Western Pennsylvania Conservancy

Participation
About 50 scientists and amateur naturalists helped collect and identify specimens. More than 25 volunteers planned and ran the event. Approximately 250 park visitors attended educational programs to learn about the event and its findings.

Highlights
Five inches of rain fell the night before the bioblitz, hampering the search for snakes and collections at aquatic study sites. The Pennsylvania endangered bridle shiner (*Notropis bifrenatus*) was documented in a new park location. All 27 documented crane flies were new records for Wayne County. (The previous state record for *Cryptolabis paradoxa*, a riverine crane fly, was in 1917.) Among plants, 29 vascular species (11 of them native) and 31 species of bryophytes were new county records. Areas prone to flooding had a higher proportion of nonnative plant species. Twenty species of ground beetles, a group that reflects specific microhabitat associations, were recorded. All mosquito specimens tested negative for West Nile virus. No bats of the genus *Myotis*, hardest hit by white-nose syndrome, were identified. Herpetofauna identifications included salamanders, newts, frogs, toads, turtles, and one snake species. Some duplication occurred among species recorded by the aquatic macroinvertebrate and terrestrial invertebrate teams, suggesting the need for better coordination among these teams in the future.

Table 1. Results of 2013 Upper Delaware Bioblitz

TWiGs	Number of Species
Aquatic macroinvertebrates (aquatic insects, mussels, snails)	67
Birds	57
Bryophytes (mosses, lichens, and worts)	67
Fish	28
Fungi (mushrooms and molds)	51
Herpetofauna (reptiles and amphibians)	16
Mammals	12
Terrestrial invertebrates (insects, worms, snails)	458
Vascular plants	268 (192 native)
Total	1,024

(Background) A mercury vapor lamp and a white sheet attract flying insects at the bioblitz. (Inset, top) Young naturalists at the Upper Delaware Bioblitz learn about fish from Dr. Richard Horwitz of the Academy of Natural Sciences. (Inset, middle) A young participant holds a salamander (*Plethodon glutinosus*) identified during the Upper Delaware Bioblitz. (Inset, bottom) Female crane fly, *Tipula bicornis*.

Publications

A final report is available at http://www.upperdelawarebioblitz.com/science/default.html. An article about the importance of protected habitats to bryophyte diversity was published in the March 2014 issue of *Evansia* (see "A list of bryophytes for Wayne County, Pennsylvania" at doi:10.1639/079.031.0104).

Educational outcomes

More than 1,000 species of plants and animals were documented in 24 hours and have been entered into the NPSpecies database. The event highlighted the diversity of life that enriches the soil, cycles nutrients, purifies water, pollinates plants, and creates air—ecosystem services that benefit and sustain humans and that cannot easily be reengineered. By involving the public in a science-based park management activity, the bioblitz supported the NPS Call to Action strategy 7, "Next Generation Stewards."

Follow-up

The park organized and held a second bioblitz in 2014, this time on the New York side of the river. For further information and to view photos of the event see http://upperdelawarebioblitz.com and https://www.facebook.com/UpperDelawareBioblitz.

Park contact

Don Hamilton (don_hamilton@nps.gov)

The All-Taxa Biodiversity Inventory

Perspectives on the ATBI

By the Editor

THE ALL-TAXA BIODIVERSITY INVENTORY (ATBI) IS A potent, ambitious, and intensive model for the discovery and study of park biodiversity. While it may not be sustainable for all parks, several have embarked on this long-term endeavor that seeks to document all life-forms in a park. Here we present interviews with **Marc Albert**, Stewardship Program director, Boston Harbor Islands National Recreation Area, Massachusetts, and **Todd Witcher**, executive director, Discover Life in America, the nonprofit partner for the ATBI at Great Smoky Mountains National Park, Tennessee and North Carolina, to gain insight into this robust inventory tool. We also share a feature article on pages 58–61 about the ongoing inventory work at George Washington Memorial Parkway to round out our coverage of ATBIs.

AYA ROTHWELL

Marc Albert in transit to the Boston Harbor Islands.

Interview with Marc Albert

***Editor:* What is an All-Taxa Biodiversity Inventory?**

Marc Albert: It's a long-term inventory process, the overall effort given to cataloging biodiversity in a park. It is an ongoing and ultimately never-ending effort that flows directly from the National Park Service mission to understand the resources in a park.

How did the ATBI at Boston Harbor Islands come about and why was it focused on arthropods?

Marc: E. O. Wilson got the idea going around 2000, based on his concept of the "microwilderness." He has been a great champion of popularizing science, and one of his big ideas is that we are all a lot closer to biodiversity than we realize. You don't need to go to Yellowstone to see biodiversity. As an entomologist he had a particular insight into all the diversity that is unnoticed underfoot. He's based at Harvard University, so when the Boston Harbor Islands was in the process of doing our first inventories—geology, soils, vertebrates, vascular plants—he attended an inventory event and challenged the park to expand those inventories to focus on invertebrates. Through his connections with a nonprofit foundation, he facilitated the first donation to support this idea. I think he saw this as an opportunity to stimulate locally what he had been thinking about as one of his broad principles.

How did you organize and run the events over the six-year period?

Marc: Brian Farrell is at the Harvard Museum of Comparative Zoology and was the principal investigator for the insect and terrestrial invertebrate portion of our ATBI. Jessica Rykken was a postdoctoral researcher who served as the project leader. She directly oversaw the collection and identifications, and also facilitated some of the educational and interpretive materials that came out of the program.

What did it accomplish?

Marc: Last year Jessica and Brian published a comprehensive technical report of the "microwilderness" ATBI from 2005 to 2010, and it provides full details.[1] But the highlights are many. Paraphrasing from this report, 40 scientists and 50 students, interns, and volunteers participated, and the latter group contributed 12,000 hours to process nearly 77,000 specimens in the lab. Altogether they identified approximately 2,000 species, including at least 239 nonnatives.[2] Beetles were the most diverse group and millipedes the least. However, a little more than half of the approximately 160,000 specimens collected remain unidentified, and flies and wasps could ultimately exceed the number of beetle species. Fifteen species are thought to be new records for Massachusetts, New England, or North America, including an agricultural pest from Europe, a click beetle. Also, we have discovered European fire ants on the islands and, though they haven't been a problem here, they are a public nuisance elsewhere, so it's good to know. The ATBI also fostered unparalleled opportunities for outreach, including chances for public participation in field and laboratory settings and school programs for thousands of students.

Was there a broader context to the science?

Marc: The investigators wanted to understand if island area and distance from the mainland, as predicted by the theory of island biogeography, would correlate with species richness for these islands, which are so heavily influenced by human disturbance. For six focal taxa they did find that as island size increased, so did species richness. Likewise, as island distance from the mainland increased, species richness declined. Also, as the distance between islands increased, the similarity in the focal taxa communities decreased, but more so for species with limited flight ability. For ecological, economic, and management reasons they also were interested in the proportion and distribution of native species to nonnatives. Compared with a control area on the mainland, the islands had fewer nonnative species but the proportion of nonnatives to natives was higher. Though six nonnative focal beetle families occurred on more islands than did natives, variation in species abundance was too great to draw a conclusion about the proportion. Comparing plants with invertebrates, they found that as island distance from the mainland increases, the proportion of nonnative to native plant species goes up more than it does for invertebrates.

Why did you refer to this as an ATBI when it focused initially on terrestrial arthropods?

Marc: When I got to the park in 2005 this project was called "the ATBI." But as time has passed and as we've had an opportunity to think more broadly, I have stopped thinking about this discrete arthropod project as the ATBI and instead, of course, think of the ATBI as our overall effort to catalog biodiversity in the park. The terrestrial insect and arthropod–targeted effort was a huge piece, but it wasn't the ATBI.

What other taxa have you investigated?

Marc: Intertidal biota. Concurrent with the beginning of the insect work was a thorough inventory of biotic assemblages of the intertidal habitats throughout the park. We funded a project manager—a graduate student from Northeastern University—and she arranged for several intertidal biologists to use more of a classic bioblitz model to collect specimens at several islands in the intertidal zone over a couple of tide cycles in one day.

Has technology played a role in your bio-discovery work?

Marc: Last year we piloted two "photo bioblitzes," as we are calling them. They emerged out of our partnership with Harvard and our work with Jessica Rykken, who helped us coordinate the first one. We viewed it as more of a pilot as opposed to a full bioblitz effort, because we wanted to figure out whether using images can work to document biodiversity scientifically or whether it's only useful—and this is valuable too—as a biodiversity discovery engagement tool. Therefore, we only registered 15 participants who were willing to be a part of this pilot and who came out to Thompson Island with their cameras. The participants had to set up their own accounts with iNaturalist. The idea was that all of the images they uploaded to iNaturalist would be grouped and shared as the Boston Harbor Islands photo bioblitz.

Some species must have been easier to identify than others.

Marc: That's the trade-off with iNaturalist. It allows you to request identification suggestions from the user community, and while professional taxonomists might browse the photos and help make identifications, it is more of an amateur enthusiast user group. Of course, amateurs can be right and they can know a lot of things, but there's definitely a quality-control step when using a crowd-sourced site like iNaturalist. That's why it was really important for us to have

[1] See https://irma.nps.gov/App/Reference/Profile/2195282.

[2] All of the records are available at http://insects.oeb.harvard.edu/boston_islands/ and https://irma.nps.gov/NPSpecies.

Jessica serve as the curator of the collection.

What did you conclude about the viability of the photo bioblitz to document species?

Marc: It worked well, although there were some technology challenges. As a scientific inventory tool, it's nondestructive and it allows us to crowd-source the collection of information and the suggested identifications. The taking of pictures can be done by a lot of people. And it's excellent as a biodiversity discovery community engagement tool. The challenge is that you still have the same basic bottleneck as you do with any inventory, which is the authority, the taxonomist, who actually curates the collection and makes the final call on species identification. You don't get around that with a photo bioblitz.

Is the ATBI over? Is it ever complete?

Marc: We have stopped broad-scale collection, processing, and identification of insects. But I would by no means say that our ATBI is over. Even if you stop collecting and transition to monitoring of a particular focal group, for example arthropods, you would almost certainly find new species as you were looking the second time and therefore add to biodiversity information in the park. So by my way of thinking the ATBI does not have an end, because we're going to continue to try to catalog the biodiversity of the park. Until this is no longer a park where understanding the resources is fundamental to our mission, it's not going to end.

So it's more of a strategy?

Marc: Right. It's an approach to understanding park resources and it flows directly from the National Park Service mission. An ATBI should be a core organizing principle around inventories in parks. However, there are funding limits, so we're not operating in the way we were during the active funded part of this work.

Are the specimens kept at Harvard?

Marc: Yes. From my perspective the National Park Service gains by having the Harvard Museum of Comparative Zoology be the curators of the collection. They know what they're doing, they have the time and resources to manage the collection, and they have collections from all over Massachusetts and the world. It is a benefit to the science and to the National Park Service to be able to look at the Boston Harbor Islands collection in the context of all these other collections.

How did you handle data management?

Marc: I was very concerned as the main inventory was winding down that we were going to end up with all of the information being over at Harvard, and that it would just get farther and farther out of reach. It did take quite a bit of discussion between the NPS Biological Resource Management Division, who maintain the NPSpecies database, the Inventory and Monitoring Program staff, park staff, and our partners at Harvard to figure out how to export the data and transform it in a way that would automatically load into NPSpecies. The main issue was figuring out which of the fields in the Harvard database[3] were in common with NPSpecies. But we eventually did do it. The transfer of this massive number of specimen records has gotten us to think about NPSpecies and its value. We're going to bring NPSpecies into more use for things like interpretive programs.

How would you characterize the level of public involvement?

Marc: Public involvement was built into our project in multiple ways and continues to be. We've had public involvement on individual collecting days. We've had several bioblitz events that were part of the overall insect inventory and the public was invited to those, plus we had the two photo bioblitzes in 2013. While most of the collecting has been done by the lead investigators and undergraduate research assistants, a little bit has been done by other members of the public as part of the engagement process. Several community volunteers were involved in the lab, because there's a role for the public in the initial sorting of insects and other groups, throwing out random parts that can't be identified, drying the specimens, and pinning them so that an expert can take a look. We also developed posters and a card game to involve the public.

Tell me more about that.

Marc: One feature that enhanced both the science and educational value of the project was high-resolution photography. Harvard has this fantastic system to take three-dimensional photographs that can then be used for measurements to help with identification, but also have been used for posters and even a custom card game. Not everyone is going to have access to a high-end system like this, but even just taking photographs with a digital camera can enhance the biodiversity discovery value of the specimens for the public. Instead of just reporting the number and names of species collected, you can share the individual images that are sometimes creepy and amazing, especially at poster size. The Great Smoky Mountains project has produced some incredible posters. We also produced clear resin–covered specimens of various invertebrates. They're used as part of a curriculum-based program in which students do math and other exercises related to food webs for understanding the ecology of terrestrial ecosystems.

[3] See http://insects.oeb.harvard.edu/mcz/.

What is the legacy of the ATBI?

Marc: I think the curated collection at Harvard is an important legacy. The inventory and the potential for further biodiversity discovery live on in that collection. For example, a mycologist from Harvard has begun to study fungi that grow on the bodies of insects. Some of the fungi biodiversity that he is discovering will be from those specimens collected eight years ago as part of the insect study.

What are the next steps for biodiversity discovery at your park?

Marc: This partnership between the Boston Harbor Islands and the Museum of Comparative Zoology at Harvard continues to lead to new investigations. Our current focus is on cataloging the fungi of the park, working with Danny Haelewaters from Donald Pfister's Harvard lab and an NPS intern from UMass Boston. For this work we're targeting two islands and one peninsula in order to try to capture a range of conditions such as varying distance from the mainland, wooded versus shrubby habitats, etc. The team is using both morphological and molecular techniques to do the taxonomy. Another spin-off that is emerging is research into the distribution of mosquito species on the Boston Harbor Islands. We might pick up a couple of species from that, and we might learn something about the public health aspects of different species acting as vectors for disease.

What management issues relate to the information you gained from the ATBI?

Marc: While the ATBI is valuable and ongoing, we do have other stakeholders, and in our case other landowning partners, in the park. I do think that at times talking about insects for six years became tiresome and even viewed as an opportunity to pigeonhole the Park Service as focusing on impractical things. Where partnerships are really critical and where funding is tight, it is important for parks to consider what their key stakeholders are interested in as well. Biodiversity can be approached from plenty of angles and there are plenty of focal groups. Not every park might focus on terrestrial arthropods and intertidal biota like we did, but certainly the opinions and interests of key partners should be considered. Part of the thinking through of taking on ambitious inventories should be to identify clear links to park management issues of concern. We have to be sensitive to the practical value of biodiversity discovery, for public health, agriculture, and visitor services, for example, at the same time as we're interested in the scientific value.

Some parks focus on different taxa as part of annual bioblitzes and can more easily manage this approach than they could an all-out ATBI. Is this a good model?

Marc: It's a terrific model for a couple of reasons. Number one is that the main leverage that we have with taxonomists is their own professional enthusiasm for the subject. The cool thing about the focused bioblitzes is that you might get a lot of taxonomists together who like being in a room talking about the thing that they love. That's a benefit compared to the "try to get everything" approach where Jessica had to be sending boxes of sorted specimens all over the country and world. It's great if you can establish those professional relationships, but then it may take a while for those taxonomists to get to our box of materials. It's not the same as "come out here and geek out in your subject-matter area with us and with other like-minded taxonomists." I think that is what makes the discrete taxa bioblitz model so fun for the participants and so efficient for the National Park Service.

Another model is to change the location of a bioblitz from year to year.

Marc: Right. That model can be excellent for parks that have a local university or institution that wants to play a big role and can themselves be the facilitators of getting taxonomists for the various groups. I was at a workshop at Valley Forge National Historical Park outside of Philadelphia last year and they were talking about doing a biodiversity event and working with the Philadelphia Academy of Natural Sciences [at Drexel University]. Of course the academy has an entomologist, a mammalian zoologist, plant and fungi people, and so they can serve as the key liaisons to the taxonomic expertise for the various groups. I think that sort of model, a local park doing a community event collecting a lot of stuff, can work when there's a dedicated institution that also sees it in their best interest to be involved.

Are there other considerations in designing a biodiversity discovery activity to meet a park's needs?

Marc: It is important to think through the scientific and community engagement objectives as distinct topics. It's great if you can have one event like the NPS–National Geographic BioBlitzes that are designed to answer scientific questions and engage the community. Their high profile may help draw taxonomic expertise, but it takes a lot of staff time and infusion of external money. It is incredibly time-consuming to take the vast amount of specimens from these events and make them into a scientifically valid set of collections. The day of collecting is a tiny piece of the effort, and then the sorting and processing and identifications can be overwhelming. I think it is all too easy for parks to be overly ambitious regarding the scientific goals. The best way to think this through is to distinguish between scientific and community engagement goals. Let's make sure we don't set up something so that we're going to be frustrated or disappointed with one or the other. It's fine to have a biodiversity discovery event in which you engage the community and they help make species lists, but it would not be smart to plan on this being *the* scientifically valid inventory for the park.

What risks need to be planned for?

Marc: Just like with any other park activity, there are potential environmental impacts and safety concerns of this type of activity. You don't want people climbing down a sheer bluff to pick a certain plant. You also have to think through the possible impact on species of special concern and on seasonal nesting species. We had to schedule our intertidal bioblitz in the fall to avoid coastal breeding bird species that nest in a lot of the low-lying areas on many of the islands.

How would you compare your inventory work with the ATBI at Great Smoky Mountains National Park?

Marc: If I understand the Great Smoky Mountains model, the organizing principle seems to be targeted research on individual groups with individual researchers and taxonomic working groups, as facilitated through their partnership with Discover Life in America. That's how they've been able to make their model work. It's this ongoing deep relationship with a nonprofit dedicated to this task. That's a good model. I think our deep ongoing relationship with a local institution is another good model. Great Smoky Mountains National Park has been able to do more projects, and so that's certainly something to aspire to.

Where is biodiversity discovery headed in the National Park Service?

Marc: I think we're in a phase of piloting all sorts of different methods for doing this and figuring out what works and what doesn't. Some of this is figuring out where to distinguish scientific goals from public engagement goals. Some of it is figuring out who the right partners are to engage with to make these things work well scientifically. And part of it is to be more strategic. I would like to see the National Park Service take a more strategic approach through which we can engage taxonomist partners in a more structured way, maybe through the idea of a taxonomist-in-parks program, or maybe dedicated funding to biodiversity inventory that is able to engage a breadth of taxonomist expertise. The key problem is that we're all going to end up asking for the same people's time. That lends itself to a strategic solution.

PS

DLIA/CHUCK COOPER

Todd Witcher, executive director of Discover Life in America, addresses participants in the annual Great Smokies ATBI scientific conference.

Interview with Todd Witcher

***Editor:* Where did the idea for an ATBI originate?**

Todd Witcher: It was the brainchild of retired ecologist Dan Janzen. He coined the term, came up with the concept, and in 1993 attempted to do an ATBI in Costa Rica that focused on lepidopterans. After enduring difficulties there, he came back to the United States with the desire to do one here. He picked Great Smoky Mountains National Park as a biologically diverse area that he felt would work well for what turned out to be a pilot ATBI. Given the park's varied physical and geographic characteristics, it seemed probable that a large portion of species had yet to be discovered, particularly among the invertebrates. These less studied species form the foundation for ecosystem functions that support more familiar animals and plants. So he rallied scientists, park staff like [ecologist] Keith Langdon and [entomologist] Becky Nichols, and community leaders around the idea. This group recognized that the National Park Service would not be able to take on something of this magnitude

DLIA/CHUCK COOPER

Todd Witcher (second from left) discusses the ATBI with a group of citizen scientists near the grounds of the Appalachian Highlands Science Learning Center at Purchase Knob.

without a lot of help. As a result our nonprofit, Discover Life in America [DLIA], was formed in 1997 to coordinate and manage the ATBI.

Can you give us an idea of the scope of this ambitious undertaking?

Todd: The goal of the ATBI is to bring researchers to the park to document every living species in every taxonomic group in the park. It's one of the largest natural resource inventories in the world. Over 15 years of fieldwork we have involved about 1,000 scientists from 20 countries and more than 25 states. Dozens of universities and museums and hundreds of educators have taken part too. We have trained more than 800 amateur specialists, volunteer scientists, students, and teachers in our citizen science program and have logged more than 50,000 volunteer hours. Additionally, hundreds of visitors have worked alongside scientists sifting through soil for millipedes, wading upriver to collect tardigrades, and crouching in sun-dappled forest to investigate ferns. The results have been remarkable: 931 species new to science, an additional 7,799 species previously unknown to the park, and nearly half a million data records. The new species to science have included 36 moths, 41 spiders, 78 algae, 56 beetles, 26 crustaceans, 57 fungi, 23 bees and their relatives, 21 tardigrades, and 270 bacteria, and more than 200 scientific publications have been disseminated. We have just begun to scratch the surface with regard to potential discoveries of bacteria.

How quickly did this ramp up and what level of activity are you experiencing now?

Todd: The decision to do the project was made in 1997. The following year the nonprofit was formed and we began to raise money. The year after that we began giving the first grants and fieldwork began. In a matter of just two years this huge project got off the ground. The activity level has been pretty consistent until the last three of four years. There is less to study now, but the biggest deterrent to our continued work is funding. Still, we host three to four major studies each year. We also hold several citizen science events, including Biodiversity Days in the Smokies, host up to four interns annually, and organize several fund-raising events.

How do you decide what taxa to study?

Todd: When we started, we threw a wide net and invited whomever to go out and do research on something we hadn't looked at before. Of course, the mini-grant program had a lot to do with directing this work. That's how things went until the last four or five years. Now we narrow it down by meeting with park Inventory and Monitoring staff and scientists to identify important groups still left in the park that we would like to know more about, for instance, pollinators, species occupying high-elevation habitats, or "keystone" species. This includes taxa for which little or no work has been accomplished, groups that need to be completed, and at-risk communities. In the introductory category we need to look at parasitic wasps, mites, nematodes, protozoa, microbes, and particular fungi, crustaceans, true bugs, and flies. We need to finish work on centipedes, earthworms, flatworms, scorpionflies, ticks, aquatic snails, dragonflies and damselflies, and bryozoans [aquatic invertebrates]. At-risk groups that need attention include Fraser fir remnant areas, hemlock stands, dry cliffs, and certain wetlands.

Your ATBI is such a massive undertaking that I'd like to ask you a number of practical questions about how you manage the effort. For example, what are TWiGs and how do they work?

Todd: They are taxonomic working groups and are a way to organize the fieldwork of the ATBI. They revolve around the expertise of taxonomists to make collections in the park and follow up with identifications in the lab. This approach was part of our initial science plan and it has worked really well for certain taxa, but not all. It can take a charismatic scientist to lead a TWiG, to gather all the specialists that are studying a particular group, and to get them involved and excited for the project. Our lepidoptera group, led by Dave Wagner at the University of Connecticut, is a great example of one that has worked really well. Dave has written a book on caterpillars of the eastern United States, developed from his work on this project. In some cases, however, you don't need a whole TWiG, because a particular animal group may not have many species or you may want to learn a lot about one species.

Has it been difficult to find taxonomists for certain animal groups?

Todd: Taxonomy has been a dying field in science for a long time. In some cases there's just nobody to identify the specimens that you need to have looked at. And that's a challenge for every park. We have tried to get younger people involved, and we've had some success through our internship and citizen science programs. We send out RFPs [requests for proposals] and do all kinds of things to try to get people interested. Our hope one day is to have an alliance-based ATBI so that the research opportunities can be shared among scientists more easily. There are Web sites used by taxonomists where we might publish this kind of information. Generally, though, it's through word of mouth that we find taxonomists. You know, a springtail expert knows a fly expert and so on.

Do scientists get a stipend to help defray their costs?

Todd: We have had a mini-grant program to entice specialists to come to the park. It helped draw scientists from a limited pool. For about 10 years we gave away around $60,000 a year in $1,000 to $5,000 increments. This money came from park fund-raising partners, Friends of the Smokies, and the Great Smoky Mountains Association, as well as from our own fund-raising efforts. We've had to try to raise more of our own funding in the last few years as partner funding has been directed at other projects. An additional focus now is getting our own fund-raising efforts off the ground. The hope had always been that recipients would be able to leverage their mini-grants with National Science Foundation or other funding. In one case several coleopterists used a mini-grant to leverage a much bigger NSF grant that resulted in a beetle and arthropod museum being established at Louisiana State University based on the work they did in the Smokies.

Where do you house visiting researchers?

Todd: The Appalachian Highlands Science Learning Center at Purchase Knob [see photo, previous page] has space, and they allow scientists who are studying on the North Carolina side of the park to stay there. We don't have a site on the Tennessee side where they can stay. Early on, park neighbors would give up a room in their house for researchers, but we've gone away from that. It was too complicated. Now we ask local accommodations to give scientists a price break. It's hard because our room needs coincide with the busiest tourist time of the year.

How are research permits handled?

Todd: Discover Life in America has a general or overlying permit from the National Park Service that we can use to train volunteers and get them involved in the ATBI, as needed. The scientists also need to get permits for the specific work that they're going to be doing.

Where are the specimens curated?

Todd: It's different with every group of scientists. Of course, every collected specimen belongs to the National Park Service. Some of our scientists return their specimens to the Park Service once they've finished with them and they go into the park collections, and some want to keep them for long periods or on permanent loan.

How are data managed and shared?

Todd: That was a challenge initially because of the number of scientists and kinds of organisms we were working with. What we did was to create our own ATBI database. We have a data manager who checks the validity, usability, and format of the data and enters them into the ATBI database, which the National Park Service maintains locally. Another value we add is that the public can access the ATBI database through a Web site, with filters, of course, for protecting location information about threatened and endangered and economically valuable species. The data are being migrated to the NPSpecies database now.

What educational activities are part of the Smokies ATBI?

Todd: We hold an annual scientific conference and it's open to the public. The conference is where scientists present their findings for the past year or multiple years, including protocols and educational products. We give scholarships to about 25–30 local and regional teachers, and we have about as big a percentage of regular citizens who attend. Attendance was about 175 per year, but we've had a drop in that number over the past several years because of travel restrictions and limits placed on conference attendance on the National Park Service and other government agencies. We hold events each year to involve citizen scientists and have helped park staff develop educational programs, such as Parks as Classrooms, focused on ATBI events and information.

Does the National Park Service have a reporting requirement for the ATBI?

Todd: There is no reporting requirement other than what we report as part of the superintendent's annual report for the park. Of course, we have always thought that the annual conference serves this purpose, and the conference proceedings are published on the DLIA Web site [www.dlia.org].

What is the legacy of the Great Smokies ATBI?

Todd: A simple thing is the baseline information. Lots of environmental changes are already taking place here, and I think they will become more severe. The information provides a baseline that will help us understand how species are responding to those changes and what qualities make species resistant or vulnerable to change. We also feel our ATBI can serve as a model for this type of work at other parks. That's part of it. We're also developing some products. We are working with the University of Tennessee on a biodiversity mapping program. It uses approximately 40 environmental layers for the park, soils, vegetation, and those kinds of things, coupled with our biodiversity data to predict where a species, whatever it might be—a fly, a bird—might be found. It's still in the development stages. Our interns are verifying some of those predictions now.

Have you come up with any new methods for inventorying?

Todd: We have. One of our goals is to develop a "best practices" set of documents for doing an ATBI. We don't have that yet, but a group of scientists we worked with from Europe called EDIT (European Distributed Institute Taxonomy) has published a manual of protocols [see http://www.atbi.eu/wp7/]. It's worth sharing as it may make a good reference.

What new techniques for biodiversity discovery are emerging?

Todd: The iNaturalist idea and the way technology is moving is an area that I think can be valuable.

Are you nearing the end of the ATBI?

Todd: This is a question we are asked a lot, and I don't think we have an exact answer. I believe we are moving more toward the end, and with NPS help we are moving toward a monitoring situation. However, if we keep finding new species at a high rate, then I think that question is hard to answer. The scope does change and adjust as we go on and unfortunately this is based more on funding than on science. We do hope to continue to be a highly valued NPS partner for years to come.

What has been a personal highlight from your involvement with the ATBI?

Todd: I love science and discovery and I can't think of many jobs that combine the two so well. But I do think that our society has a low level of knowledge of science, and this project is a great way of reversing that by involving citizens in real-world science.

For parks that are not able to mount a long-term ATBI, can information from individual bioblitzes be accrued and integrated into something like an ATBI?

Todd: It depends how well the data are collected and managed by the park. At Great Smokies, we want to know where and when species were found—more circumstances than just a running list—so that the information can be better integrated into management. For example, the mapping program I mentioned uses ATBI data and essentially will be able to map the biodiversity of the park. This tool could be used to show decision makers, who are contemplating the location for building a structure or road, where rare, endemic, or critical species exist so that they can then make a more informed decision. For a bioblitz to provide this context it comes down to how it is planned and managed, what information comes out of it, and the assurance that identifications are validated by experts.

How do you view the state of knowledge of biota in the national parks?

Todd: I would say it's pretty low. I think parks know a lot about relatively few species (the charismatic fauna), and not much about everything else. I hope the National Park Service is moving in the right direction, but so many things tend to sidetrack federal agencies, including lack of funding. I hope that we can keep the focus on understanding and saving biodiversity.

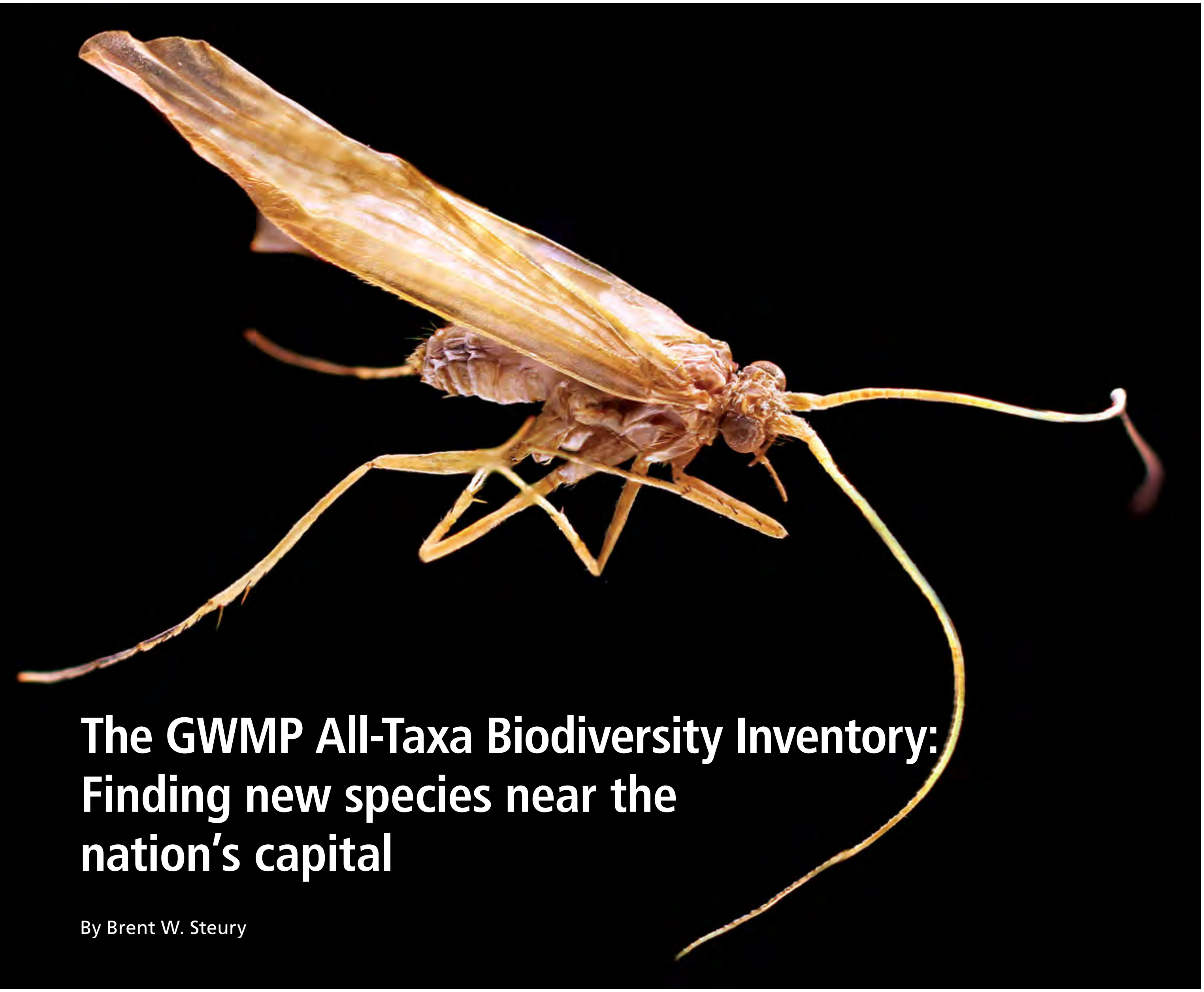
How does biodiversity discovery contribute to park protection?

Todd: Park management needs to know what species exist in the parks. Maybe not every single thing, but much more about all groups than any park currently does. It is impossible to do a good job protecting parks without this knowledge. I also believe that by collecting these data and involving citizens we build a broader love for parks and wild places. In the long run this will better protect parks because people will better realize their value.

—Jeff Selleck, Editor
(jeff_selleck@nps.gov)

The GWMP All-Taxa Biodiversity Inventory: Finding new species near the nation's capital

By Brent W. Steury



B. E. SMITH

Figure 1. ***Neophylax virginica*****, a caddisfly species new to science, was discovered at George Washington Memorial Parkway in 2004.**

DR. OLIVER S. FLINT JR. HAD long suspected that a new species of caddisfly lay hidden in one of the many streams emptying into the Potomac River Gorge (fig. 1). It might be found, he reasoned, flitting around the floodplain forests in Turkey Run Park in northern Virginia, not far from the nation's capital. Caddisflies are members of the insect order Trichoptera and have aquatic larvae that often hide in cryptlike protective tubes made of sand or other stream debris. The adults appear mothlike, with their two pairs of hairy membranous wings and slow flight, as if blowing on a breeze. As curator emeritus of neuropteroids (net-winged insects) in the Department of Entomology at the Smithsonian Institution's National Museum of Natural History, Dr. Flint had described more than 1,000 species of caddisflies from 32 different countries, and he was on the trail of yet another one only a few miles from his office.

The entomologist had been tipped off to the potential presence of this new species when he was reviewing the vast Smithsonian collections and found a single female caddisfly that he could not identify. It had been collected in 1921 by W. L. McAtee of what was then the U.S. Bureau of Biological Survey, now the U.S. Fish and Wildlife Service. The label indicated that the specimen had been taken near "Turkey Run," now protected in Turkey Run Park, a unit

[An estimated] 86% of extant species are still undescribed. . . . Should it be surprising that other smaller forms of life—amphipods, beetles, caddisflies—are being found just outside the nation's capital in an area with one of the highest densities of museums, universities, and research institutions on the planet?

of the George Washington Memorial Parkway.

Coincidentally, around the time Dr. Flint was pondering this unique specimen, parkway staff members were working on their All-Taxa Biodiversity Inventory (ATBI) and contacted him to inquire if he could help with caddisfly identifications. Within a few weeks permits were in place and Dr. Flint and NPS staff found themselves on the bank of Turkey Run on a dark, drizzly October night glaring at a hanging white sheet lit brightly by UV light to attract insects. Of the hundreds of caddisflies attracted to the sheet, a male and four females, plus two males and two females that congregated at lights on the front of the resource management building in Turkey Run Park a few weeks later, proved to be the new species that Dr. Flint later described as *Neophylax virginica* (Flint and Kjer 2011) (fig. 1). Caddisfly collection efforts lasted four years and were expanded to include Great Falls Park a few miles to the north. This work documented 111 species of caddisflies (Flint 2011).

While Dr. Flint was documenting caddisflies, a Smithsonian colleague, Dr. Wayne Mathis, also took an interest in the Potomac River Gorge. Dr. Mathis is a world-renowned expert in shoreflies (Ephydridae), a family of diminutive flies usually found on beaches and riverbanks. His three-year study found four new species of shoreflies, and a new species of snail-killing fly, in the area near where *Neophylax virginica* was discovered (Mathis et al. 2009; Mathis and Zatwarnicki 2010).

Millions and millions (probably)

Between 1.4 and 1.9 million species of living organisms have been described worldwide (Hamilton et al. 2010; Wilson 1992), and approximately 15,000 new species are added each year (May 2010). Mora et al. (2011) estimated that 86% of extant species are still undescribed and a cottage industry has developed around estimating the number of species on Earth. Erwin (1982) hypothesized that there may be as many as 30 million species of tropical arthropods; Mora et al. (2011) calculated 8.74 million eukaryote species; and May (2010) suggested that a range of 3 to 100 million species is defensible. Undoubtedly, most undescribed species are found in remote tropical latitudes that have long been a draw to biologists enamored with the intricacies, forms, and colors of the diversity of life. Bates (1892) found 700 species of butterflies within an hour's walk of his Brazilian home, while the 76 butterfly species documented from George Washington Memorial Parkway have remained constant since that number was established in 2004. Tropical locations are so diverse that even in urban areas new bird genera are being discovered (Pacheco et al. 1996). Some researchers, such as Hawksworth and Rossman (1997), have recognized urban temperate areas as being havens for new species within some kingdoms, such as fungi. So should it be surprising that other smaller forms of life—amphipods, beetles, caddisflies—are being found just outside the nation's capital in an area with one of the highest densities of museums, universities, and research institutions on the planet?

Urban biodiversity, look locally

George Washington Memorial Parkway has been conducting its ATBI for 10 years. To date, 4,976 species have been documented, including 58 species new to science, 3 species new to North America, 83 new to Virginia, 7 new to the District of Columbia, and 49 listed as rare by the Natural Heritage Programs of Virginia or Maryland. Since 2004, 50 peer-reviewed journal articles have been published concerning the biodiversity and ecology of the parkway. Highlights of these studies include

- Documenting 1,313 species of vascular plants, including 2 native species new to Virginia and a nonnative species new to North America (Steury 2011; Steury et al. 2008; Steury et al. 2013b)
- 480 species of macro-moths, including 1 species new to Virginia and 11 species state-listed for rarity (Steury et al. 2007)


NPS PHOTO/EMILY ZIVOT

Figure 2. Park Biologist Erik Oberg and Natural Resources Program manager Brent Steury look under a cover board in Turkey Run Park to check for carabid beetles. A nine-year study using eight capture methods documented 184 carabid species from the George Washington Memorial Parkway, including 7 species new to Virginia and 7 species new to the District of Columbia.

- 323 species of beetles in five families, including 3 species new to science, 12 species new to Virginia, and 7 species new to Washington, D.C. (Cavey et al. 2013; Steury et al. 2012; Steury et al. 2013a; Steury and Messer 2014) (fig. 2)
- 91 species of bees from a globally rare plant community type, including 2 species new to Virginia (Steury et al. 2009)
- 55 species of land snails and slugs, including 3 species new to Virginia (Steury and Pearce 2014)
- A crustacean new to science (Holsinger 2009)
- A turtle new to Virginia (Mitchell et al. 2007)
- Three studies of the pollination biology of rare plant species (Barrows et al. 2011, 2012, 2013)
- A 48-hour 2006 bioblitz that documented 19 beetles, 5 true bugs, a fly, a bee, and a copepod new to Virginia (Evans et al. 2008)

Perhaps the greatest challenge now lies not in knowing how many extant species remain unknown, but in finding them before they go extinct. Current extinction rates exceed those of prehuman levels by 100 to 1,000 times (Pimm et al. 1995), and the professional taxonomists needed to describe new species are also becoming rarer (Mora et al. 2011).

George Washington Memorial Parkway will reach the milestone of 5,000 species in 2014. Seven inventory projects are currently under way and four additional projects will be funded through 2018. It is not unreasonable to expect that the parkway will surpass 10,000 species and see an additional 50 journal articles published in the next 10 years. A recent parkway survey of hexapods (collembolans), commonly known as springtails, reported 37 species new to science, but to date, nothing has been published on these finds. Despite continual progress, there is a long way to go to document all taxa at George Washington Memorial Parkway.

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About the author

Brent W. Steury *(brent_steury@nps.gov) is the Natural Resources Program manager at George Washington Memorial Parkway, Turkey Run Park Headquarters, McLean, Virginia 22101.*

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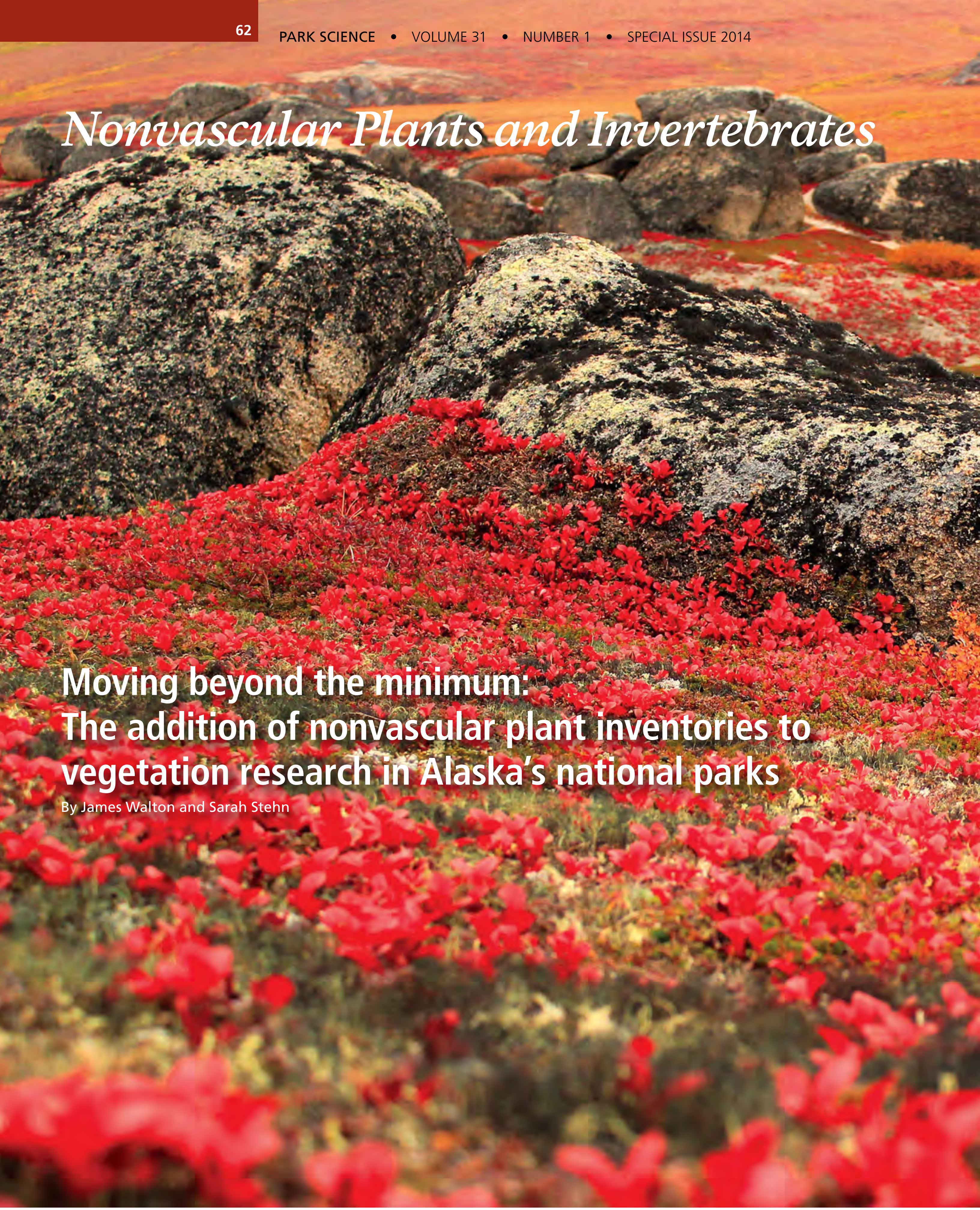

Nonvascular Plants and Invertebrates

Moving beyond the minimum: The addition of nonvascular plant inventories to vegetation research in Alaska's national parks

By James Walton and Sarah Stehn

NPS/KATE CULLEN

Abstract

Alaska's national parks encompass a wide range of habitat types and climate gradients known to support a rich and diverse flora. At such northern latitudes, nonvascular plants, particularly bryophytes and lichens, contribute a significant portion to overall biomass and biodiversity, provide a wide range of ecosystem functions, and can serve as important indicators of air quality and climate change. A number of Alaskan parks have recently completed or are conducting comprehensive inventories that are documenting extraordinary nonvascular plant diversity. Alaska's Inventory and Monitoring networks have also developed vegetation and air quality vital-sign monitoring programs that include nonvascular plant communities in their baseline sampling. University partnerships have played an important role in contributing to our understanding of nonvascular vegetation communities in Alaska's national parks. Such collaboration has provided a strong foundation for future studies and has enhanced NPS efforts toward resource management goals.

Key words

air quality, Alaska, bryophytes, inventory, lichens, monitoring, vegetation

Lichen-covered rock outcrops in Bering Land Bridge National Preserve

Figure 1. Comprising 16 units of the National Park System, the four inventory and monitoring networks of Alaska recently have been conducting nonvascular plant inventories and have incorporated nonvascular plant communities into vegetation and air quality vital-signs monitoring.

ALASKA'S NATIONAL PARKS include nearly two-thirds of the land area in the entire National Park System and some of the most spectacular and intact arctic and subarctic ecosystems in the world. The Alaska Inventory and Monitoring (I&M) Program, organized into four I&M networks and covering 16 national park units (fig. 1), oversees natural resource inventories and monitoring programs across these lands. Nationally, the I&M Program provides funding for parks to complete a set of 12 basic natural resource inventories (NPS 2009), 2 of which are intended to produce species lists and species occurrence data for vascular plants and vertebrates.

Nonvascular plants, particularly bryophytes (mosses, liverworts, hornworts) and lichens, dominate much of Alaska's landscape and serve a number of important ecological functions (fig. 2). Although the original 12 baseline inventories did not include nonvascular plants, a number of Alaska parks have recently completed or are conducting comprehensive inventories. In addition, several of the I&M networks have developed vegetation monitoring programs that include nonvascular plants in their baseline sampling (table 1, page 66).

Bryophytes and lichens are a significant component of the vegetation in many of Alaska's ecosystems (fig. 3). In Gates of the Arctic National Park and Preserve, for example, nonvascular plants account for more than 50% of all plant species present (Nietlich and Hasselbach 1998) and may represent a dominant or codominant portion of the biomass in certain community types. In the Southwest Alaska Network, bryophytes and lichens have been found to comprise 60 to 70% of all plant species recorded in vegetation monitoring plots. At Denali National Park and Preserve in the Central Alaska Network, the proportion of nonvascular plants is 30% of total vegetative richness over more than 1,000 monitoring plots.

Nonvascular plant species are also often key components of primary succession, nutrient cycling, and carbon sequestration (Turetsky 2003). Lichens may provide a sizable portion of fixed nitrogen in the nutrient-poor ecosystems of the Arctic (Longton 1992), and they serve as an important winter food source for caribou (Joly et al. 2010). Bryophytes, when abundant, can alter soil moisture and temperature, regulating the presence of other plant species (Turetsky et al. 2010).

NPS/JAMES WALTON

Figure 2. The yellow moose dung moss (*Splachnum luteum*) spreads its spores via flying insects that visit the herbivore's dung on which the plant grows and helps to decompose.

Air quality monitoring

Perhaps one of the earliest discoveries about bryophytes and lichens from a land management context was their potential utility as a monitoring device: serving as an indicator species for monitoring air quality. Because bryophytes and lichens do not possess roots, they must get their mineral nutrition from the atmosphere. They are uniquely adapted to absorbing these required elements through deposition by air, dust, and precipitation and thus can be used as passive samplers by collecting tissue


NPS/KATE CULLEN

Figure 3. Lichen-covered boulders in Bering Land Bridge National Preserve. Lichens are a major component of the flora in many of Alaska's national parks.

for elemental analyses. When exposed to even low levels of certain pollutants, particularly sensitive species will decline or die, making nonvascular community composition or richness also a good indicator of ecosystem health. Local, regional, and global pollution sources are of considerable concern in some of Alaska's national parks.

The Arctic Network has used the widespread moss *Hylocomium splendens* (fig. 4) as a passive sampler for 15 years to explore the concentration of mine-related and fugitive dustborne heavy metals along the Red Dog Mine haul road in Cape Krusenstern National Monument (fig. 5). Zinc, lead, and cadmium levels found in moss tissue decrease with distance from the road, and the rich-


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Figure 4. The stair-step moss (*Hylocomium splendens*) is used in several Alaska parks to monitor deposition of airborne contaminants.


NPS PHOTO

Figure 5. Along the Red Dog Mine haul road in Cape Krusenstern National Monument, a switch to solid-sided ore trucks since 2001 and the application of dust palliatives (primarily calcium chloride) to the road surface have helped control dust, which has led to a decrease in heavy metal contamination in moss tissues in the park.

Table 1. Status of nonvascular plant projects across the Alaska Inventory and Monitoring Region

Network and Network Parks	Bryophtye Inventory Status	Lichen Inventory Status	Bryophytes and Lichens Used in Vital Sign Monitoring	Select Publications and Reports
Central Alaska Network				
Denali National Park and Preserve	x	p	x	Stehn et al. 2013b
Wrangell–St. Elias National Park and Preserve			x	
Yukon-Charley Rivers National Preserve			x	
Arctic Network				
Bering Land Bridge National Preserve		x	x	Holt et al. 2007; Holt et al. 2008; Holt and Neitlich 2010a
Cape Krusenstern National Monument		x	x	Ford and Hasselbach 2001; Hasselbach et al. 2005; Neitlich et al. 2014a, b; Holt and Neitlich 2010a
Gates of the Arctic National Park and Preserve		x	x	Neitlich and Hasselbach 1998; Holt and Neitlich 2010a; Nelson et al. 2014
Kobuk Valley National Park		x	x	Holt and Neitlich 2010a
Noatak National Preserve		x	x	McCune et al. 2009; Holt and Neitlich 2010a
Southwest Alaska Network				
Alagnak Wild River				
Aniakchak National Monument and Preserve	x	x		Hasselbach 1995
Katmai National Park and Preserve		ip	x	McCune et al. in progress
Kenai Fjords National Park	p	ip	x	Walton et al. 2014
Lake Clark National Park and Preserve		ip	x	McCune et al. in progress
Southeast Alaska Network				
Glacier Bay National Park and Preserve		ip	x	Schirokauer et al. 2008
Klondike Gold Rush National Historical Preserve		x	x	Spribille et al. 2010
Sitka National Historical Park	x	x	x	LaBounty 2005

x = Comprehensive inventory complete.
p = Comprehensive inventory partially complete.
ip = Comprehensive inventory in progress.

ness of nearby lichen communities is closely linked to moss tissue elemental concentrations (Hasselbach et al. 2005; Neitlich et al. 2014a). Dust control efforts implemented in part because of this monitoring have led to a decrease in contamination of moss tissues (Neitlich et al. 2014b). Moss and lichen community monitoring continues to track recovery.

The Southeast Alaska Network uses epiphytic lichen tissue samples as part of their airborne contaminants monitoring. Tissue concentrations from lichens collected over 10 years in Klondike Gold Rush National Historical Park (NHP) contained evidence of increased nitrogen and decreased lead and nickel, which were both attributed to changes in local source contaminants (increased cruise ship port time and cessation of uncontained mining ore transfers, respectively). Because of its success, lichen tissue monitoring as part of the airborne contaminants program was expanded to include all Southeast Alaska Network parks in 2008 (Schirokauer et al. 2008).

Vegetation community monitoring

Bryophyte and lichen species are important components of the many plant communities currently monitored in Alaska. Because particular species are both abundant and sensitive to changes in the environment, they can serve as useful indicators for detecting long-term trends in the larger ecological community. The Central Alaska, Arctic, and Southwest Alaska Networks track nonvascular species occurrence in their vegetation monitoring programs.

Since 2001, the Central Alaska Network has collected data on vascular and nonvascular species occurrence and now has one of the largest species-level data sets of ground-layer bryophyte and macrolichen communities in North America, with more than 1,000 vegetation plots installed in Denali National Park and Preserve, and intensive work also occurring in Yukon-Charley Rivers National Preserve and Wrangell–St. Elias National Park and Preserve with several hundred additional plots installed. The Arctic Network has more than 500 lichen monitoring plots for ungulate grazing habitat, contaminant effects, and trends in diversity, and approximately 200 vegetation structure monitoring plots that include lichens and bryophytes in their ground strata. The Southwest Alaska Network has more than 130 vegetation monitoring plots that include ground-layer bryophyte and macrolichen occurrence, with an additional 29 epiphytic macrolichen community plots.

Inclusion of nonvascular plants in these plots has been a challenge because of the difficulty of species detection and identification, and time-intensive sampling because of high species diversity. However, because the nonvascular species data have been collected with a broad set of other ecological variables such as tree and shrub cover, soil temperature, and vascular plant richness, researchers are able to develop a more complete understanding of these organisms and their environment. For example, repeat photography and preliminary data from vegetation monitoring plots suggest that climate change is leading to increasing shrub cover across subarctic and arctic landscapes (Hinzman et al. 2005). One of the expected impacts of this is the encroachment of shrubs into abundant forage, lichen-dominated plant communities. This encroachment has the potential to increase shade and leaf debris at the ground layer and, as a result, cause shifts in species composition through time, including the loss of lichen and moss cover, which may in part affect the distribution and population dynamics of caribou populations. For the Western Arctic Caribou Herd, which can contain up to 500,000 animals and is one of the largest free-roaming herds in North America, the consequences of lichen habitat decline could be substantial for the ecosystem and the subsistence economies of local communities (Joly et al. 2010).

Nonvascular plants . . . dominate much of Alaska's landscape and serve a number of important ecological functions.

NPS/EVAN HECK

Figure 6. A researcher from the University of Gräz in Austria collects lichens during an inventory for Katmai National Park and Preserve.

Assessing the diversity of nonvascular species in the parks

Recent inventories conducted within national parks of Alaska have revealed that lichen and bryophyte diversity is high. An inventory completed in Klondike Gold Rush National Historial Park (Spribille et al. 2010) reported the largest number of lichens per unit acre on record and the largest number of lichen species recorded from any national park. More than 766 taxa of lichenized and lichenicolous fungi were detected in this park, with at least 196 taxa new to Alaska, 34 new or confirmed taxa for North America, and 4 described as new to science. An inventory of the western arctic parklands (Holt and Neitlich 2010b) described 491 lichen species, 16 of which are new to Alaska or North America and 3 of which are new to science. Lichen inventories currently under way in Katmai National Park and Preserve and Lake Clark National Park and Preserve are documenting several hundred previously unreported taxa for southwestern Alaska, including at least one species new to science. A bryophyte inventory in previously unexplored regions of Denali National Park and Preserve, including its remote southern regions, has increased the number of known taxa by nearly 30%, with 499 species now documented (Stehn et al. 2013b). In Kenai Fjords National Park, an inventory of bryophytes and lichens along the park's remote coastal forests identified hundreds of

When exposed to even low levels of certain pollutants, particularly sensitive species will decline or die, making nonvascular community composition or richness . . . a good indicator of ecosystem health.

previously undocumented species for the park, including several new state records and many regionally rare to uncommon taxa (Walton et al. 2014).

These recent inventories have benefited greatly from university cooperation, primarily from institutions in North America and Europe. The number of participants for each project varies, but has included world and regional taxonomic experts (fig. 6, previous page). The inventories have resulted in a number of peer-reviewed publications and have provided a foundation for further studies in and around Alaska's national parks. For example, discovery of the globally critically endangered epiphytic lichen *Erioderma pedicellatum* in Denali during inventory work instigated a park-funded occupancy and abundance study that revealed the south-central Alaska population to be the largest known in the world (Stehn et al. 2013a).

All data collected on nonvascular plant communities of Alaska's national parks are making an important contribution to NPS resource management goals by documenting species diversity and changes in the structure and composition of ecological communities. As environmental and anthropogenic stresses increase, Alaska's I&M networks are establishing important baseline data sets that can be used to set benchmarks for measuring levels of ecological integrity. Continued and future investment in scientific capacity through partnerships with universities and other research institutions will further contribute to our understanding of nonvascular vegetation communities in Alaska's national parks.

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About the authors

James Walton *(james_walton@nps.gov) is a botanist with the Southwest Alaska Network in Anchorage, Alaska.* ***Sarah Stehn*** *(sarah_stehn@nps.gov) is a botanist with the Central Alaska Network in Denali National Park and Preserve, Alaska.*

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About the authors

Gretchen M. Baker *(gretchen_baker@nps.gov) is an ecologist at Great Basin National Park in Baker, Nevada.* ***Nancy Duncan*** *(nancy_duncan@nps.gov) is the Natural Resource Program manager at Mississippi National River and Recreation Area in St. Paul, Minnesota.* ***Ted Gostomski*** *(theodore_gostomski@nps.gov) is a biologist and science writer with the NPS Great Lakes Inventory and Monitoring Network in Ashland, Wisconsin.* ***Margaret A. Horner*** *is a supervisory biological technician at Great Basin National Park.* ***David Manski*** *(david_manski@partner.nps.gov) is the former chief of Natural Resource Management and acting deputy superintendent at Acadia National Park, Bar Harbor, Maine. An "emeritus" employee, he recently retired from the National Park Service after a 35-year career on various natural and cultural resource assignments in the United States and abroad.*

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All along the watchtower: Larval dragonflies are promising biological sentinels for monitoring methylmercury contamination

By Roger J. Haro

Abstract

Humans have used other organisms to detect environmental danger for centuries (e.g., the canary in the coal mine). The use of "biosentinels" has developed and expanded to become a mainstay for monitoring environmental contaminants like methylmercury, a pervasive and largely anthropogenic neurotoxin. Biosentinels provide insights on how and where contaminants are entering and moving through aquatic food webs. Many water bodies in the Great Lakes region, including those in national park units, have fish-consumption advisories because of the atmospheric deposition of mercury and its conversion into methylmercury, which can biomagnify. For many years young yellow perch served as the principal biosentinel for monitoring methylmercury. Resent research shows that the diverse assemblage of dragonflies in this region can provide an additional suite of biosentinels, complementing the use of perch among water bodies with fish and expanding the reach of methylmercury monitoring to include fishless ecosystems (e.g., small ponds and wetlands).

Key words

biosentinels, contaminant monitoring, dragonfly larvae, fish-consumption advisories, methylmercury

IN THE POPULAR FANTASY SERIES *Game of Thrones*, the Night's Watch portrays vigilant sentinels silently watching for trouble and sending word to the people behind the wall to prepare and react if danger approaches. Humans similarly rely on biological sentinels to detect dangerous substances in the environment and depend on them as early warning signals. Stories about the sensitive canary succumbing to low levels of toxic gases, alerting miners to take evasive action, illustrate the idea of a biological sentinel. Now, instead of bringing the canary to the site of a potential hazard, scientists and resource managers are recognizing the importance of the stories that resident organisms can convey about the environmental condition or health of their ecosystems. These organisms are called biological sentinels or, simply, *biosentinels*. The diversity of organisms in an ecosystem provides an array of candidate biosentinels, each one telling a slightly different story about the environmental health of the local environment.

Today the stories told by biosentinels can be vastly more informative than a simple signal that it is time to leave the mine. These stories can reveal the risk of exposure to contaminants such as methylmercury. The organisms are sampled after accumulating the contaminants from their environment, and their tissues are then analyzed to estimate the contaminant concentration. These analyses can provide clues to how and where a contaminant entered the biosentinel. The story can expand to identify other players, for example how contaminant levels in the biosentinel are transferred to predators, or how their own dietary preferences and feeding behaviors affect their exposure to bioaccumulative contaminants that are transferred in food webs. Thus the stories biosentinels tell can be extremely informative and useful.

Useful biosentinels are those organisms that consistently "integrate" uptake of contaminants over a range of concentration in both space and time. The bioavailability of a contaminant to an organism depends not only on the biogeochemical behavior of the contaminant but also on specific traits involving the life history, physiology, and trophic ecology of the organism. Any combination of conditions and traits that would prevent or limit the organism's exposure to a specific contaminant lowers its value as a potential biosentinel. Another practical consideration is the ease with which the organism can be collected, identified, and analyzed. If such conditions are satisfied, biologists and resource managers weigh the cost-effectiveness of using a specific biosentinel. This is especially important if the biosentinel is to become part of a sustained monitoring program. Such practical considerations have focused attention on larval dragonflies as potential new biosentinels for monitoring methylmercury contamination in freshwater systems, especially in our national parks.

Mercury in the environment

Instead of bringing the canary to the site of a potential hazard, scientists and resource managers are recognizing the importance of the stories that resident organisms can convey about the environmental condition or health of their ecosystems. These organisms are called . . . biosentinels.

Mercury (Hg) is a naturally occurring element in the environment, but human sources now contribute about 70% of the mercury in the atmosphere. The atmospheric transport and deposition of mercury in both dry and wet forms pose a considerable threat to areas far from traditional point sources of mercury, such as mines and industrial sources. Lacking local, geologic mercury sources, organic methylmercury is formed from inorganic mercury that has been atmospherically deposited and transformed by mercury-methylating bacteria, which can occur naturally, for example, in the shallow sediments of lakes and wetlands. Take Ryan Lake in Voyageurs National Park as an example: a gorgeous, southern boreal lake surrounded by rugged rock outcroppings and white pines. Located in northern Minnesota near the Canadian border, the lake is accessible only by boat and a 1.5-mile (2.4 km) hike. Yet the predatory fish inhabiting its tea-stained waters have the highest known concentrations of methylmercury documented for any lake in Minnesota. Mercury in the form of methylmercury bioaccumulates and biomagnifies through the Ryan Lake food web so that a filet of a northern pike contains more than 1,000 parts per billion of Hg, a concentration exceeding the U.S. Environmental Protection Agency's fish-tissue criterion for methylmercury (300 parts per billion wet weight), which was established to protect the health of humans who eat noncommercial fish. The risk of neurological damage to humans from eating contaminated fish, like the northern pike from Ryan Lake, prompted the issuance of fish-consumption advisories for thousands of water bodies throughout the United States, including many in our national parks. This problem is exacerbated by the sensitivity of certain water bodies to mercury pollution, which is highly location-specific and depends on a number of physical, chemical, and landscape factors. For example, the mercury concentration in prey fish and predatory fish can vary almost 10-fold among inland lakes of Voyageurs National Park (Wiener et al. 2006).

As states and nations strive to reduce anthropogenic emissions of mercury into the atmosphere, how will we know whether concentrations of methylmercury in food webs, fish, and wildlife respond and decline? Conversely, how will we know whether mercury emissions from distant but rapidly developing nations like China are impacting our aquatic ecosystems? How can we adequately expand our understanding of a contaminant that displays such high spatial and temporal variability? For freshwater ecosystems in the Great Lakes region, such challenges may require the monitoring of biosentinel organisms beyond those that have been used.

Use of small prey fish as biosentinels

As the scope of the mercury deposition problem became evident to scientists and resource managers in the 1980s, they soon realized that there were key contaminant transfer points in affected food webs. One was the pathway for human exposure from the consumption of contaminated sport fish. However, there were other vulnerable end points in the food web, such as the common loon, an iconic avian piscivore in Canada and the United States. This is where small yellow perch (*Perca flavescens*) come into the story. As young fish, they serve as an important trophic link to both game fish, such as northern pike and walleye, and breeding common loons that nest and raise their young in northern lakes. It is not surprising that the yellow perch became an important biosentinel for monitoring mercury in many lentic waters (e.g., lakes, ponds, or swamps) (Wiener et al. 2007). Yellow perch are ubiquitous and often very abundant in the northern temperate and boreal lakes of North America. They are found in a wide array of water quality conditions, from soft, poorly buffered, low-pH lakes to hard-water marl lakes. Numerous studies have shown that the concentration of mercury in one-year-old yellow perch is strongly correlated with the mercury concentration of coexisting game fish. Their distribution in lakes surrounding the industrial Rust Belt of North America and their intermediate position in the food webs of those lakes have made small yellow perch an effective biosentinel for monitoring methylmercury in much of the eastern United States and Canada.

There are limitations to the use of yellow perch and other small prey fishes as

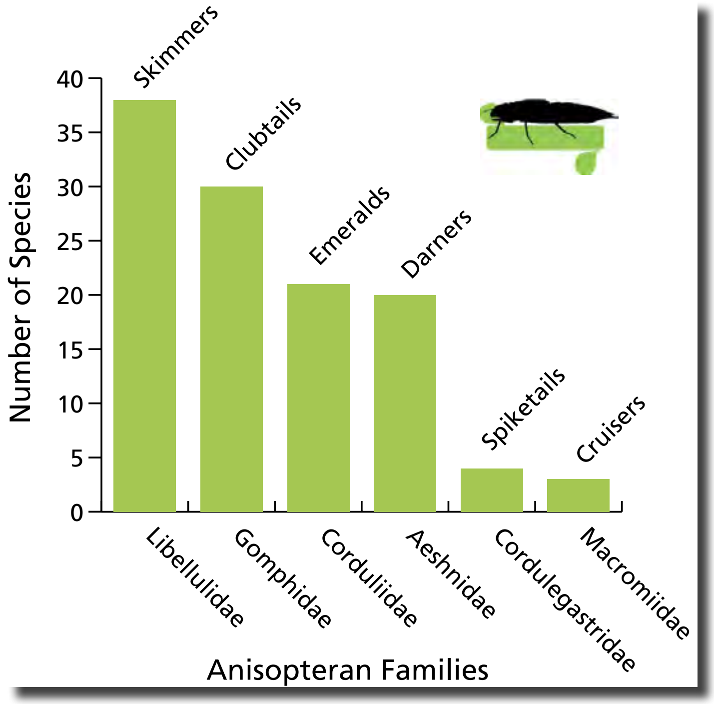

Figure 1. Number of dragonfly species by family recorded across counties containing six national park study units in the Great Lakes region. In total, 116 species of dragonflies (Anisoptera) were recorded. Common names for each dragonfly family appear above each bar. Species distribution data were derived from Abbott (2007).

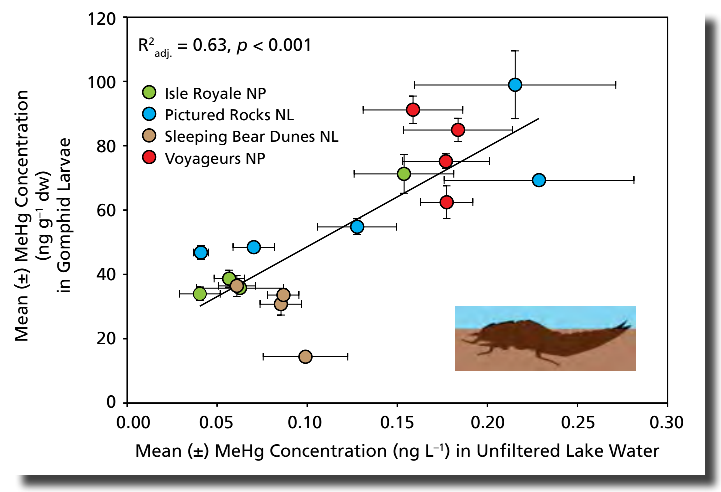

Figure 2. Relation between mean (±SE) concentrations of MeHg in burrowing gomphid larvae and unfiltered water from 17 lakes in the northwest Laurentian Great Lakes region. Data for coexisting species of burrowing gomphids were combined to estimate mean MeHg in larvae for each lake. Means for MeHg in water were calculated from samples collected in 2010, 2011, and 2012. Means for gomphids were calculated from samples collected in 2008, 2009, and 2010. The linear regression model is shown as a solid line.

biosentinel organisms. Although yellow perch are often abundant in lentic systems, they do not typically inhabit lotic habitats (i.e., those characterized by fast-moving water) and certain wetlands, such as bogs and ephemeral ponds. Moreover, recent research has shown that emergent aquatic insects from fishless water bodies can be important points of methylmercury transfer to terrestrial consumers, such as spiders, invertivorous birds, and bats (Blackwell and Drenner 2009).

Larval dragonflies as biosentinels for mercury

A diverse assemblage of dragonflies inhabits the aquatic environs surrounding the Great Lakes (fig. 1). Upon emergence as adults, they are conduits for the transfer of methylmercury from the aquatic to the terrestrial ecosystem. These insects are promising biosentinels of methylmercury in aquatic food webs, given that they inhabit a diverse array of aquatic and wetland habitats and their use as biosentinels can extend the assessment of food web contamination to fishless aquatic habitats. All dragonfly larvae are obligate predators, bioaccumulate methylmercury (fig. 2), and are restricted to the water body where they were hatched. Most are identifiable to species, and sufficient numbers and sample mass can be readily obtained with simple, inexpensive gear (e.g., a D-shaped net). Their ecology is well documented at the genus level, which greatly facilitates and enhances the interpretation of data from chemical analysis of larvae.

The utility of burrowing dragonfly larvae as biosentinels of methylmercury in aquatic food webs has been examined by Haro et al. (2013), who collected late-instar (i.e., individuals near maturity and adult emergence from the aquatic environment) dragonfly larvae in the genus *Gomphus* spp. (clubtails) from 17 inland lakes in four national parks in the western Great Lakes region (Isle Royale National Park, Pictured Rocks National Lakeshore, Sleeping Bear Dunes National Lakeshore, and Voyageurs National Park). They conducted a statistical analysis to determine the number of dragonflies to collect in order to detect a 20% difference in mean total mercury concentration in their tissue from a lake. The same was calculated for young yellow perch sampled from the same group of lakes. The results indicated that only 10 dragonfly larvae needed to be sampled, whereas 40 yellow perch were required (fig. 3). In the Great Lakes region, the logistical advantages are clear for adding dragonfly larvae as biosentinels for mercury monitoring. The sampling gear required for collecting age-one yellow perch is more difficult to carry into hard-to-reach lakes like those in the rugged interior of Isle Royale. Nevertheless, if lakes of interest are close to one another, it is not unreasonable to expect that multiple lakes could be sampled in a single day us-

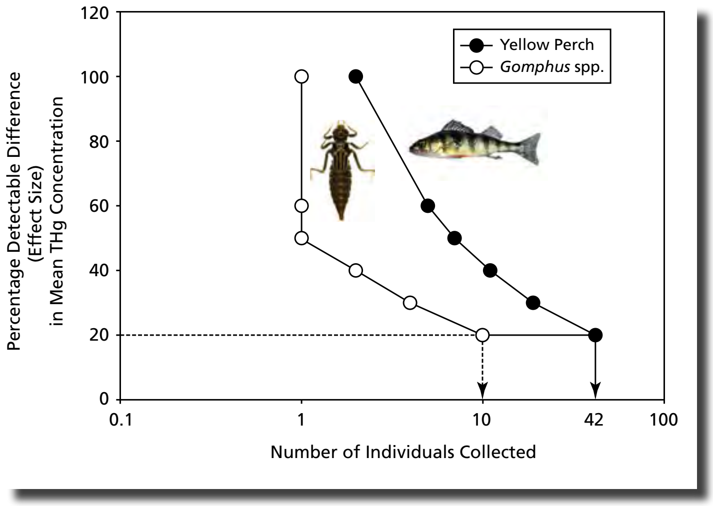

Figure 3. Estimated sample sizes (i.e., the numbers of individuals required) needed to detect differences in concentration of total mercury (THg) in small, whole yellow perch (total length ≤ 76 mm or 2.9 in) and larval *Gomphus* in lakes of the northwestern Great Lakes region with a Type I error (α) of 0.05 and a statistical power (1–β) of 0.80.

The risk of neurological damage to humans from eating contaminated fish, like the northern pike from Ryan Lake, prompted the issuance of fish-consumption advisories for thousands of water bodies throughout the United States, including many in our national parks.

ing dragonfly larvae as biosentinels. Their ease of collection is also a strong impetus for their use in a nationwide citizen science–based monitoring program (see the article by Flanagan Pritz et al. on page 74).

More research is needed on the mechanisms behind the uptake of methylmercury as well as on its trophic transfer from larval dragonflies. The larvae obtain their oxygen by actively drawing water into their rectum, where their gills reside. This rectal ventilation may be an additional pathway for the uptake of methylmercury. Furthermore, behavioral and physiological differences among the taxonomic families of dragonflies may also affect the uptake of methylmercury. These issues will provide important lines for additional research. These unanswered questions do not detract from the fact that larval dragonflies are a new and potentially powerful biosentinel for expanding our ability to assess mercury in the waters of our national parks and beyond.

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About the author

Roger J. Haro *(rharo@uwlax.edu) is an aquatic entomologist and professor of biology at the University of Wisconsin–La Crosse. He is the assistant director for the UW–La Crosse River Studies Center, a research center with more than 30 years of history studying the delivery and movement of methylmercury through aquatic food webs.*

The Call to ~~Action~~ Collect Dragonflies

Citizen scientists study mercury contamination in national parks

By Colleen Flanagan Pritz, Sarah Nelson, and Collin Eagles-Smith

IT'S A CRISP AUGUST MORNING at Lily Lake, Rocky Mountain National Park. Twelve Arizona high school students arrive at the parking lot, beaming with excitement about their journey to Colorado and the adventures that await them, all dressed in the same green-colored T-shirts: "BioBlitz." The year is 2012. They grab nets and waders, magnifying glasses, and field guides; some wear GoPros to video-record the experience. They head for the lakeshore in search of little bugs that live in the water. But not just any little bugs … dragonfly larvae.

The students—citizen scientists—seek out little faces with two big, beady eyes and a sinister "smile" made of extending (prehensile) mouthparts, an apparatus with jagged, grasping edges used to snatch prey and devour it whole. This underwater creature is the dragonfly in its larval stage, before it morphs into the colorfully aerial, adult dragonfly we all know.

Dragonfly larvae are widespread across the United States and are an important food source for fish, amphibians, and birds. They live underwater for up to five years before undergoing incomplete metamorphosis. At this time they crawl out of the water onto emergent vegetation, the shore, a dock, a rock, or any dry place, then shed their exoskeleton, dry their wings, and fly off. Robert DuBois, naturalist and author of the field guide *Dragonflies and Damselflies of the Rocky Mountains*, describes the transformation: "After months or years of clambering about underwater, the nymph is freed from the shackles of this ignoble existence in one grand moment of emancipation. Almost instantly it becomes one of the most graceful, elegant, and masterful flying creatures under the sun."

A student steps out from the cattails and asks, "Is this one?" She hands over a shallow plastic spoon holding a bug, about 10 millimeters (0.4 in) in length, eyes very large in proportion to its head, wriggling in a thin veil of water.

"How many legs does it have?"
"Six," she replies.

"Would you call the abdomen slender or bulky?"
"It's skinny and long," she says with certainty.

"What are those three feathery things extending from the tip of the abdomen?"
"Hmm." She pages through the field guide. "Gills?"

"Yes." She pauses. "Is it a dragonfly nymph?" She looks back at the book.
"Aw, man! It's a *damsel*-fly…"

"Keep looking. You were close!"

Thanks to the foundation laid by the Acadia Learning Project, an opportunity arose to engage citizen scientists in a project that both educates participants about park science and provides parks with valuable environmental information.

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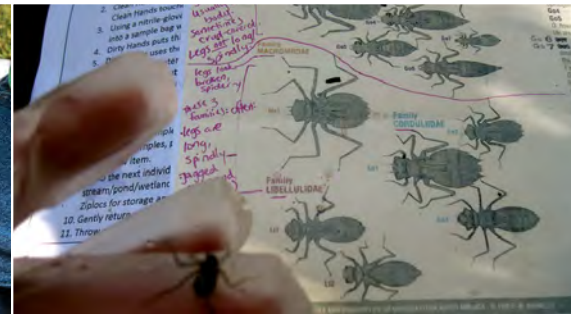

(Facing page) A student from Sabino High School in Arizona searches for dragonfly larvae at Lily Lake, Rocky Mountain National Park, Colorado. (Above) A classmate of hers searches a net for larvae.

A student measures the length of a larva. The students traveled to the park in August 2012 and sampled dragonfly larvae as part of the National Park Service–National Geographic Society "BioBlitz."

A student refers to a field guide to identify dragonfly larvae at Great Smoky Mountains National Park, Tennessee. Dragonfly larvae are being tested for use as an indicator of mercury contamination in the national parks.

Mercury rising

Both dragonflies and damselflies belong to the order Odonata, "toothed ones," which includes some of the most ancient and beautiful insects that ever roamed Earth, as well as some of the largest flying invertebrates ever to have lived. Dragonflies belong to the subgroup *Anisoptera*, and damselflies to the group *Zygoptera*. Among other differences, the abdomen of the larval dragonfly is shorter and bulkier than that of the damselfly. Odonates are set apart from other aquatic macroinvertebrates by their relatively large size, particularly large eyes, and prehensile mouthparts.

Like their adult counterparts, dragonfly larvae are predatory insects. These voracious eaters maintain a higher position on the food chain than other aquatic insects like mosquito larvae and caddisflies, sometimes even eating small fishes. Organisms near the top of the food chain, such as dragonfly larvae, are more sensitive to environmental pollutants like mercury that both build up (bioaccumulate) and increase in concentration higher on the food chain (biomagnify).

Contaminant exposure can be dangerous for humans and wildlife because of the potential for negative health effects. Mercury, a toxic heavy metal, is a contaminant of particular concern, given its ubiquitous nature and ability to induce neurological and reproductive impairment. Mercury threatens the natural resources and values the National Park Service is charged with protecting.

Although there are natural sources of mercury such as volcanoes, much of the mercury that affects national parks is the result of air pollution, and more specifically coal-burning power plants. Waste incinerators and mining operations are other human-caused sources of mercury. Human activities have increased levels of atmospheric mercury at least threefold over the past 150 years. Mercury has an especially long residence time in the atmosphere, and may arrive in parks from distant places such as Asia. Atmospherically deposited mercury can harm the ecological integrity of aquatic and terrestrial communities in national parks and the wildlife that depend on them.

Biosentinels

Concentrations of mercury in dragonfly larvae could indicate the potential risk for the ecosystem. Similar to the "canary in the coal mine," dragonfly larvae are *sentinel species*, or biosentinels. As surrogates for ecosystem health, they can be used to detect the potential risk to humans and wildlife by providing advance warning of a danger.

Levels of mercury in dragonfly larvae can serve as proxies for mercury in fish from the same water body. This has potential implications for organisms higher on the food chain, including fish-eating birds and humans. More than 16 million lake acres (6 million ha) and 1 million river miles (1.6 million km) in the United States are under fish-consumption advisories because of mercury, and 81 percent of all fish-consumption advisories issued by the U.S. Environmental Protection Agency are due to mercury contamination. Fish-consumption advisories for mercury are in effect in all 50 states.

While fish are perhaps the most commonly used indicator for mercury contamination because they occur across a wide geography and provide strong links to human and wildlife health, dragonfly larvae are far easier to collect, and they represent the risk from mercury in fishless ecosystems like shallow ponds, ephemeral pools, and marshes—some of the most productive and ecologically important aquatic habitats. They remain in the pond or stream where they hatched from eggs, giving researchers and managers a clearer picture of mercury risk within the watershed where they are caught.

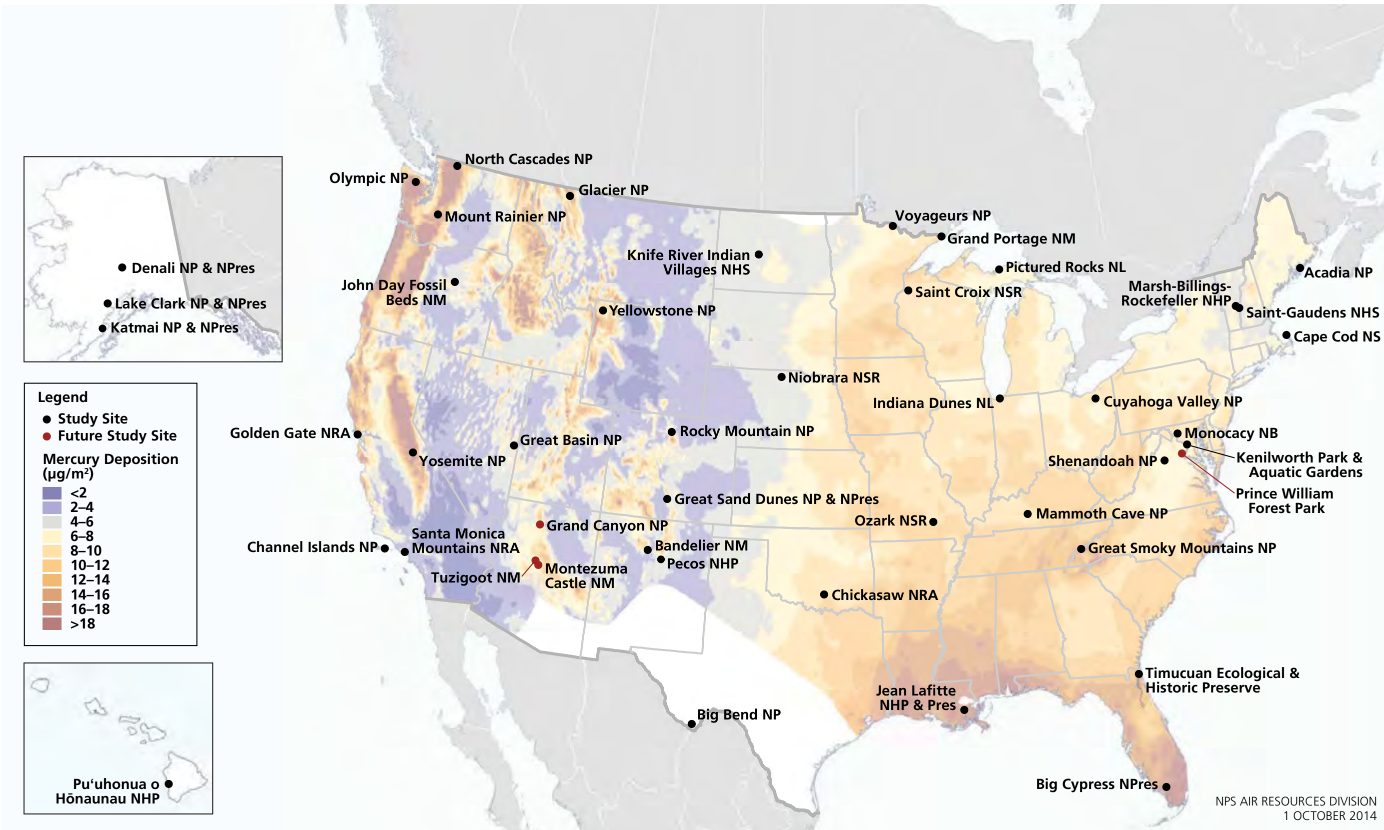

Figure 1. Parks participating in the dragonfly mercury study, 2014. The map background shows measured and interpolated mercury deposition data from 2012, courtesy of the National Atmospheric Deposition Program/Mercury Deposition Network.

Dragonfly larvae present an ideal vehicle for researchers and park managers to engage citizen scientists in connecting with the natural world. In addition to connecting people to parks and advancing the educational mission, the scientist-citizen partnership makes dragonfly larvae cost-effective tools for monitoring mercury dynamics across many locations.

Results

Forty-two of 46 participating parks have engaged in sampling to date (fig. 1), from Denali National Park and Preserve (Alaska) and Big Cypress National Preserve (Florida) to Acadia National Park (Maine) and Golden Gate National Recreation Area (California), collecting more than 800 dragonfly larvae at 60-plus sites. Close to 300 citizen scientists, including students, Youth Conservation Corps, volunteers (VIPs), bug camp attendees, and bioblitz participants, have thus far contributed approximately 1,800 hours of volunteer time.

Citizen scientists, such as the high school students from Arizona, are collecting dragonfly larvae in at least 50 park units across the nation over five years (2011–2015) for analysis of mercury. The species are being tested as biosentinels, shedding light on the risk of mercury contamination throughout the National Park System. Results indicate that no single water chemistry parameter, landscape variable, or dragonfly characteristic adequately describes the pattern of mercury in dragonfly larvae. However, analyses found that dissolved organic carbon, total mercury in water, and pH are important variables, with some influence exerted by east-west position, topography (e.g., wetlands), and habitat guild. Furthermore, site differences within parks reveal that dragonfly larvae can describe fine-scale differences in mercury risk, which supports the utility of these species as biosentinels.

Other research reveals that mercury in dragonfly larvae was correlated with both mercury in water and mercury in fish in the same water bodies (see the article by Roger Haro on page 70). Resource managers and the public appreciate an understanding of mercury levels in the ecosystem because people (and wildlife) rely on the services a healthy ecosystem provides, such as clean water, fish, and enjoyment of the landscape. Bird lovers visit parks to observe birds, not a lack thereof.

The project Web page (http://www.nature.nps.gov/air/Studies/air_toxics/dragonfly/index.cfm) includes the data, available for use by citizen scientists and parks. Final results will be published in the peer-

SARAH NELSON

Dragonfly larva of the family Gomphidae, collected at Hodgdon Pond, Acadia National Park, Maine, 2012.

reviewed literature and incorporated into larger-scale mercury research synthesis efforts.

The student returns with another specimen:

"Is THIS it?!" The bug is big and has huge eyes.

"What's different about this one?"
"It doesn't have feathery gills," she says.

"And the abdomen?"
"Short and bulky," she continues, "and it ends with three short spines."

"Congratulations!"

From field to lab

She excitedly hands the dragonfly larva to her clean-handed, latex-gloved partner, who carefully places it into a labeled, resealable zipper storage bag, double-bagged to further prevent contamination. They proceed to identify the sample to family, a determination that is validated in the lab by an odonatologist. Each family maintains a slightly different ecological niche, a variable that can contribute to differences in mercury concentrations.

The samples are preserved on dry ice in the field, then shipped overnight to labs at the University of Maine, Dartmouth College, or the U.S. Geological Survey, where field notes are validated and the samples are analyzed for mercury. Water and sediment samples are collected at the same sampling sites to inform scientists about the influence of environmental characteristics, including pH, dissolved organic carbon, and wetland coverage.

While searching for odonates, citizen scientists also learn about the great diversity of ponds, pools, and other slow-moving (lentic) aquatic systems. Water skimmers, midges, mosquito larvae, and water boatmen are only a handful of other aquatic macroinvertebrates that appear in the sampling nets. Fish, slugs, tadpoles, and baby snapping turtles have also been found, enlightening youth and the public about biodiversity and the influence humans have upon natural systems.

The year is 2011. The NPS director issues a Call to Action in an effort to foster stewardship and engagement in the national parks leading up to the centennial celebration of the National Park Service in 2016. Great Smoky Mountains National Park (North Carolina/Tennessee) agrees to be one of two pilot parks for the citizen scientist study of mercury in dragonfly larvae. A Cherokee High School student yells, "I think I found one!"

About the authors

Colleen Flanagan Pritz *(colleen_flanagan@nps.gov) is an ecologist with the NPS Air Resources Division, Lakewood, Colorado.* ***Sarah Nelson*** *is an associate research professor, University of Maine, Orono.* ***Collin Eagles-Smith*** *is a supervisory research ecologist with the U.S. Geological Survey, Corvallis, Oregon.*

Local experts identify insect biodiversity in Catoctin Mountain Park

By Becky Loncosky

CATOCTIN MOUNTAIN PARK has been expanding its knowledge of the biodiversity of invertebrates in the park through the help of local experts to inventory insects. At just 5,872 acres (2,376 ha) in size, Catoctin is a small park in northern Maryland surrounded by rural and suburban development. The park has been going through environmental changes related to white-tailed deer (*Odocoilius virginiana*) population reduction, and in 2014 completed the fifth year of reductions as prescribed in its deer management plan/environmental impact statement. This work has resulted in a decrease in white-tailed deer from 123 to 36 per square mile (319–93/sq km). Park staff are tracking the rate of tree seedling regeneration and have already seen the first signs of recovery.

But herbivores are not the only animals putting pressure on park forests. Pests and diseases also have had a negative impact, changing understory environments. Dogwood anthracnose (*Discula destructiva*) and hemlock woolly adelgid (*Adelges tsugae*), respectively, are responsible for the loss of many of the understory dogwoods (*Cornus florida*) and eastern hemlocks (*Tsuga canadensis*), which has led to a rise in stream temperatures. The emerald ash borer (*Agrilus planipennis*) is found within 50 miles of the park, and resource managers expect that ash (*Fraxinus*) species will soon decline.

As a result of this dynamic environment and in order to document future changes, the park realized it needed to determine what species of invertebrates live in the park. Insect biodiversity could increase as the forest recovers from deer overpopulation, but the only insect groups to have been studied previously in the park are butterflies and moths (Lepidoptera) and stream macroinvertebrates, from 1987 to 2004. We focused on dragonflies and damselflies (Odonata) initially, followed by ground-beetles and other select Coleoptera (Carabidae, Scarabaeidae, Geotrupidae, Trogidae, Tenebrionidae, Silphidae), and finally bees (Apoidea).

RICHARD ORR

Figure 1 (above). The southern pygmy clubtail (*Lanthus vernalis*), a dragonfly species, is listed as rare in Maryland but was collected as part of the dragonfly-damselfly inventory at Catoctin Mountain Park.

RICHARD ORR

Figure 2. The sable clubtail (*Gomphus rogersi*) is listed as rare, in need of conservation, in Maryland. The nymph form is shown here.

Insect surveys

The surveys were funded through the regional portion of the Natural Resource Protection Program. Costs ranged from $8,200 to $18,800. We contracted two groups of researchers whom we learned about from staff at other parks in the National Capital Region and from our regional Natural Resource and Science office.

Dragonflies and damselflies

Richard Orr of Mid-Atlantic Invertebrate Field Studies (MAIFS) conducted the survey for dragonflies and damselflies in 2009 and sampled all park wetlands, including Owens Creek, Big Hunting Creek, Lantz Marsh, Round Meadow Lagoon, Sawmill

NPS PHOTO

(INSET) JOHN S. STRAZANAC

Figure 3 (inset). ***Chlaenius emarginatus*** **is one of the many ground-beetles inventoried at Catoctin.**

Figure 4. One of the products of the bee survey was a voucher specimen collection prepared for incorporation into the park's museum collection. This is one of two drawers prepared in this manner.

Pond, and Hog Rock Seep. Adults, exuvia (the cast skins of the larvae), and larvae were included in the survey. In total, 28 species of dragonflies and damselflies were found to use park habitats. Two species (southern pygmy clubtail and sable clubtail, figs. 1 and 2) are of conservation importance because of their rarity in Maryland. Data collected from each individual included date, location, and other relevant information and were summarized in a spreadsheet for analysis. In addition, this information was augmented with data from a multiyear survey conducted by the Maryland Department of Natural Resources, which covered all the Catoctin mountains that occur in the state.

Ground-dwelling beetles

The beetle survey was to be focused on wood-boring beetles because of the potential for the loss of so many tree species; however, we were not able to locate a researcher with the needed expertise for this survey. It is difficult to get insect experts to work in our small park. So we contacted researchers at the Smithsonian Institution who directed us to Cynthia Fitzler and John Strazanac. They were interested in doing a ground-beetle survey and had the necessary subject knowledge. This was a fortunate connection, and we used a sole-source contract to secure their involvement.

The researchers collected pitfall trap samples at 15 sites every two weeks for 15 consecutive sampling periods from 5 April to 3 November 2011. Ground-beetles (Carabidae) were the most abundant (3,800 individuals) and species rich (67 species) in six targeted families (fig. 3). Specimens in five other families were identified to species: (1) dung beetles, May and June beetles, and chafers (Scarabaeidae: 17 species collected, 523 individuals); (2) darkling beetles (Tenebrionidae: 8 species, 55 individuals); (3) earth-boring scarab beetles (Geotrupidae: 5 species, 219 individuals); (4) carrion beetles (Silphidae: 5 species, 1,019 individuals); and (5) hide or skin beetles (Trogidae: 1 species, 9 individuals). The researchers assembled a voucher collection that included one of each species of beetle. The final report includes maps of the collecting sites and a species list for each site.

For a park of its size, and compared with other surveys in the region, Catoctin Mountain Park has high species richness in ground-dwelling beetles. The researchers collected and identified 103 species in six families. Thus the park's ground-dwelling species list rose from 11 to 114—a 10-fold increase! This relatively high number of species may be the result of the diversity of the park's forest communities that are at different stages of succession. Recent natural perturbations, like tornadoes and charcoal logging before Catoctin became a national park, have created a dynamic and spatially heterogeneous forest.

Insect biodiversity could increase as the forest recovers from deer overpopulation, but the only insect groups to have been studied previously in the park are butterflies and moths . . . and stream macroinvertebrates.

Bees

Catoctin personnel enrolled in a bee sampling and online identification class offered by the U.S. Geological Survey and carried out the bee-monitoring transect work in 2008. However, making identifications through online resources proved intractable. So we enlisted researcher Richard Orr (MAIFS), who carried out two additional years of bee surveys in 2012 and 2013. The researchers used bee bowl transects (one day or less sampling), propylene glycol cup transects (continuous sampling), and targeted netting during the survey. Catoctin biologists helped Mr. Orr with the bee transects in 2012 and 2013. We targeted various habitats for sampling, including areas that are heavily impacted by nonnative plants, those that were composed primarily of native plants, high- and low-elevation sites, and a location that had burned previously. The three sampling methods yielded 3,004 bees, representing 93 species or species groups. Additionally, 42 bee species had not previously been reported from Frederick County; one of the leaf-cutting bees, *Stelis nitida*, proved to be new for Maryland. Spring woodland native bees are negatively affected by Japanese stiltgrass (*Microstegium vimineum*) and white-tailed deer, which decrease native plant abundance in the park. The researcher provided the park with collection data in spreadsheet form along with a reference collection of the bee specimens (fig. 4, previous page).

Conclusion

Before these surveys Catoctin had next to no information on these three groups of insects. On the original park insect list were only six dragonfly or damselfly species, 11 ground-beetles, and no bees. Now the insect list has been extended from 364 to 588 species, greatly expanding our knowledge of these important insect groups. We are very happy with the products that have come from the surveys, as the species lists and insect collections have already been useful for public outreach and education and will be an important resource in the future when the park conducts repeat surveys.

About the author

Becky Loncosky *is a biologist with Catoctin Mountain Park in Thurmont, Maryland. She can be reached by e-mail at becky_loncosky@nps.gov.*

PS

The Crayfish Corps

By Amy Ruhe

NATIONAL PARK SERVICE

VALLEY CREEK IN VALLEY Forge National Historical Park is threatened by an invasion of rusty crayfish (*Orconectes rusticus*). The last 2 miles (3.2 km) of this creek flows through the park to its confluence with the Schuylkill River in front of General Washington's Headquarters. Historically and ecologically significant, Valley Creek is a state-designated "Exceptional Value Waterway" and Class A Cold-Water Fishery that supports a variety of species, including a naturally reproducing trout population. The rusty crayfish, native to the Ohio River drainage, is an invasive species that was first documented in Pennsylvania in the 1970s. Since its introduction, it has spread into the Delaware, Potomac, Schuylkill, and Susquehanna river watersheds, and in 2008 it found its way into Valley Creek via the Schuylkill River.

Nonnative crayfish are one of the biggest threats to crayfish diversity in North America (Butler et al. 2003), with urbanization and associated habitat destruction also posing a significant threat to Pennsylvania's native crayfish species (Lieb and Carline 1999, 2000; Butler et al. 2003). Crayfish can make up more than 50% of the invertebrate biomass in streams and rivers and are an important food source for trout and other large fish, transferring energy and nutrients up the food chain (Huryn and Wallace 1987; Momot 1995). Rusty crayfish are highly aggressive, which, combined with their larger body size and voracious appetite, gives them a competitive advantage over Pennsylvania's native crayfish species. In addition to direct competition for resources, rusty crayfish displace native species from preferred habitat, making native crayfish more susceptible to predators as they move to find unoccupied spaces and diminishing foodstuffs. The thicker exoskeleton and aggressive defense posture of the rusty crayfish also make them less vulnerable to fish and other predators than native species (Garvey et al. 1994). Once established, rusty crayfish can disrupt the entire aquatic ecosystem by eliminating native crayfish species, reducing or eliminating aquatic vegetation, reducing the abundance and diversity of aquatic insect populations, and ultimately affecting predators such as trout.

A 2003 crayfish inventory did not find rusty crayfish in Valley Creek but did document two crayfish species, one of which was a previously undescribed species and a member of a species complex (*Cambarus acuminatus*) that had not been documented in Pennsylvania. Results from ongoing surveys in the area suggest that the range of the previously undescribed species is likely restricted to Valley Creek and a few nearby streams, and that it is probably native to the state (Lieb et al. 2007b). Additional research is needed to determine whether this crayfish is a new or introduced species; however, if it is a native species, it is possibly one of the most threatened aquatic species in Pennsylvania because of its limited range, proximity to urban centers, and nearby populations of rusty crayfish (Lieb et al. 2007a). Based on recommendations from crayfish and aquatic invertebrate specialists, the park decided to manage the crayfish as a new species until additional evidence indicates that it is not native.

Managing the invasion

Following the 2008 discovery of the rusty crayfish in Valley Creek, park staff quickly assessed the extent of the invasion and determined that the initial density of this species was approximately one in every four crayfish sampled. Without quick action the population was likely to explode. Valley Forge National Historical Park is situated as the first line of defense in the 24-square-mile (62 sq km) Valley Creek watershed and, with only a small natural resource staff available to manage the invasion, the park established the Crayfish Corps in 2009 to protect aquatic biodiversity and the potentially new crayfish species. From April to October, volunteers from schools, summer camps, corporate groups, conservation organizations, families, and other park neighbors don hip waders and enter Valley Creek to catch and remove rusty crayfish using only nets and muscle (fig. 1, next page). The park investigated additional suppression methods to help control rusty crayfish in Valley Creek, including chemical treatments, electrical barriers, and trapping. These methods have the potential to control the

NPS PHOTO

Figure 1. Members of the Valley Forge Crayfish Corps remove invasive rusty crayfish from Valley Creek, a state-designated "Exceptional Value Waterway."

rusty population but are nonselective, and could significantly impact native crayfish and other nontarget aquatic species. Crayfish Corps is proving to be an effective method to selectively suppress the rusty crayfish population while minimizing impacts to other species.

The Crayfish Corps is one of three resource stewardship activities that make up Valley Forge's Stewards of Native Diversity program, a natural resource initiative that focuses on the preservation and restoration of native biodiversity. These programs are designed to engage youth in meaningful stewardship activities and promote hands-on learning to achieve resource management goals. Under the direction of National Park Service staff, Crayfish Corps participants systematically search sections of Valley Creek, removing rusty crayfish while counting and releasing native crayfish. They learn proper search and capture techniques, how to minimize habitat disturbance, species identification, and the impact of rusty crayfish on native diversity. In addition to hands-on learning in the field, the park created lesson plans to link field activities back to the classroom, making the program increasingly popular with local schools. Promotional brochures, buttons, and T-shirts featuring the Crayfish Corps logo (previous page, at top) help promote the program with park visitors and families and encourage long-term engagement. During the last four years, more than 6,000 volunteer hours have resulted in the removal of more than 11,000 rusty crayfish and achievement of the park's goal of suppressing the invasive species' population so that it remains at initial invasion levels. Focused on the creation of future park stewards and management of park biodiversity, the Crayfish Corps is now the park's most popular volunteer program and the only one in which the majority of participants are under age 18.

In addition to contributions from volunteers, hundreds of staff hours are spent each summer supervising participants, catching crayfish, and collecting, managing, and analyzing data. To inform the resource management strategy and promote science-based decision making, park staff collect data on stream temperature, species captured, location, sex, reproductive status, volunteer efforts, and size. Subsequent analysis enables staff to evaluate changes in the relative abundance of crayfish species, determine trends, understand changes in population structure, and assess the overall efficiency and effectiveness of the program. The analysis indicates that through the Crayfish Corps the park has managed to maintain a native–to–rusty crayfish ratio of 4:1, preventing the loss of native crayfish species and helping to maintain biodiversity in the aquatic ecosystem. Additionally, the average total body length of rusty crayfish is decreasing, which indicates that the Crayfish Corps is effectively removing most of the large reproductive individuals. Interestingly, data also indicate that stream sections with cooler average water temperatures (coincidently the sections with the most well-established riparian buffers) have fewer rusty crayfish than warmer sections, and that an old dam near Valley Creek's confluence with the Schuylkill River may be slowing the movement of rustys into the watershed. We presented these results at the 2011 George Wright Society meeting and the Schuylkill Watershed Congress.

Continued vigilance

To help prevent the continued spread of the species, the park incorporated a "no live bait" policy into its superintendent's compendium and regularly provides literature and educational materials about invasive species to park visitors. In 2012 a

[Participants] learn proper search and capture techniques, how to minimize habitat disturbance, species identification, and the impact of rusty crayfish on native diversity.

park internship project investigating the relative abundance and distribution of the three crayfish species in the Valley Creek watershed found, unfortunately, that the rusty crayfish has continued to advance up Valley Creek beyond the park boundary. Valley Forge National Historical Park is working with partners at Valley Forge Trout Unlimited, Stroud Water Research Center, and Cabrini College to develop a Crayfish Corps that extends into stream sections outside the park to help suppress the invasion as it moves farther up the watershed.

Valley Forge National Historical Park translated an urgent need for invasive species control into the most popular multiage volunteer program at the park. Through volunteer help and community support, a small natural resource staff are able to effectively control an immediate threat to biodiversity while engaging thousands of volunteers in hands-on lessons in the importance of stewardship. As parks face limited budgets and staff, this program can serve as a model for achieving invasive species control, citizen engagement, and biodiversity management.

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About the author

Amy Ruhe *(amy_ruhe@nps.gov) is a biologist at Valley Forge National Historical Park in Pennsylvania.*

PS

Pollinators

Pollinators in peril? A multipark approach to evaluating bee communities in habitats vulnerable to effects from climate change

By Jessica Rykken, Ann Rodman, Sam Droege, and Ralph Grundel

CAN YOU NAME FIVE BEES IN your park? Ten? Twenty? Will they all be there 50 years from now? We know that pollinators are key to maintaining healthy ecosystems—from managed almond orchards to wild mountain meadows—and we have heard about dramatic population declines of the agricultural workhorse, the honey bee, yet what do we really know about the remarkable diversity and resilience of native bees in our national parks?

A large proportion of flowering plants in most parks rely on insect pollinators for successful reproduction, and native bees are almost always the most efficient and diverse of these insects, with 3,604 described species in North America north of Mexico, and what are thought to be another 400 undescribed ones. Bees are known to be at risk from various human-mediated threats, such as habitat loss and alteration, pesticides, introduced parasites, and invasive plant and insect species. Climate change also poses a significant risk to native bees, with potential consequences including range shifts (especially upslope or northward), population declines, and mismatches in the phenology of plant-pollinator relationships.

At particular risk are bee communities (including rare and endemic species) in habitats most vulnerable to effects from warming temperatures, altered climates, and rising seas. These include high-elevation meadows, inland arid areas, and coastal dunes—in other words, many of the iconic landscapes protected in our national parks. In fact, the geographically and ecologically diverse landscapes preserved and protected by the National Park Service provide an ideal natural laboratory in which to investigate large-scale patterns of bee distribution in sensitive habitats and to model how strongly climate change may affect these patterns.

In 2010, collaborators from the National Park Service (Ann Rodman, Yellowstone National Park), USGS (Sam Droege and Ralph Grundel), and Harvard University (Jessica Rykken) were awarded funding from the NPS Climate Change Response Program to launch just such an investigation in almost 50 units of the National Park System (fig. 1). The main objectives of this multiyear project were to:

1. Compare bee communities in three "vulnerable" habitats (high elevation, inland arid, coastal) and paired "common" habitats, representative of the landscape matrix, in order to determine whether vulnerable habitats

Figure 1. Forty-six parks in the National Park System participated in the bee inventory research.

have a distinctive bee fauna that may be at higher risk under climate change scenarios.

2. Inform natural resource managers at each park about the bee fauna at their paired sites, including the presence of rare and endemic species, and make suggestions for active management strategies to promote native bee habitat if warranted.

3. Increase awareness among park natural resource staffs, interpreters, and visitors of native bee diversity and natural history, the essential role of bees in maintaining healthy ecosystems, and potential threats from climate change to pollinator-dependent ecosystems.

The challenge of a multipark approach

The project was designed so that the cost and effort of sampling for each park would be minimal, while the information provided by uniformly collected bee data from dozens of parks across the continent would be of unprecedented scope and power. Each park was responsible for selecting a pair of vulnerable and common sites and then sampling both sites five times between the earliest spring flowering and the end of the blooming period in the fall. Sampling procedures were designed to be simple, repeatable, and volunteer-friendly. At each of the two sites, 30 "bee bowls" were set out along a transect, spaced 5 m (16 ft) apart. The cups were painted blue, yellow, and white to resemble flowers and attract bees (fig. 2). Once inside the "flower," bees were trapped in soapy water. Ideally, bowls were left out for 24 hours when conditions were calm and sunny. Bees were then collected, labeled, bagged, and sent off for identification. To facilitate communication between project organizers and participating parks, a "bees in parks" e-mail list was set up early on. This was useful for discussions about where and when to sample (which varied greatly depending on park location, habitat, and local climate) and, later, to pass along interesting bee discoveries directly from bee biologists to parks.

NPS PHOTO

Figure 2. Collecting bees involves pouring the contents from one of the painted "bee bowls" through a strainer. Contents from all 30 bowls of a transect were combined, transferred to a plastic bag, and shipped to the bee lab in Maryland.

As is commonly the case with insect biodiversity studies, collecting is the easy part. One of the largest challenges for a project of this scale is preparing, identifying, and databasing the tens of thousands of specimens that can be sampled in a relatively short period of time. With bees coming in from Alaska to Maine, southern California to Florida, and everywhere in between (fig. 1), the potential number of specimens and the pool of possible species (several thousand) were somewhere between thrilling and completely overwhelming. USGS biologist Sam Droege took on the herculean task of processing all the bees at his Bee Inventory and Monitoring Lab at the Patuxent Wildlife Research Center in Beltsville, Maryland, where his efficiency rating ("bees per minute") rises ever higher in the nimble hands of high school and college students. Identification of the bulk of the eastern bees and some of the western bees was also completed within his lab; however, most of the western bees were sent to the USDA Bee Biology and Systematics Lab in Logan, Utah.

Preliminary results: Many cool bees!

A total of 46 national park units participated in the study (fig. 1). These included 30 national parks, preserves, and monuments; 10 national lakeshores and seashores; and six national recreation areas, historical parks, and parkways. All NPS regions in the lower 48 states (with the exception of the National Capital Region) were well represented, as were Alaska and the Virgin Islands. Several parks without any of the target vulnerable habitats also participated in order to enhance their knowledge of local bees in other sensitive habitats. In Alaskan parks, all habitats were considered potentially vulnerable to

Figure 3. The eastern sweat bee, *Augochlorella aurata*, one of the most common bees in eastern North America, and the most abundant bee in the study. Color varies from metallic deep purple (above left) (Cumberland Island, Ga.) to green (above right) (Md.), depending on the region.

Figure 4. A dorsal shot of a sweat bee, *Lasioglossum marinum*, from Fort Matanzas (Fla.). As its name suggests, this bee is a coastal dune specialist and builds its nest in deep sand.

Figure 5. The mason bee, *Dianthidium simile*, is a rare dune specialist, found on the shores of the Great Lakes (this one is from Sleeping Bear Dunes, Mich.). Females build nests at the base of grass clumps; cells are constructed of conifer resin and sand grains.

USGS BEE INVENTORY AND MONITORING LAB (4)

climate change because of their northern location. Many parks also placed a transect near a visitor center for interpretive value, and some parks added transects in additional habitats. Among them, the 46 parks ran an impressive 809 bee bowl transects, sampling more than 43,000 bees from 2010 to 2013.

Full sets of results have been completed for some parks and regions (mostly in the eastern and midwestern United States), but the enormous task of identifying all the western bees has fallen to a very few western taxonomists, and many of these identifications are still pending. Additionally, there are some taxa that are so diverse and difficult to separate (e.g., the diabolical subgenus *Dialictus*, with almost 100 species in eastern North America alone) that some or all of these bees have been passed on to individual specialists around the country (see acknowledgments). As is also often the case with insect biodiversity studies, taxonomists are in short supply and in high demand. To date, more than 25,000 specimens have been identified, representing 43 genera and approximately 685 species. Among these are many interesting discoveries.

Some bee species are noteworthy because they are so abundant or widespread. Not surprisingly, the nonnative honey bee (*Apis mellifera*) showed up in relatively large numbers in half the parks surveyed, all across the continent. Other cosmopolitan "weedy" (but native) species included the two sweat bees *Halictus confusus* and *H. rubicundus*, both found in 17 parks, the latter from Redwood (Calif.) to Glacier (Mont.) to Assateague Island (Md.). The most commonly collected bee overall, with 2,012 individuals (4.6% of the bee total), was *Augochlorella aurata*, a brilliant green sweat bee found in 17 parks, from Big Thicket (Tex.) eastward (fig. 3). In a previous study at Indiana Dunes (Grundel et al. 2011), this species was also the most frequently captured bee, making up 16% of all bees surveyed, and was observed on more than 60 plant species, suggesting that this generalist forager is a pollination workhorse in the eastern parks.

Of greater interest to this project were the habitat specialists, some of which were also very abundant across parks. For instance, more than 1,000 individuals of *Lasioglossum marinum*, a coastal dune specialist, were found in seven parks down the Atlantic coast, from Boston Harbor Islands (Mass.) to Biscayne (Fla.) (fig. 4). In contrast, the polyester bee *Colletes brevicornis*, found only in the dune site at Assateague Island (Md.), is a much rarer dune specialist restricted to the Atlantic coastal plain. The mason bees *Dianthidium simile* (fig. 5) and *Osmia michiganensis* are also rare dune specialists, but are found on the shores of the Great Lakes. These and other species that depend on deep sand for nesting suggest that dune habitats of lakeshores and seashores do have a distinctive fauna, including rare and endemic species (see sidebar, page 88). If sea and lake levels change with warming climates, or extreme weather events like Hurricane Sandy reshape coastlines, these bee communities are at risk of losing habitat.

As the two other focal habitats (inland arid and high elevation, figs. 6 and 7) are concentrated in the western United States, we are still awaiting species data, and thus patterns of bee diversity across these landscapes are not yet clear. However, interesting discoveries have already been made. For instance, the digger bee, *Habropoda pallida*, found at Mojave (Calif.), is a dune specialist from the desert Southwest, thought to be a specialist on creosote bush. The tiny desert-dwelling mining bee, *Perdita albihirta*, collected at Petrified Forest (Ariz.), is not well-known, but is probably a pollen specialist like many of its relatives (fig. 8). Michael Orr from the Logan bee lab, who has been working with many of the western bees, has emphasized

Figure 8 (above). This tiny mining bee, *Perdita albihirta geraeae*, collected at Petrified Forest (Ariz.), measures just a few millimeters long.

USGS BEE INVENTORY AND MONITORING LAB (2)

Figure 9. Prior to being collected at Canaveral National Seashore (Fla.) in 2013, there had been no collection records for the southeastern endemic polyester bee, *Colletes titusensis*, since 1938.

the importance of collecting in undersampled areas (i.e., most of our national parks), and illustrates this point with two specimens from Santa Monica Mountains (near Malibu, Calif.) that look very much like the cactus bee, *Diadasia australis*, but are likely a new undescribed species.

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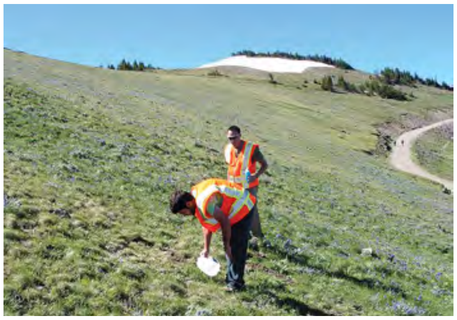


NPS PHOTO

Figure 6 (top). Arid dune pollinator habitat at Mojave National Preserve.

Figure 7. Interns set up a transect of bee bowls at a high-elevation meadow site at Yellowstone National Park.

Bumble bees are another group of bees of great conservation interest, as several species have shown precipitous declines in all or parts of their ranges during the last two decades. These hardy bees make up a large component of high-elevation and northern-latitude bee faunas, so as results come in from western mountain and Alaska parks, we hope to contribute important range information that will help us assess the status of bumble bees in these regions.

In the deep South, many rare and unusual discoveries are being made in Florida parks, including sand specialists, such as the metallic sweat bee *Augochloropsis anonyma* from Biscayne and Canaveral, and the rarely collected southeastern endemic, *Dianthidium floridiense*. Another exciting find at Canaveral was the polyester bee *Colletes titusensis*, named after the town nearest to Canaveral, Titusville (fig. 9). The last recorded specimen of this rare endemic was collected in 1938.

Next steps: Discerning patterns and making links to climate change

Once the 43,000+ bee records for all 46 parks are complete and ready for analysis, the resulting database will represent the largest replicated survey of native pollinators anywhere in the world. The study design allows analysis of bee diversity and distribution patterns at multiple scales. For instance, we can compare bee communities between vulnerable and common habitats within individual parks to determine whether vulnerable habitats have more rare and endemic species or are distinctive in other parameters (e.g., species richness, diversity, nesting guilds, proportions of floral specialists or parasitic bees). This already seems to be the case with coastal and lakeshore dune habitats, where we have found many dune specialists (see sidebar, next page).

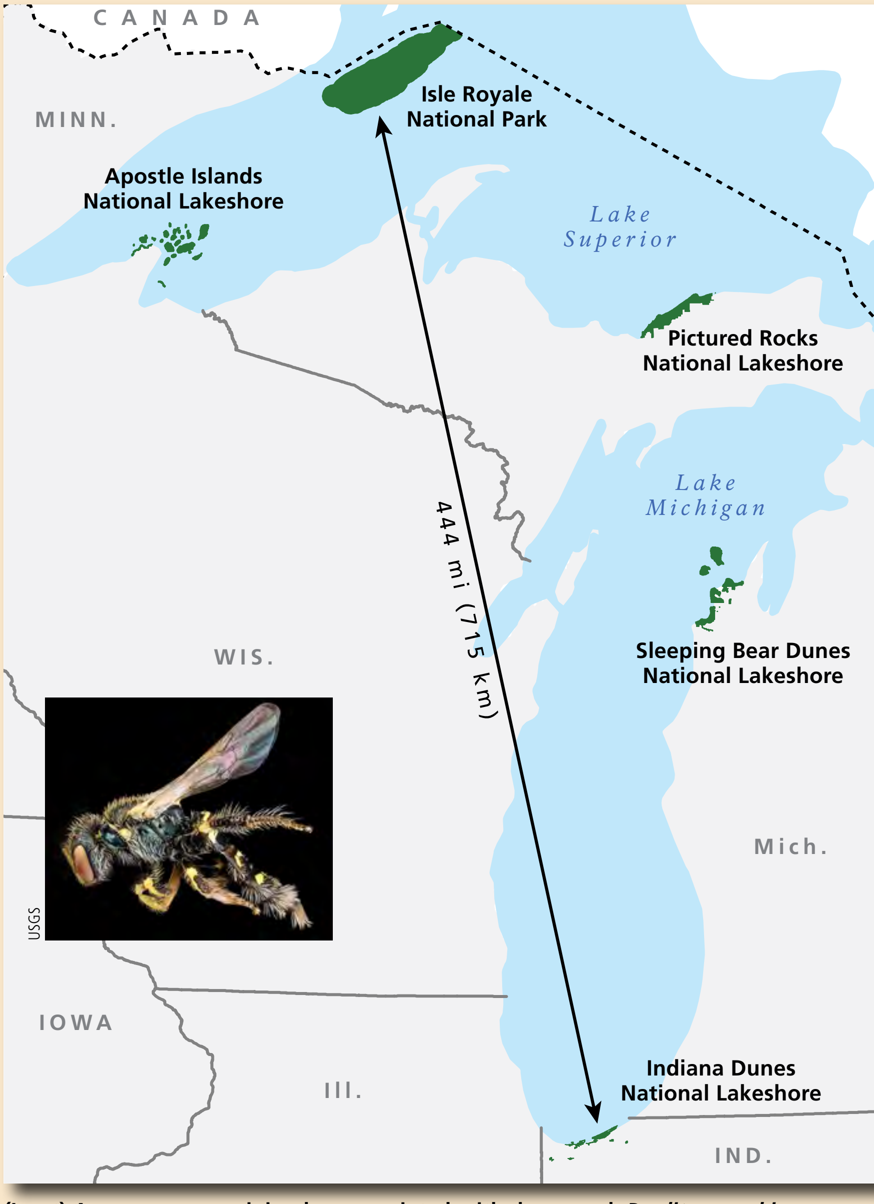
We can also make these comparisons across regions to determine whether, for example, bee communities in coastal dune sites across the Atlantic coastal plain are more similar to each other than bee communities in paired vulnerable-common sites within parks are to each other. If so, this indicates a strong regional "dune signal" (versus a "park signal") and suggests that we can assess the threats of climate change to these more vulnerable habitats at a regional scale, and perhaps also develop regional management guidelines and conservation partnerships. Similarly, we will make these comparisons for dune

Great Lakes Pollinators

By Jessica Rykken, Ann Rodman, Sam Droege, and Ralph Grundel

The lakeshore dune site at Pictured Rocks (Mich.) on Lake Superior.

Around the western Great Lakes, bees were sampled at five parks (see map) in paired foredune and inland habitats. The two habitats were compared within and between parks (photo, at left). Dune ecosystems are often restricted to a narrow zone near the Great Lakes, and we might expect that species inhabiting such restricted habitats are more vulnerable to extirpation from changing climate than bees in more common inland habitats. Although parks in this region are separated by up to 715 km (444 mi), a site in one of the habitat types (dune or inland) shared more bee species with like habitats across parks than it did with its paired (different) habitat within the same park (fig. 1). The marked difference between dune and inland bee communities suggests that forces of environmental change differentially affecting habitat types across this region will act on different sets of pollinators (fig. 2).



(Inset) An uncommon mining bee associated with deep sand, *Perdita swenki,* was found in large numbers at the vulnerable lakeshore dune site at Pictured Rocks. It was also found in the dunes at Indiana Dunes (Ind.) and Gateway (N.Y.).

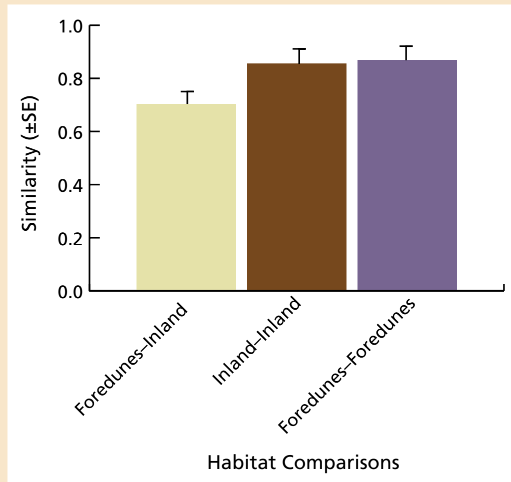


Figure 1. Bee species are more similar among like habitats (foredunes or inland) across five different parks than they are among foredune/inland–paired habitats within parks.

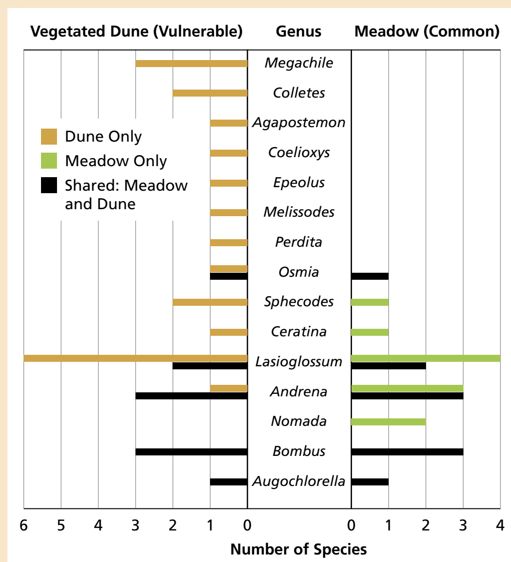


Figure 2. Comparison of bee species richness in vegetated dune (vulnerable) and meadow (common) sites at Pictured Rocks (Mich.), showing the number of species unique to each habitat type.

The geographically and ecologically diverse landscapes preserved and protected by the National Park Service provide an ideal natural laboratory in which to investigate large-scale patterns of bee distribution in sensitive habitats and to model how strongly climate change may affect these patterns.

versus inland communities on the Great Lakes and the Pacific coast, for sand-dominated areas versus other open habitats in southwestern deserts, for subalpine/alpine versus lower-elevation meadows in the western mountains and in subarctic regions of Alaska, and so on. Ordination and regression analyses will help us decipher what the dominant environmental (e.g., elevation, latitude, aspect, soil type) and climatic (e.g., mean air temperature, precipitation) drivers are for any patterns we see within and across habitats.

We are developing climate summaries for each sampling location that compare historical and current conditions with future predictions from the latest downscaled climate models. Climate changes are already evident, but the change is not uniform across the country. Rates of change in temperature and precipitation patterns, especially the timing during the growing season, will likely have profound effects on the future makeup of a park's native bee populations. With these climate data we can begin to make predictions about the fate of bee communities. By examining species distributions across the environmental and climatic gradients surveyed, we can comment on the likelihood that a particular species will persist under new regimes of these gradients, such as a new combination of mean temperature and different soil type. Predictions for individual species can be combined and scaled up into estimates of effects of climate change on entire bee communities.

Long-term monitoring of bee communities from sensitive and common habitats in any of the 46 parks will also be possible now that we have established a baseline against which we can measure change. The sampling protocols are simple to repeat and can be replicated in many other habitats of interest. Monitoring to assess the trajectories of bee abundance, richness, and other parameters in climate-sensitive habitats may be especially informative on a regional scale.

Catching the buzz: Getting the word out about bees

Another key objective of the project was to educate park staff, volunteers, and visitors about the remarkable diversity and ecological importance of native bees, as well as their potential vulnerabilities to climate change. We encouraged parks to actively engage interns, volunteers, and citizen science groups by recruiting them to run the sampling transects. For example, a group of Virginia Master Naturalists ran samples at George Washington Birthplace (Va.), while Santa Monica Mountains and Channel Islands (Calif.) combined forces to train students from two local colleges and an after-school youth leadership program to collect their bees. Student Conservation Association and Youth Conservation Corps volunteers sampled bees from high-elevation meadows in Yellowstone (Wyo.). Great Basin (Nev.) cleverly timed some of its bee sampling to coincide with its Hymenoptera bioblitz. It is clear that more than a few office-bound permanent NPS staff saw bee sampling as an ideal opportunity to escape their offices for a pleasant sunny day in habitats abuzz with flowers and bees. Who can blame them?

Each participating park will receive a summary of the bee data collected at its site in the form of a two-page resource brief, and species data will be available digitally through the Inventory and Monitoring Program's NPSpecies database. The resource brief will include a description of the sampling methods and a map of the transect locations (for future reference), a graphical comparison of the species found in common and vulnerable sites, a discussion of significant finds, contrasts, predicted risks to bees in vulnerable habitats with climate change, and suggestions for management actions or conservation concerns if warranted. These may include maintaining or restoring host plants for bee specialists or ensuring the availability of suitable nesting sites. The briefs will provide an effective way to share information about the project with administrators, resource managers, scientists, interpreters, and visitors. We will also prepare regional resource briefs to summarize findings in vulnerable habitats across regions and to suggest regional management guidelines.

We want to provide parks with engaging interpretive tools. For example, we can know a lot about bees, appreciate them as pollinators, and feel concern for their well-being in the face of environmental threats, but it is difficult to truly connect with an organism you can't see very well. Perhaps one can fall for the charm of a bumble bee, but most bees are just too small to admire aesthetically. Sam Droege and colleagues have been working hard to overcome this problem with a cost-effective camera setup for putting even the tiniest sand-dwelling *Perdita* bees in a highly magnified spotlight (bottom photo, page 88). Several hundred images of bees collected in national parks, demonstrating a magnificent diversity of form, color, texture, and pelage, are available for any type of educational use at www.flickr.com/photos/usgsbiml/sets/72157630468656672 (with many additional western species in the photographic queue).

Once the 43,000+ bee records for all 46 parks are complete and ready for analysis, the resulting database will represent the largest replicated survey of native pollinators anywhere in the world. The study design allows analysis of bee diversity and distribution patterns at multiple scales.

Another (free) resource for fostering an appreciation for the diversity of bee bodies, natural history, ecology, and behavior is Bee Observer Cards, which were developed collaboratively by the Encyclopedia of Life and the Farrell Lab at Harvard University. Much of this work was funded by the National Park Service for this bee project, and all participating parks will receive hard-copy decks of the cards, which can also be downloaded electronically from eol.org/info/498.

In the end, among the most significant outcomes of this ambitious project will be the simplest: an awareness that native bees deserve attention in our national parks, and a realization that there are important discoveries to be made in almost any habitat we choose to investigate. Many parks have already engaged in new bee-focused activities as a result of their participation in the project. For example, at Fire Island (N.Y.), interpretive programs highlighting native bee diversity are planned at the William Floyd Estate this season; at Organ Pipe Cactus (Ariz.), new sampling transects were set up to document the bee fauna associated with an endangered acuña cactus; and at Isle Royale (Mich.), a college intern was recruited to extend its collections and photograph bees. Says Paul Brown, chief of natural resources at Isle Royale, "Prior to the study we knew of only a handful of bee species on the island . . . now we are aware of over 60 species." We hope the success and relevance of this work will inspire even more parks to catch the buzz.

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Acknowledgments

Quite simply, without skilled taxonomists we could generate no data from biodiversity studies. The following taxonomists are identifying tens of thousands of bees for this project: Michael Arduser, John Ascher, Jason Gibbs, Terry Griswold, Kimberly Huntzinger, Jonathan Koch, Michael Orr, and Karen Wright.

Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. government. This article is contribution 1854 of the U.S. Geological Survey Great Lakes Science Center.

About the authors

Jessica Rykken *(jrykken@oeb.harvard.edu) is an associate with the Farrell Lab, Harvard University Museum of Comparative Zoology, in Cambridge, Massachusetts.* ***Ann Rodman*** *(ann_rodman@nps.gov) is branch chief for Physical Resources and Climate Science at Yellowstone National Park, Wyoming.* ***Sam Droege*** *(sdroege@usgs.gov) is a research wildlife biologist with the USGS Patuxent Wildlife Research Center in Beltsville, Maryland.* ***Ralph Grundel*** *(rgrundel@usgs.gov) is a research ecologist with the USGS Great Lakes Science Center in Porter, Indiana.*

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Insect pollinators of Denali: A survey of bees and flower flies

By Jessica Rykken

DENALI NATIONAL PARK and Preserve's Researcher-in-Residence program, coordinated by the Murie Science and Learning Center, was created to bring academic and other researchers to Denali (Alaska) and to facilitate sharing of knowledge and resources among scientists and Denali resources staff, interpreters, and visitors. For obvious reasons, much of the wildlife research carried out in Denali's vast wilderness to date has focused on the "big five" (caribou, wolves, grizzly bears, moose, and Dall's sheep). However, in 2012, my proposal to survey "the other fur-bearers" of Denali, namely insect pollinators, was met with great enthusiasm by park staff, and I was awarded the grant.

Pollinators are critical to maintaining healthy plant communities and functioning ecosystems, and in the subarctic wilderness of Denali they may be especially vulnerable to effects from climate change. Changes in pollinator diversity, abundance, phenology (e.g., timing of pollinator emergence and foraging activity), and range over time may also serve as effective indicators of change for larger ecosystem processes. Establishing baseline data on these insects has potential long-term benefits for monitoring, in addition to giving the park new information about lesser-known realms of biodiversity.

The survey focused on bees (Hymenoptera: Anthophila) and flower flies (Diptera: Syrphidae). I spent five weeks collecting these pollinators in various habitats along the 145 km (90 mi) park road, and was joined by park staff and volunteers on several days. Collecting techniques included active netting and two types of traps: "bee bowls" (small painted cups filled with soapy water) laid out in transects and individual "vane traps," which lure pollinators into a blue vane attached to a collecting jar. Focal habitats included alpine and shrub tundra, rocky ridges and summits, river gravel bars, edges of roads and trails, and lower-elevation meadows.

JESSICA RYKKEN

A male ***Bombus sylvicola*** **(forest bumble bee) feeds on Eskimo potato (*****Hedysarum alpinum*****).**

JESSICA RYKKEN

The author with net: Looking for pollinators in an Alaska summer often requires a wool hat and rain gear.

JESSICA RYKKEN

Vane trap: Pollinators are attracted to the blue color of the trap.

THE PRESIDENT AND FELLOWS OF HARVARD COLLEGE

Bombus balteatus**, the golden-belted bumble bee, is a species of high elevations and latitudes.**

In all, the survey yielded 13 species of bumble bees (502 specimens), 7 species of solitary and parasitic bees (50 specimens), and 42 species of flower flies (328 specimens). Bees were identified by me, with assistance from Jamie Strange and Terry Griswold at the USDA Agricultural Research Service Bee Biology and Systematics Lab in Logan, Utah; all flower flies were identified by F. C. Thompson at the Smithsonian Institution. Among the pollinators were one

CONTINUED ON PAGE 93

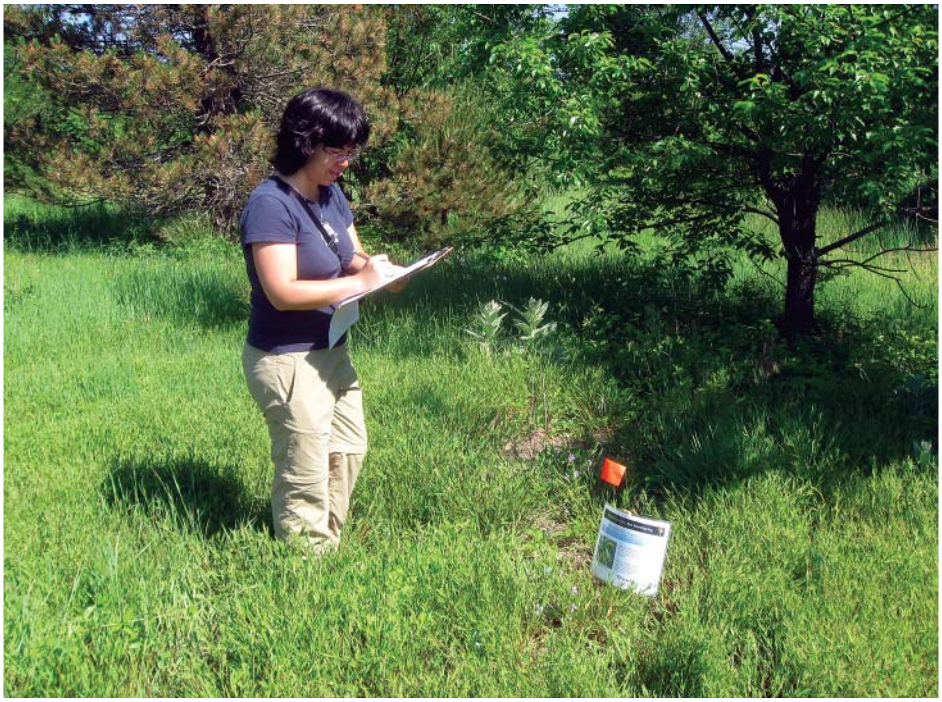
Monitoring bee diversity and abundance in Boston Harbor Islands National Recreation Area: A pilot study

By Jessica Rykken

BOSTON HARBOR ISLANDS received NPS Challenge Cost Share Funding in 2010 to pilot a native bee monitoring project. This extended the first phase of an All-Taxa Biodiversity Inventory (focused on terrestrial arthropods) the park had been conducting for the previous five years in collaboration with Harvard University's Museum of Comparative Zoology. Globally, bees have been of conservation concern because of their critical role as pollinators in natural and agricultural ecosystems, but populations of many species are declining and there is evidence to suggest that their ranges are shifting in response to changing climates. Native bees are an ideal group to monitor on the Boston Harbor Islands because they are diverse and abundant, easy to sample with a standardized, repeatable protocol, and have a taxonomy that is relatively well known.

The two main objectives of the project were (1) to develop and pilot a monitoring program with adequate power to detect relatively small changes in bee abundance and diversity over five-year intervals, and (2) to assess the feasibility of involving citizen scientists in all phases of the project, including field collecting and lab processing. We used "bee bowls" (small painted cups filled with soapy water) to sample bees. Each sampling transect comprised 30 bee bowls spaced 5 m (16 ft) apart. Sixteen transects were set up on nine islands and sampled at intervals during the blooming season (April to October). This work yielded an impressive 3,938 identified bees, comprising 104 species (approximately 60% of the total bee diversity known from the islands) and including 23 new park records. Among the bees were 26 "cleptoparasitic" species, also called "cuckoo bees." As their name suggests, cuckoo bees lay their eggs in the nests of other host bees, and their developing larvae kill the host progeny and eat their pollen and nectar provisions. Cuckoo bees are thought to be good indicators of the health of the entire bee community, as they are dependent on robust host bee populations for their survival. Three nonnative bees, *Apis mellifera* (honey bee, introduced by European colonists in the 1600s), *Andrena wilkella*, and *Lasioglossum leucozonium*,

The project involved developing a foldout field guide to bee genera found at Boston Harbor Islands NRA.



JESSICA RYKKEN

A volunteer records data while setting out bee bowls on a warm, sunny day—just right for pollinators.

were collected in small numbers; none are of management concern for the park.

In addition to one full-time entomologist from the Museum of Comparative Zoology (me) and one dedicated paid intern, 24 students, volunteers, NPS staff, and other professionals logged more than 450 hours with the project, including 57 field hours and 394 hours in the lab sorting, pinning, labeling, and databasing specimens. I identified the majority of the bees with assistance from Sam Droege at the USGS Patuxent Wildlife Research Center, Beltsville, Maryland, who also helped with developing the statistical design for the monitoring program, and John Ascher at the American Museum of Natural History. This project successfully integrated scientific and community involvement goals. All sampling and processing protocols were developed and documented with citizen scientists in mind, so that they will be easily replicable in future monitoring efforts. We also produced a field guide to the bees of the Boston Harbor Islands, which includes photos and descriptions of 24 bee genera found in the park and provides easily accessible information about important park pollinators to park staff, volunteers, and visitors alike.

JESSICA RYKKEN

Signs were set out at both ends of each bee bowl transect to inform passersby about the bee monitoring project and to ensure that the cups were not mistaken for trash.

About the author

Jessica Rykken *(jrykken@oeb.harvard.edu) is an associate with the Farrell Lab, Harvard University Museum of Comparative Zoology, in Cambridge, Massachusetts.*

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“DENALI” CONTINUED FROM PAGE 91

specimen of *Bombus occidentalis*, a bumble bee that has all but disappeared farther south in its range but is apparently thriving in many locations in interior Alaska, and a single specimen of a flower fly new to science in the genus *Cheilosia*. Several of the flower flies represent new published records for the state of Alaska, and almost all species, with the exception of at least seven bumble bees, are new records for the park.

Denali’s Researcher-in-Residence program also promotes outreach, and at the park I engaged in various activities to educate park staff and visitors about Denali’s pollinators. This included leading a “Denali-ology” seminar; delivering presentations to the public, interpretive staff, and natural resource management staff; and giving weekly microscope sessions at the Murie Science and Learning Center to show visitors the diversity of pollinators up close. After leaving Denali I worked with park staff to create a pollinator fact sheet for the park, and I’m currently collaborating on a “Virtual Tour of Denali Pollinators” for the visitor center and the Denali Web site.

About the author

Jessica Rykken *(jrykken@oeb.harvard.edu) is an associate at the Museum of Comparative Zoology, Harvard University, in Cambridge, Massachusetts. She has been involved in biodiversity discovery work at Acadia National Park, Boston Harbor Islands NRA, George Washington Birthplace National Monument, and Yellowstone National Park.*

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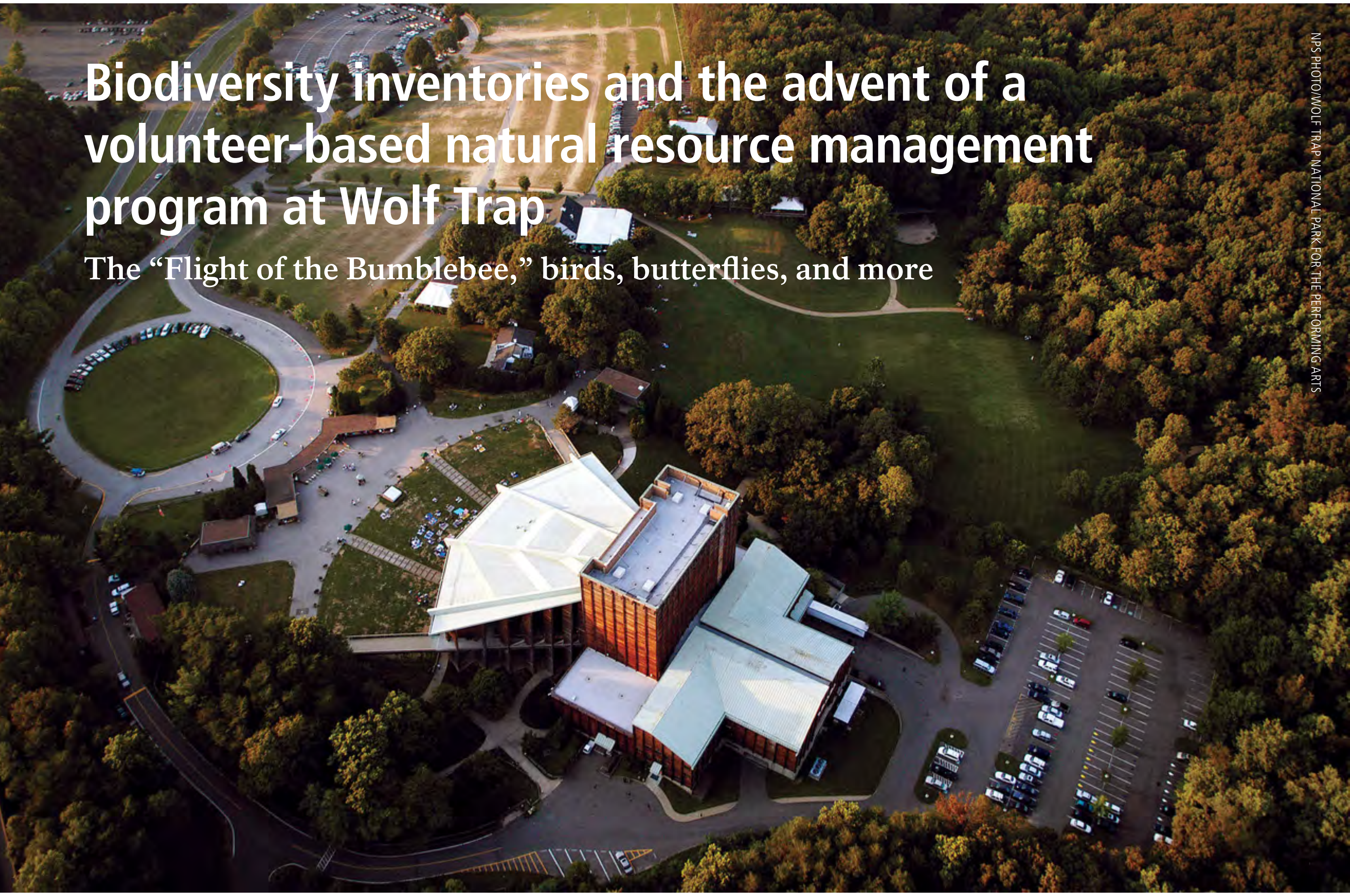
Cultural Sites and Biodiversity

Biodiversity inventories and the advent of a volunteer-based natural resource management program at Wolf Trap

The "Flight of the Bumblebee," birds, butterflies, and more



NPS PHOTO/WOLF TRAP NATIONAL PARK FOR THE PERFORMING ARTS

Figure 1. For tens of thousands of visitors annually, the performance at Wolf Trap is all they are exposed to. However, surrounding this venue is approximately 60 acres of naturalized landscape complete with two streams, a pond, and a newly implemented hiking trail.

By Christopher Schuster

LONG REGARDED FOR ITS outdoor performing arts venue, Wolf Trap now incorporates a focus on natural resources. Wolf Trap was established in 1966 as the first, and still only, national park devoted to the performing arts. The complex is the direct result of the energy and philanthropy of Catherine Filene Shouse, who donated the land, partially funded a theater building, and spearheaded the legislative effort to establish the park. The Filene Center, which seats approximately 3,500 people under cover and 3,500 more outdoors on a sloping lawn, is the centerpiece of the park and has been hosting performances every summer since 1971 (fig. 1). An 800-seat outdoor amphitheater, the Children's Theatre-in-the-Woods, is also tucked away next to the stream that runs through the park.

An integral part of Ms. Shouse's vision, and the primary mission of the park, is the experience of live performances in an outdoor setting. The 117 acres (47 ha) donated by Ms. Shouse had been a working farm for several hundred years, and was and still is split roughly evenly between open grass/developed area and woodland. The iconic Wolf Trap visitor experience was established early in the park's history as dining al fresco under shade trees around the old farmhouse and picnicking inside the performance area seated on the grassy lawn while listening to the symphony.

Natural resources?

Though picturesque and beautiful to behold, this controlled image of the outdoors relied on intense human maintenance. The parkland in the main visitor and theater area was treated as a landscape setting and heavily maintained for turf, ornamental trees, and shrubs; the natural resources in other portions of the park were ignored almost completely. The only walking trail in the park was a small, informal trail linking to neighborhood paths; many areas in the park were not accessible and therefore went unmanaged and unobserved. Interpretation of natural resources, including climate change and other NPS priorities, was neglected, even though the park has received more than 400,000 visitors each year. Still, park files and species lists from the 1970s and early 1980s attest to early efforts to address natural resource management policies of the National Park Service, but these endeavors never gained much traction.

Despite the presence of 60 forested acres (24 ha), two streams, several wetlands, and severe problems with exotic-invasive plant species and overabundant white-tailed deer, Wolf Trap had virtually no natural resource program. Vascular plant and vertebrate inventories were carried out by the National Capital Region's (NCR) Inventory and Monitoring Program and other resource needs were addressed by the NCR Office of Natural Resource Science with minimal involvement by park personnel. Although it is recognized as having significant natural resources, the park has never established a resource management position. Also, the general management plan completed in 1996 did not result in any new research or additional inventories of natural resources.

Start of a natural resource–minded program

In 2007, Philip Goetkin began working in the park as a gardener (fig. 2). He readily admits that he was guilty of many of the unsustainable landscaping practices performed there at the time. In 2009 he enrolled in a course for which Doug Tallamy's book, *Bringing Nature Home*, was the required text, and he was inspired.

Mr. Goetkin recognized the utter lack of science-based natural resource management in the park and decided that something needed to be done. He also understood that gaining support would be difficult in an environment that was so heavily focused on the maintained landscape. He would make it his mission to prove that ecological value and aesthetic quality could coincide and enhance the park experience and park purposes.

He saw the visitor area of the park in and around the Filene Center, parking lots, and picnic grounds as an opportunity to educate the public about environmentally friendly landscaping practices. In 2009 the park staff and a group of volunteer Girl Scouts removed turf grass in a small area near the main entry to the Filene Center and replaced it with native plants. The idea was to showcase how native species could be used instead of cultivars to create a decorative garden area that would pass aesthetic muster in the Washington, D.C., suburbs. This was the beginning of a paradigm shift at Wolf Trap National Park for the Performing Arts.

In 2010, Mr. Goetkin became the park's head gardener and a maintenance supervisor and began implementing a number of forward-looking projects. For the first time in park history, funding was obtained through youth program sources to hire natural resource interns, who dedicated themselves to carrying out the innovative projects. This was a turning point in convincing park staff, visitors, and partners of the value of developing an active natural resource program at Wolf Trap. That year, a cooperative agreement was signed with the Potomac Appalachian Trail Club to construct a 2.5-mile-long trail in the park's wooded areas. Not only does this trail enhance outdoor recreation at the park, another of the park's legislated purposes,

WOLF TRAP NATIONAL PARK FOR THE PERFORMING ARTS

Figure 2. Head gardener and grounds supervisor Philip Goetkin coordinates with Claudia West, ecological sales manager at North Creek Nurseries, and Catherine Zimmerman, author of *Urban and Suburban Meadows*, to plant native plugs in the meadow.

WOLF TRAP NATIONAL PARK FOR THE PERFORMING ARTS

Figure 3. Located directly in front of the Filene Center main gate and box office is the area commonly referred to as the "Dimple." This 1-acre site, used primarily as a stormwater holding area and for parking, was once monoculture lawn and cost approximately $2,000 annually to maintain.

but it also provides accessibility through many of the wooded portions of the park. This access, which did not exist before, has proven invaluable in subsequent natural resource inventory work. In 2011 the park decided to convert a 1-acre (0.4 ha) site of manicured lawn that is encircled by the Filene Center's entry into a meadow of native grasses and forbs (figs. 3–5, above and on pages 96–97). A $30,000 grant provided by the Wallace Genetic Foundation (a private foundation) was used to purchase native plants.

NPS/WOLF TRAP NATIONAL PARK FOR THE PERFORMING ARTS

Figure 4. In April 2012 more than 100 volunteers helped transform the Dimple into a native meadow when they planted 21,000 vegetative plugs.

The native garden, wildflower meadow, and Wolf Trap Trail attracted attention and interest almost immediately. Park visitors and area residents quickly volunteered to help with manual labor, and several highly skilled natural resource professionals also volunteered their services. Rather than defining research projects and then looking for professional scientists to carry them out, the park attracted the scientists and volunteers first and then used their expertise to address park needs. Since then, the park has added a cadre of trained volunteers, and the network of contacts the park has made with local and national partners has continued to grow.

Inventories take shape

Sheryl Pollock is a retired field biologist from the U.S. Geological Survey who began visiting the park to photograph insects in the native meadow. Her interest quickly evolved into a more ambitious project to photograph and identify all insects and native flora in the park. Ms. Pollock has taken thousands of photographs at Wolf Trap and uploads her pictures to an online photo-sharing service along with notes on species identifications. Her work provides a photographic record of particular species on specific dates in the park. Her efforts, in conjunction with other surveys, will help to update the park's official NPSpecies list, which documents the occurrence and status of species on National Park Service lands.

What started as a hobby for Ms. Pollock developed into the launching of an All-Taxa Biodiversity Inventory at Wolf Trap in 2013. Teaming up with USGS wildlife biologist Sam Droege, Ms. Pollock now aids park staff in collection and processing of bee species. Mr. Droege graciously volunteers his time to identify the bees as we work to generate a baseline of pollinator species in the park. The work also informs Mr. Droege's larger study of native bees in the Maryland, Virginia, and Delaware region. The survey, which started in July 2013, resulted in identification of 37 pollinating bee species, and we expect to tally many more with a full field season of work in 2014.

Since beginning the bee survey, staff from the NCR Office of Natural Resource Science have suggested that we expand our work to include Lepidoptera and have recommended that we team up with entomologist and private contractor Nathan Erwin, former curator of the Smithsonian

Figure 5. After its second growing season in fall 2013, the native meadow shows its colors.

Rather than defining research projects and then looking for professional scientists to carry them out, the park attracted the scientists and volunteers first and then used their expertise to address park needs.

Insect Zoo. Mr. Erwin conducted multiple training sessions to teach volunteers how to identify various species of butterflies and to prepare them to carry out a butterfly inventory of the park. We identified 32 species in 2013 and, although 2014 surveys have gotten off to a slow start as a result of poor weather conditions, we hope to exceed last year's species count with the longer survey season. Volunteers meet every other week to document butterfly sightings.

The Audubon Society of Northern Virginia also has taken an interest in the park. Learning that Wolf Trap had no comprehensive bird list, they have been working with park staff for more than a year to document park birds. Nearly 30 Audubon volunteers divided the park into quadrants and, thanks to the new trail, are able to access the entire park, identifying birds and monitoring their densities. They regularly upload their findings to the online eBird .org database and have identified more than 100 bird species in the park.

An amazing transformation

In just five years since park staff exchanged a small area of lawn for native plants, Wolf Trap National Park for the Performing Arts has instituted a vibrant, public participation–oriented natural resource program. Although the park still does not have a natural resource manager, an energized grounds crew and other workers enthusiastically tell visitors about park biodiversity and the volunteer program of biodiversity inventories. In addition to the bird and butterfly surveys, bee and other pollinator bioblitzes, and photo documentation of park flora and fauna, the park has added four forest monitoring plots, begun to monitor water quality in Wolf Trap Creek, and established "no-mow" zones and native plant areas. The Inventory and Monitoring network is now engaged in population monitoring of deer and control of destructive infestations of oriental bittersweet and English ivy in highly visible park areas. We also have developed relationships with several organizations for obtaining free or reduced-price supplies for incorporating native plants into the park scene.

Interpretive projects have also blossomed, so to speak. We are developing scientifically accurate interpretive signage about the park's natural resources and now provide tours of the native gardens and meadow areas. The park's Web site and Facebook page feature a "plant of the week" along with information about its natural history. Finally, we have developed a Web-based climate change–monitoring station online where citizen scientists can post photos and related observations of changes in seasonal timing of periodic biological events. Thus citizen science at Wolf Trap is contributing to a larger understanding of phenology at the landscape level.

All the natural resource projects and related achievements have been accomplished without a dedicated natural resource management position or a natural resource management budget. The program owes its existence to the ideas, energy, support, and work of maintenance and interpretive staffs, the park's superintendent and volunteer coordinator, summer interns, college students, the Youth Conservation Corps, volunteer groups and individual volunteers, private foundations and local businesses, and the NPS National Capital Region. As a result, natural resource management has established a strong foothold at Wolf Trap, and the park now has an expanded audience, not just for the traditional theater and music offerings but also for the natural resources and recreational values of this special suburban park.

About the author

Christopher Schuster *(christopher _schuster@nps.gov) is a gardener with Wolf Trap National Park for the Performing Arts in Vienna, Virginia. He has a bachelor's degree in landscape architecture and coordinates many of the resource management activities at the park.*

Bird diversity reflects battlefield park's natural setting

By Bryan Gorsira

THE DECLINE OF GRASSLAND birds has been called the conservation crisis of the 21st century (Brennan and Kuvlesky 2005). It is estimated that since the mid-1800s, grassland ecosystems in North America have declined by 80%. In Virginia, idle grasslands have been reduced by an estimated 55% since 1945. Recent analysis of the Bull Run watershed, which encompasses the park, indicates that nearly 10,000 acres (4,050 ha) have been developed since 2002. Understanding the importance of grasslands to regional conservation, natural resource managers at Manassas National Battlefield Park have been actively managing park grasslands since 1997 by converting more than 1,000 acres (405 ha) from nonnative cool-season grasses to native warm-season grasses. The native grasses function better as sources of food and cover for wildlife, stabilize the soil, are drought tolerant, and require very little maintenance. Yet they retain the character and overall appearance that are important for historical interpretation of the battlefield. These converted grasslands offset some of the development in the area by providing a refuge for resident and migratory breeding birds like the northern bobwhite quail, prairie warbler, and other grassland species.

Annual Audubon Northern Virginia bird survey counts at Manassas have been held every year in June and July since 1995 and follow a standardized point-count methodology to closely monitor and assess bird populations and trends. Whereas bird counts have noted a decline in several species throughout the country, no significant changes in species numbers or composition have been detected at Manassas from 1995 to 2009. This analysis helps to confirm the importance of this park for birds. In addition, the park was recently nominated as an Important Bird Area by the Audubon Society, based primarily on the quality of the park's grasslands. The park supports some of the best examples of grassland and shrubland habitat types in the region, with healthy populations of eastern meadowlark, grasshopper sparrow, field sparrow, prairie warbler, brown thrasher, and eastern towhee—all species of conservation concern in Virginia.

Manassas National Battlefield Park is an example of how a relatively small national park (around 5,000 acres, or 2,023 ha), and one established for cultural and historical purposes, can make a significant contribution to regional biodiversity. Of the 18 migratory species listed in 2008 by the U.S. Fish and Wildlife Service as regional birds of conservation concern, 9 occur in the park. Manassas supports more than 160 bird species, 54 of which are confirmed breeders, and more than half of those are migratory. In addition, nearly 50 butterfly species, more than 200 moth species, and approximately 700 vascular plants have been documented in the park. Last year's grasslands survey documented 51 bird species, 12 butterfly species, representatives of five bee genera, and 49 plant species. Ten of the birds observed were of regional conservation concern and three of continental concern. As more and more parks take part in biodiversity discovery activities throughout the National Park System, we will gain a clearer picture of the importance of "cultural" parks like Manassas to preserving native biodiversity.

NPS PHOTO/BRYAN GORSIRA

Northern bobwhite quail at Manassas National Battlefield Park.

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About the author

Bryan Gorsira *(bryan_gorsira@nps.gov) is a wildlife biologist and Natural Resource Program manager at Manassas National Battlefield Park, Virginia.*

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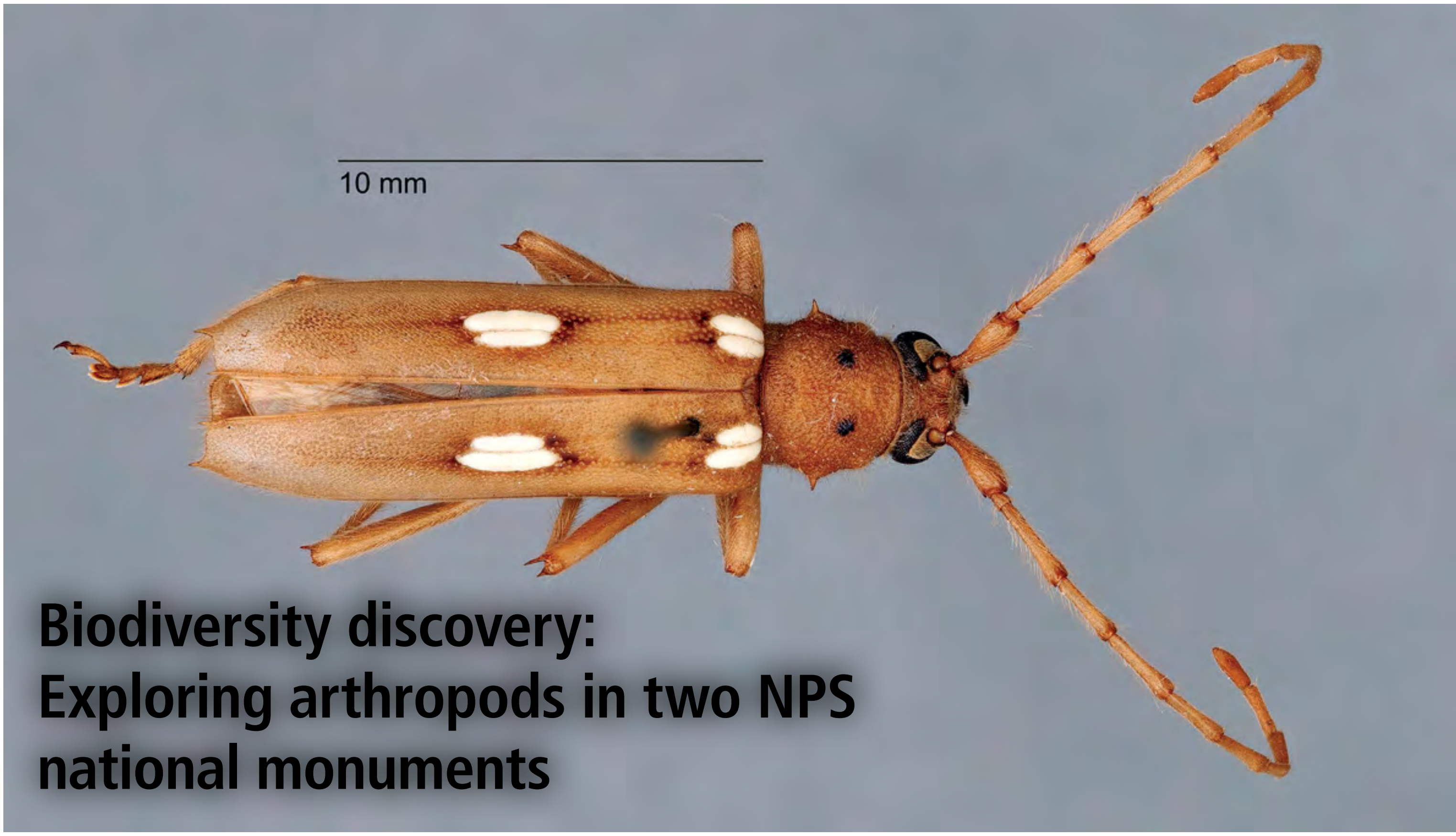


Biodiversity discovery: Exploring arthropods in two NPS national monuments

Figure 1. The ivory-spotted longhorn (*Eburia quadrigeminata*) beetle is one of the species collected, imaged, and cataloged during a bioblitz conducted at George Washington Birthplace National Monument, Virginia, through a partnership with Northern Arizona University. This beetle spends most of its lifetime feeding inside hardwood trees and can live up to 40 years.

By Jennifer Leasor, Amy Muraca, Rijk Moräwe, and Neil Cobb

SCIENCE IS SHOWING THAT parks that are thought of primarily as repositories for the nation's historical and cultural heritage should not be overlooked when it comes to biodiversity. George Washington Birthplace National Monument, Virginia, and Pipe Spring National Monument, Arizona, are two such parks. Both national monuments were part of the Inventory and Monitoring Program established by the National Park Service in 1992 to assist the 270 parks with significant natural resources assess and document the condition of those resources. Inventory and monitoring efforts have been ongoing, and recently Northern Arizona University (NAU) and the National Park Service have partnered to explore arthropods in these two parks as part of "Biodiversity Discovery." Biodiversity Discovery refers to multiple efforts of the National Park Service to explore and document our natural heritage that often focus on smaller life-forms such as arthropods. Biodiversity Discovery activities, like previous Inventory and Monitoring efforts, are helping to uncover the vast diversity of life found in these national monuments.

George Washington Birthplace

George Washington Birthplace National Monument is a 550-acre (223 ha) colonial site on the Potomac River that encompasses a wide range of habitats, including hardwood forests, pine plantations, open meadows, brackish marsh, estuaries, coasts, freshwater ponds, and swamps. This natural environment supported an agrarian society in the mid-17th century that persists today as a fairly intact rural economy. In 2009 the partnership began an effort as part of the Biodiversity Discovery to develop an All-Taxa Biodiversity Inventory (ATBI) program for the monument, which built upon several previous small-scale bioblitzes, or rapid inventories. The creation of an integrated ATBI program, which is to be completed before the National Park Service's centennial in 2016, has three objectives: (1) increase by 10-fold the monument's biodiversity inventory, (2) involve at least 30 schools and universities in ATBI research, and (3) involve and train at least 50 volunteers in carrying out this scientific program.

NORTHERN ARIZONA UNIVERSITY/CHRISTIAN CLARK

The partnership at the national monument included outreach to local schools, professionals, and partners through activities such as presentations and a "birding weekend." However, NAU scientists focused on documenting what Dr. E. O. Wilson, the eminent American biologist and leading authority on ants, has called the "microwilderness," or the world of tiny creatures. General insect surveys at George Washington Birthplace conducted in 2008, 2009, and 2012 have so far documented some 377 species of arthropods, with more identifications expected as the process continues. For example, the inventory identified 144 species of Coleoptera (beetles) (fig. 1, previous page, and fig. 2), 105 species of Hymenoptera (ants, wasps, and bees), and 33 species of Lepidoptera (butterflies). Citizen scientists such as the Northern Neck Master Naturalists, who participated in several bioblitzes in an attempt to document the arthropod biodiversity found in the national monument, were critical to the work. Currently, George Washington Birthplace National Monument has a permanent collection of approximately 3,000 arthropod specimens on-site that are sorted by taxonomic order.

Pipe Spring biodiversity

Established in 1923, Pipe Spring National Monument is located in Mohave County, Arizona, surrounded by the Kaibab Paiute Indian Reservation. This 40-acre (16 ha) park commemorates the area's rich Native American culture and Mormon pioneer heritage. Listed in the National Register of Historic Places, the monument preserves archaeological sites, historical structures, and Pipe Spring, a year-round source of

Figure 2. Northern Arizona University researchers used sweep nets to collect arthropod specimens at George Washington Birthplace National Monument, Virginia. It is expected that 500 arthropod species will be documented when the specimen-identification process is complete.


NATIONAL PARK SERVICE/KODY CALLISTER

Figure 3. Park staff used pitfall traps to collect ground-dwelling arthropods, including beetles, ants, and spiders, at Pipe Spring National Monument, Arizona. In the summers of 2012 and 2013, pitfall traps and other standard methods were used to collect more than 8,000 specimens of aquatic and terrestrial invertebrates.

water. The monument's natural springs are one of the few persistent water sources in this arid strip of desert situated between Grand Canyon and Zion National Parks, creating a small riparian ecosystem. Archaeological evidence indicates that springs have attracted people to the monument area for the past 8,000 years. Documented biodiversity of the monument includes at least 48 mammal species, 166 bird species, 12 reptile species, and 3 amphibian species. A recent bat study (NPS and Southern Utah University) increased the number of bat species found at the monument to 18 of the 28 found in all of Arizona (Taylor et al. 2013). As of 2013, inventory efforts have documented 335 vascular plant taxa for the monument, and the herbarium has vouchers for 275 (82%) of these species.

In 2012, park resource managers initiated an arthropod inventory, as arthropods represent a significant portion of the food base for vertebrate species, particularly the numerous bat and bird species that winter and breed on the monument. Additionally, very little was known about the monument's native arthropod populations and exotic species and their potential to affect native species and habitats. Northern Arizona University was asked to collect arthropod specimens; provide training in the collection and storage of the specimens to park staff, volunteers, and members of the neighboring Kaibab Band of Paiute Indians; create a reference collection for the monument; and develop a database to ensure that cataloged specimens would be available online. Standard insect-collecting techniques, including nets, malaise and pitfall traps, and night lights, were used during the summers of 2012 and 2013 to collect more than 8,000 specimens of aquatic and terrestrial invertebrates (fig. 3). Specimens are now being identified, imaged, and cataloged using state-of-the-art software that produces high-resolution images, allowing scientists across the country to access the collection online for research purposes.

Clearly, historical and cultural parks of all sizes are important to documenting and preserving the nation's biodiversity. In the case of arthropods, we are just beginning to understand how little we know about these tiny creatures and the roles they play in natural systems. Arthropods may be the next frontier of discovering biodiversity. As efforts at George Washington Birthplace and Pipe Spring National Monuments illustrate, the NPS Biodiversity Discovery program has created opportunities for national parks to work with partners, engage volunteers, and focus on smaller life-forms to document the diversity of life found in the microwilderness.

Reference

Taylor, J. R., A. Bornemeier, A. Alfen, and C. Jack. 2013. Bat research and interpretive programming: Increasing public interest in Pipe Spring National Monument. Park Science 30(1):14–19. Available at http://www.nature.nps.gov/ParkScience/archive/PDF/Article_PDFs/ParkScience30(1)Summer2013_14-19_Taylor_et_al_3648.pdf.

About the authors

Jennifer Leasor *is curator at Pipe Spring National Monument.* ***Amy Muraca*** *is museum curator at George Washington Birthplace National Monument and Thomas Stone National Historic Site.* ***Rijk Moräwe*** *is chief, Natural and Cultural Resources Management, at Organ Pipe Cactus National Monument.* ***Neil Cobb*** *(neil.cobb@nau.edu) is director, Merriam-Powell Center of Environmental Research, Northern Arizona University.*

Technological Applications

Cameras and cell phones at the bioblitz

By the Editor

PHOTOGRAPHY HAS LONG been used as a tool for wildlife documentation, identification, and education. More recently, however, it is being coupled with communications such as those made possible by cell phone technology and wireless Internet (WiFi). Mobile phone cameras are the norm, and nature observation "apps" are increasingly being developed for smartphones and tablets, which facilitate natural history observations and reporting. Photo-hosting Web sites such as iNaturalist.org are popular for involving citizen scientists in the assembly of photo collections and nature observation libraries, though collection curators with specialized knowledge are still a necessity to confirm observations. In national parks associated with population centers, bioblitz participants who have preregistered with a host Web site and installed the corresponding app may be able to take and upload photos and observations directly from the field to a predetermined photo gallery or database for later study. In parks where WiFi or cell phone service is not easily accessible or when photos need subsequent processing, these records can be shared when participants return home. Technical challenges come with the territory, of course, but the digital devices that park visitors commonly carry now make it possible for them to more easily contribute their skills to the study of park biota. As we report below (and on pages 22 and 51),

Vermont Atlas of Life Field Days

National park
Marsh-Billings-Rockefeller National Historical Park

Dates
20 July and 29 September 2013, and 19 July 2014

Focus
Digital technology to contribute natural history observations to online databases

Key partners
- Vermont Center for Ecostudies (advertising, coordination, presentations)
- NPS–Natural Resource Stewardship and Science (funding through the Call to Action initiative item 7: "Next Generation Stewards," ONPS 2014)

Background
The Vermont Atlas of Life is an online repository of state biodiversity knowledge. It was conceived to harness and coordinate independent surveys conducted by naturalists, scientists, state and federal agencies, and conservation organizations. The initial events—Vermont Atlas of Life Field Days—were hosted at Marsh-Billings-Rockefeller NHP to demonstrate the feasibility of using citizen scientists to catalog park and state biodiversity. A follow-up event in 2014 ran under the moniker "bioblitz." It attracted more visitors and resulted in more observations than the 2013 events.

Methods
Staff made presentations on how to obtain and use iNaturalist and eBird accounts, status of databases, bumble bee identification, and the value of citizen science to research. Individual field walks were conducted on birds, ferns, trees, wildflowers, aquatic invertebrates, bumble bees, dragonflies and damselflies, and moths. Participants contributed their own nature sightings to the Vermont Atlas of Life in real time and after the events. Most observations were of live animals or vegetation, though some invertebrates were collected for later identification, and were made with cameras, sound recorders, and field notes.

Participants
In 2013 approximately 60 people attended the two events, one-third of whom brought a smartphone camera and had preinstalled the iNaturalist app; about two-thirds were equipped with a traditional digital camera and uploaded photos at a later time. One NPS staff (20 hours) and two partner staff (80 hours) helped present and guide activities. In 2014 approximately 50 people attended the bioblitz and they stayed for multiple programs, for a total of 137 program participants.

Results
Observations made during park walks and reported to iNaturalist numbered 111 in 2013. This year observations reported increased

park staffs have begun to explore ways to engage this next generation of park stewards through the use of these technologies and to evaluate the scientific robustness of this information.

On the following pages we also profile several parks that are using remotely operated cameras to survey wildlife and environmental conditions. This mechanism is versatile in how and where it can be employed, and techniques for analyzing the vast number of photos that result are rapidly improving. Data derived from the pictures can be used to estimate wildlife populations, and the images themselves document wildlife behavior. Compared with traditional surveys, this camera technology also reduces costs and human disturbance while increasing chances of documenting highly secretive species. Protocols are available to help users design and deploy such systems, which have potential for wildlife community monitoring at the landscape level. Several parks have received funding from the Biological Resource Management Division to launch wildlife camera projects later this year and in 2015.

—Jeff Selleck (jeff_selleck@nps.gov)

to 847 from 338 species. Most insect species were new park records (see photo) and included 4 new species of bumble bees for the park in 2013, and 2 more in 2014. Fifteen species of birds were reported on the first field day; 11 were recorded the second day. In 2014, 47 species of birds were reported for the bioblitz.

Resources

- Photo collections are viewable at http://www.inaturalist.org/places/marsh-billings-rockefeller-national-historical-park-woodstock-vt-us.
- Bird observations are mapped and summarized by month online at http://ebird.org/ebird/vt/GuideMe?src=changeDate&getLocations=hotspots&hotspots=L271555%2CL769957%2CL697684%2CL697688%2CL697689%2CL769958&parentState=US-VT&reportType=location&monthRadio=on&bMonth=01&eMonth=12&bYear=1900&eYear=2014&continue.x=47&continue.y=10.

Publications

Accomplishments reports are available at https://irma.nps.gov/App/Reference/Profile/2204770 and https://irma.nps.gov/App/Reference/Profile/2215605.

Park contact

Kyle Jones (kyle_jones@nps.gov)

With a wingspan of 2.4 inches (62 mm), the ilia underwing (*Catocala ilia*), a moth, was first documented for Marsh-Billings-Rockefeller National Historical Park during the first of two Vermont Atlas of Life surveys in 2013.

Camera-trap surveys in the southeastern Arizona national parks

Parks
Chiricahua National Monument, Fort Bowie National Historic Site, and Coronado National Memorial

Time frame
Fort Bowie camera-trap bioblitz: fall 2013
Long-term camera-trap water source monitoring (all three parks): 2009 to present

Focus
Bioblitz: Small to medium-sized mammals
Monitoring: Medium-sized to large mammals, birds, human activity

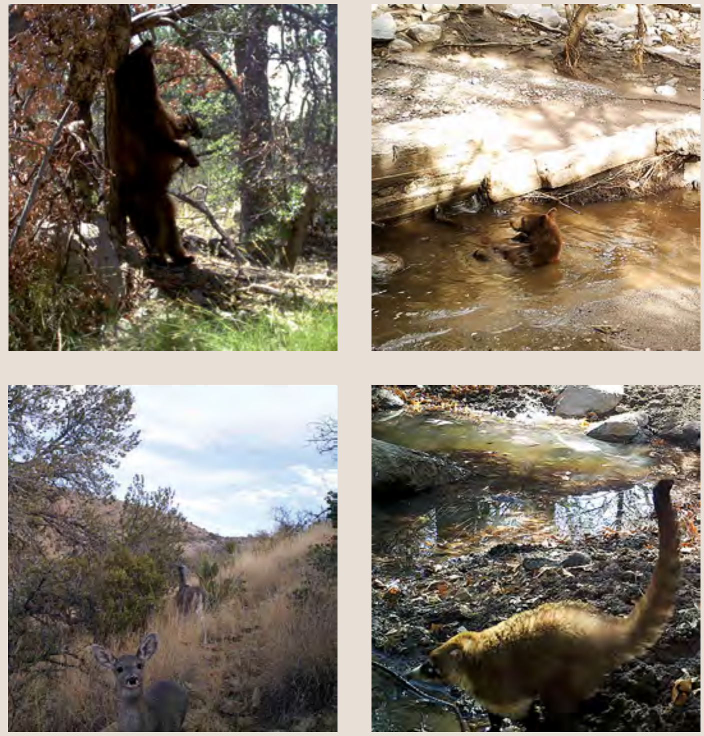
Key partners
Saguaro National Park, Sonoran Desert I&M Program, U.S. Fish and Wildlife Service

Participation
Bioblitz: Eight full-time park employees and five Student Conservation Association interns, totaling 142 hours

Methods
Bioblitz: We conducted a six-week-long mammal census involving 44 remotely triggered, randomly and non-randomly placed cameras. Using a protocol developed by Saguaro National Park's Nic Perkins and Don Swann, staff analyzed photos for presence and activity of wildlife, and identified animals to species level. Photo Mechanic software was used to edit metadata, including recording information on species, location, identification, and camera setup.

Monitoring: We also operate 14 camera traps year-round at water sources and two trailheads in the parks to monitor for the effects of human traffic on wildlife corridors. Software is used to analyze photos for species, revealing behavior and use patterns related to time of year.

Results
Approximately 13,000 of 345,000 photos from the six-week Fort Bowie bioblitz were of wildlife, which helped inform development of a species list for the park. Randomly placed cameras were not as successful at capturing wildlife images as those placed by biologists. An additional 300,000 photos were from the longer-term water source monitoring project, which confirmed hibernation of black bears, nocturnal activity of skunks, diurnal patterns of coatimundi, the size of javelina litters, and the time of year when white-tailed deer bucks lose their antlers and fawns lose their spots.



NPS PHOTOS (4)

(Clockwise from top left) The automated cameras captured activities of a black bear scratching a tree at Garfield Spring in Chiricahua, a bear using a stream to cool off during summer at Stafford Dam in Chiricahua, daytime spring use by coatimundi, and white-tailed deer at Fort Bowie.

Number of species
30 species identified

Applications
In addition to improving our understanding of park wildlife, the findings from the two camera projects are being used to help assess impacts on wildlife resulting from human activity along the U.S.-Mexico border. The information is also useful for monitoring ecological recovery following wildfires, signaled in part by the return of wildlife to burned areas. Photos and time-lapse videos are also very popular for educational programs and public outreach. The randomly placed cameras also help managers assess wildlife distribution across the parks.

Publications
Two reports are in production and will be published in the Natural Resource Data Series. A methods summary and project briefing brochure also will be published.

Parks contact
Jason Mateljak (jason_mateljak@nps.gov)

Mammal diversity monitoring in Saguaro National Park, Arizona

Focus
Medium-sized and large mammals

Methods
Randomly placed, unbaited wildlife cameras (camera traps) to monitor species richness and other community parameters

Key partners
Friends of Saguaro National Park, National Park Foundation, Sky Island Alliance, and others

Participation
Park biological technicians, youth interns (as many as 10), volunteers, and high school students

Number of species
24 native species, plus nonnative dogs, cats, and cows

Summary
We used unbaited camera traps in a random design to estimate species richness of large and medium-sized mammals for long-term monitoring. We stratified the park's two units by elevation, established and randomly selected 1 km^2 (0.4 mi^2) grids, and designated random points within each grid. We set cameras in a location where they operated continuously for six weeks. We then moved the cameras to a different location for another six-week sample. This pattern of moving cameras throughout the sampling period of May 2011 to August 2012 helped us attempt to equalize sampling effort in each stratum. We collected 4,751 photos of 24 native medium-sized and large species over 14,693 camera nights. We estimated that 25 (SD = 0.91) medium-sized and large mammal species occur in Saguaro National Park. We compared our results with a similar randomized, though less comprehensive, survey in 2000–2002, and determined that no significant change in species richness has occurred parkwide over the past decade. However, we did not detect several species in the Tucson Mountain District that were photographed previously. This project also included a large educational component. We had students set and check wildlife cameras throughout the year and as part of the 2011 NPS–National Geographic Society BioBlitz. We also created a dedicated Web site for wildlife photos with the Friends of Saguaro National Park (https://saguwildcams.shutterfly.com/).

Implications
Mammals are a high-profile taxonomic group in many parks, but most mammal monitoring is limited to threatened species or charismatic game species. Wildlife cameras are often used to monitor marked animals or at artificial water sources; however, few parks use them to monitor their mammal biodiversity. Saguaro National Park's long-term monitoring program uses camera traps to track the status of the entire community of medium-sized and large mammals in the park, which includes both high-profile species (e.g., mountain lions) and very elusive and vulnerable species (e.g., ringtails and American badgers). We are working with our partners in southern Arizona to develop a protocol for other parks and refuges that includes occupancy analysis and builds on knowledge gained from two international camera-trap programs that are particularly relevant for U.S. national parks: the Wildlife Picture Index (WPI) and the Terrestrial Ecology Assessment and Monitoring (TEAM) network (see article below).

Park contact
Don Swann (don_swann@nps.gov)

Camera traps for monitoring biodiversity

By Don Swann

CAMERA TRAPS (ALSO CALLED WILDLIFE CAMERAS), USED in many parks to document species occurrence and estimate population size, are emerging as an exciting new technology for monitoring biodiversity, particularly for mammals and terrestrial birds. Two efforts stand out that are particularly relevant for monitoring mammal communities in U.S. and Canadian national parks: the Wildlife Picture Index (WPI; O'Brien et al. 2010) and the Terrestrial Ecology Assessment and Monitoring (TEAM) network (Ahumada et al. 2011, 2013). Both approaches use arrays of multiple camera traps set in a randomized design to sample mammals on a landscape scale. Results from the TEAM network show that the surveys effectively track trends in species diversity, including species richness, evenness, and dominance. The Wildlife Picture Index has been described as "a promising new indicator derived from camera trap data that measures changes in biodiversity from the occupancy estimates of individual species" (Ahumada et al. 2013), and is being used to monitor mammal communities in Mongolia, Costa Rica, and other areas.

CONTINUED ON PAGE 111

Research Reports

Engaging park stewards through biodiversity discovery: Social outcomes of participation in bioblitzes

By Kirsten M. Leong and Gerard T. Kyle

Abstract
Large-scale bioblitzes, such as those conducted jointly by the National Park Service and National Geographic Society, provide an opportunity for visitors to engage directly in inventories of lesser-known species in parks. Working side by side with scientists, members of the public contribute to the development of knowledge about park resources, learn about the scientific method, and experience the park in a new way. This study examined the social outcomes of this type of citizen science effort to improve the design and promotion of future biodiversity discovery events. Results indicate that these bioblitzes are meeting primary social objectives and attract participants with a strong stewardship ethic and desire to contribute to the betterment of society and the environment. Bioblitzes also provide an opportunity for participants to deepen their connections with national parks. Future events should emphasize science contributions of bioblitz activities to help meet participants' needs related to learning, conservation, and contributing to a greater good. This, in conjunction with the activity itself, can help improve the relevancy of parks, a goal of the National Park Service.

Key words
bioblitz, citizen science, National Geographic Society, social-psychological science, visitor experiences

RESOURCE MANAGEMENT PROJECTS THAT incorporate public participation in scientific research (i.e., citizen science) are often designed, evaluated, and scrutinized with respect to the rigor of scientific data collection and analysis. Yet the social benefits of these endeavors are becoming increasingly recognized (Bonney et al. 2014; Kyle and Eccles 2009; NPS 2010) and can contribute directly to the National Park Service (NPS) mission. The Service has been engaging in bioblitzes at various scales since the term was coined in 1996 at an event at Kenilworth Park and Aquatic Gardens in Washington, D.C. The first long-running program to regularly incorporate bioblitzes was the All-Taxa Biodiversity Inventory initiated at Great Smoky Mountains National Park in 1997 (NPS 2010). Most bioblitzes at parks engage on the order of tens to hundreds of participants. In 2006 the National Park Service and National Geographic Society (NGS) entered into a partnership to cosponsor a large-scale "BioBlitz" each year for 10 years in a national park located near a large urban area, with the final event occurring in 2016, the year of the NPS centennial celebration. These bioblitzes attract thousands of participants and typically are compressed, 24-hour events[1] in which teams of volunteer scientists, families, students, teachers, and other community members work together to find and identify as many species of plants, animals, microbes, fungi, and other organisms as possible. They also include an educational "biodiversity fair" component with exhibitors, activities, and entertainment, as well as opportunities to engage with scientists processing specimens, entering data, or giving talks about their research. The NPS-NGS partnership has brought attention to the range of possibilities to engage the public in park inventories, particularly of lesser-known taxonomic groups, and also addresses the NPS Call to Action item "Next Generation Stewards" (NPS 2013), which emphasizes citizen involvement in biodiversity discovery in national parks, including urban units.

Large-scale NPS-NGS BioBlitzes also enable the evaluation of broad social-psychological outcomes because of the large number of participants and the range of activities available. Like other research activities in national parks that involve the public, NPS-NGS BioBlitzes serve multiple purposes. They document the diversity of life in parks and engage curious citizens, educators, and other park supporters in science and stewardship. While the gain in scientific information is invaluable to park management, it is important to understand social-psychological outcomes to determine the degree to which bioblitzes achieve the goal of developing participants' appreciation of science and stewardship.

To better understand bioblitz participants' experiences, motivations, feelings about the natural environment, and demographic characteristics, we conducted a series of studies at the NPS-NGS BioBlitzes held at Biscayne National Park (hereafter "Biscayne," near Miami, Florida) in 2010, Saguaro National Park ("Saguaro," near Tucson, Arizona) in 2011, and Rocky Mountain National Park ("Rocky Mountain," near Denver, Colorado) in 2012. Results can be used to improve the design and promotion of future biodiversity discovery events based on audience characteristics, motivations, and satisfaction. In addition, results demonstrate the degree to which these events attract and engage the public in science and

[1] NPS-NGS BioBlitzes typically start at noon on a Friday and run through noon on the following Saturday, to accommodate both school groups and the general public. This timing may be different from that of smaller-scale bioblitzes.

PHOTO COURTESY OF PARKER BATT

Figure 1. A student from Texas A&M University surveys visitors at the NPS-NGS BioBlitz at Rocky Mountain National Park in 2012.

While the gain in scientific information is invaluable to park management, it is important to understand social-psychological outcomes to determine the degree to which bioblitzes achieve the goal of developing participants' appreciation of science and stewardship.

stewardship of parks. Full details of each study will be made available in the Natural Resource Stewardship and Science Natural Resource Report Series in 2015 (http://www.nature.nps.gov/publications/nrpm/nrr.cfm). In this article we highlight study results with particular management application.

Methods

Data collection

On-site survey data were collected from participants at each bioblitz over a 26-hour period from 10 a.m. on Friday through noon on Saturday. This sampling period covered the duration of the event. Researchers were stationed at designated event parking lots, shuttle drop-off points, and event exhibition areas. Every second visitor was approached to participate in a brief (approximately three-minute) on-site survey (fig. 1). For groups of more than one, adults (>18 years of age) with the most recent birthday were asked to participate. We collected basic information about participants and an e-mail or postal address so that they could participate in a more in-depth survey following their bioblitz experience. Based on their stated preference, respondents then received either an e-mail or paper mail-back questionnaire one to two weeks after the bioblitz. Reminders, follow-ups, and thank-you notes were periodically sent to nonrespondents following protocols for the administration of mixed-mode surveys (Dillman et al. 2008). The survey questions were divided into five sections that related to (1) respondents' participation in past bioblitzes and park programs, (2) their experiences at the specific bioblitz, (3) their experiences with the park, (4) their feelings about the natural environment, and (5) sociodemographic information.

Data analysis

Completed and usable survey data were coded and entered into a database for analysis using SPSS (Statistical Package for the Social Sciences) version 20. For various response categories, we estimated frequency distributions and valid percentages (i.e., percentages excluding missing values from skipped questions). Also, we calculated descriptive statistics to illustrate mean values (i.e., averages) and standard deviations, and created figures for selected variables to guide interpretation of the study findings.

Results

We received 133 completed follow-up surveys from participants at Rocky Mountain, 159 from Saguaro, and 100 from Biscayne, with response rates of 37.7%, 69.7%, and 66.2%, respectively. We used the initial contact information to compare characteristics of respondents with those of nonrespondents and did not see any significant differences that would indicate a nonrespondent bias. At all three parks, visitors reported similar levels of participation in past bioblitzes and other NPS programs in addition to the current bioblitz. Respondents did not report extensive previous experiences with bioblitzes in general; however, approximately six respondents at each park had participated in a previous bioblitz at locations ranging from other national parks and natural areas near their homes to Mexico. While visiting the respective parks, approximately one-third of respondents took part in NPS presentations or programs outside of the NPS-NGS–sponsored event.

The majority of respondents at Biscayne, Saguaro, and Rocky Mountain participated in the event with friends, family, or col-

Table 1. Reported motivation among participants in the three bioblitzes

	Rocky Mountain		Saguaro		Biscayne	
Motivation	Mean	SD	Mean	SD	Mean	SD
Involve myself in something meaningful	4.2	1.0	4.0	1.5	3.7	1.2
Seek out and enjoy the wonders of nature	4.2	1.1	3.9	1.5	3.9	1.1
Feel like I am supporting the park	4.1	1.0	4.1	1.4	4.0	1.0
Feel I can play a role in the conservation of nature	4.0	1.6	4.1	1.1	3.9	1.1
Make life better for the coming generation	4.0	1.1	3.9	1.1	3.9	1.1
Learn about different species of flora and fauna	4.0	1.0	3.8	1.5	3.9	1.2
Have an opportunity to try new things	4.0	1.0	3.8	1.0	3.6	1.1
Be optimistic about nature's future	3.9	1.2	3.5	1.3	3.6	1.1
Be of benefit to society or the community	3.8	1.6	3.8	1.1	3.9	1.1
Learn how nature works	3.8	1.2	3.7	1.2	3.6	1.4
Learn about the practice of science	3.8	1.1	3.5	1.6	3.3	1.3
Feel I am doing something useful	3.7	1.7	3.9	1.2	3.8	1.2
Meet friendly and interesting people	3.7	1.3	3.6	1.1	3.5	1.1
Refine my understanding of science	3.7	1.6	3.2	1.3	3.3	1.2
Apply my scientific skills	3.5	1.9	2.4	2.1	3.1	1.4
Help me with my personal growth	3.4	1.5	2.7	1.3	2.7	1.4
Stay healthy	3.4	1.5	2.7	1.4	2.6	1.3
Be in a quiet peaceful spot	3.2	2.0	2.1	1.5	2.7	1.3
Work with different age groups	3.0	1.7	3.0	1.4	3.0	1.5
Be alone with my thoughts	2.7	2.2	1.7	1.4	1.9	1.1
Build my self-confidence and personal growth	2.6	1.7	2.1	1.2	2.0	1.2

leagues, and learned about the bioblitz through various outlets, including others' recommendations and newspaper and magazine articles. For respondents at all three bioblitzes, contributing to society and opportunities to learn from others compelled participants to engage in the event. Items that scored particularly high as reasons for their participation related to getting involved in something meaningful, seeking out and enjoying the wonders of nature, supporting the park, playing a role in the conservation of nature, making life better for the coming generation, learning about different species of flora and fauna, and being a benefit to society or the community (table 1).

Impacts from participation in the bioblitz were widespread. On average, respondents at all parks agreed that the bioblitz was meeting objectives related to providing opportunities for visitors to learn from professionals, experience the park in a new way, and learn about science (fig. 2). In addition, they agreed that participation in the event increased their knowledge of the local ecosystem and its life-forms. At Rocky Mountain and Saguaro, a series of related questions was presented to respondents about potential implications of the bioblitz program for the National Park System as a whole. On average, respondents agreed that this kind of event

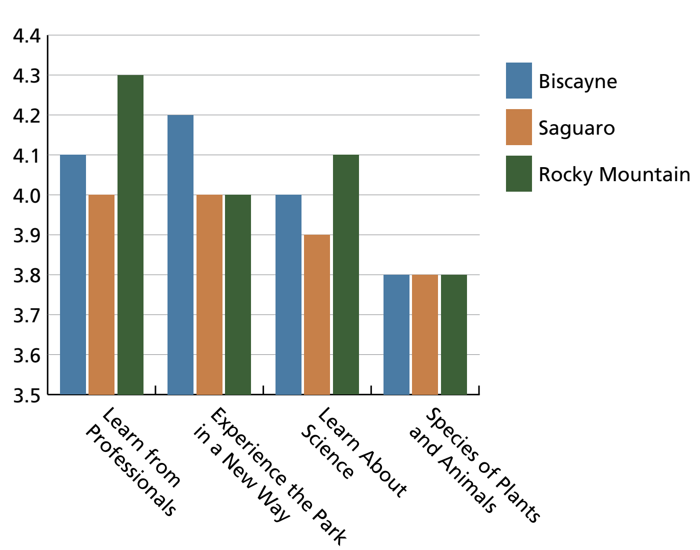


Figure 2. Comparison among mean values of responses with four statements reflecting the human impact of participation in bioblitz programs across three national parks, measured on a Likert scale where 1 = strongly disagree, 2 = disagree, 3 = neither disagree nor agree, 4 = agree, and 5 = strongly agree.

Table 2. Bioblitz participants' values associated with nature- and human-oriented stewardship at three national parks

Dimension and Survey Value	Factor 1*	Factor 2*	National Park	Mean	SD
Nature-oriented stewardship					
Preserving the environment in its natural state	0.763		Biscayne	4.5	0.7
			Saguaro	4.5	0.6
			Rocky Mountain	4.0	0.9
An ethical responsibility to care for the environment	0.819		Biscayne	4.4	0.7
			Saguaro	4.5	0.6
			Rocky Mountain	4.5	0.7
All animals' and plants' right to exist	0.699		Biscayne	4.3	0.8
			Saguaro	4.3	0.8
			Rocky Mountain	4.1	1.0
Protecting the environment for future generations	0.779		Biscayne	4.6	0.6
			Saguaro	3.9	1.0
			Rocky Mountain	4.5	0.6
Trying to reduce my negative impact on the environment	0.560		Biscayne	4.2	0.8
			Saguaro	4.4	0.7
			Rocky Mountain	4.4	0.7
Human-oriented stewardship					
Managing our natural resources wisely to provide for human needs		0.770	Biscayne	3.8	1.1
			Saguaro	3.9	0.9
			Rocky Mountain	4.0	1.0
Protecting all species because we may find a use for them later (e.g., curing disease)		0.570	Biscayne	3.7	1.0
			Saguaro	3.9	1.0
			Rocky Mountain	3.7	1.2

Note: Bioblitz participants were asked the question "When I hear the term 'natural resource stewardship' in relation to [park name] I think of [value in list]." Their responses were measured on a Likert scale where 1 = strongly disagree, 2 = disagree, 3 = neither disagree nor agree, 4 = agree, and 5 = strongly agree.

*Principal Axis Factoring with Varimax rotation and Kaiser normalization was used to determine underlying factors that each item represented. Two underlying factors were identified, which we labeled "nature-oriented" and "human-oriented" stewardship. Primary factor loadings for each item are shown.

would aid in management of the park's natural resources, add to science-based knowledge, increase understanding of biodiversity, and inform the public about park resources.

Respondents at all sites reported they had a strong stewardship ethic, reflected in their agreement with statements related to protecting the environment for future generations, having an ethical responsibility to care for the environment, and taking individual responsibility for actions that could affect the park. Respondents at Rocky Mountain considered themselves to be natural resource stewards to a greater degree than did those at the other two parks. Bioblitz participants at Biscayne showed the lowest levels of self-reported affinity for stewardship. Across all three parks, survey respondents perceived natural resource stewardship to be more nature-based than people-oriented, and displayed an intrinsic appreciation for nature regardless of its functional utility ($z_{\text{Biscayne}} = 5.57$, $p < 0.001$; $z_{\text{Saguaro}} = 5.75$, $p < 0.001$; $z_{\text{Rocky Mountain}} = 5.23$, $p < 0.001$; table 2). Participants reported moderate willingness to engage in park protection behavior, such as volunteering time and paying more for products and services that improve park environments.

Survey respondents formed connections with all three parks. Bioblitz participants at Rocky Mountain reported the highest levels of place attachment as well as more extensive visitation histories at the park. That is, over time Rocky Mountain respondents have developed connections with the park based on emotional ties (e.g., feelings of belonging and happiness), individual identity (e.g., believing the park is part of oneself), and opportunities to socialize (e.g., spending time with family and friends). Across all three parks, affect and emotion as well as social and individual factors underpinned human-place bonds. Sociodemographic characteristics were consistent across the three national parks. More males than females completed the survey, and most were in their mid-40s, well educated, and employed outside the home. Between half and three-quarters of respondents at the three parks reported earning more than $50,000 annually. The majority were white and of non-Hispanic origin.

Discussion

Results from these surveys suggest that NPS-NGS BioBlitzes are meeting the main social-psychological objectives related

Given the strong desire of participants to make a difference, bioblitz organizers will need to be careful not to allow future bioblitzes to swing so far to the education side that the scientific and conservation contributions of the event are minimized.

to providing park visitors with an opportunity to learn from professionals, experience the park in a new way, and learn about science and park ecosystems. Respondents believed their efforts helped manage the park's natural resources, added to science-based knowledge, increased understanding of biodiversity within the park, and informed the public about park resources. They reported a strong stewardship ethic and were willing to engage in park protection behavior.

Respondents' motivations for participation included seeking opportunities to contribute to society in a meaningful way and to learn about and contribute to the conservation of nature, indicating that the promotion of these events appropriately attracted individuals desiring a citizen-science experience. Like many research endeavors involving the public, bioblitzes can be designed to focus more strongly on either the science or education components of the event. Given the strong desire of participants to make a difference, bioblitz organizers will need to be careful not to allow future bioblitzes to swing so far to the education side that the scientific and conservation contributions of the event are minimized. In addition to teaching the scientific method and getting kids and adults outside, activities billed as inventories should include discussion of how public participation is helping to further our understanding of park resources and advance conservation of these resources.

Levels of place attachment were most pronounced in the Rocky Mountain sample and relatively low among participants at Biscayne. Affective/emotional bonds are key components of the connections formed between people and places, which can be maintained through experiential opportunities. Bioblitzes may help to foster attachment to park settings by allowing participants to interact with a park and its flora and fauna in new and exciting ways that conventional visitors seldom experience. Having natural and cultural histories interpreted by scientific guides also gives participants a unique understanding of the resource that they might not otherwise be exposed to during a typical visit. By nurturing attachment to parks, bioblitzes contribute to increasing the relevancy of national parks for participants.

On the whole, bioblitzes in the national parks are a relatively recent phenomenon. While some parks have engaged in them since the mid-1990s, Service-wide attention to these types of events has not been prevalent until the last decade. The NPS-NGS partnership initiated in 2006 has raised awareness of these events as a means to engage the public in science and stewardship, and since then, bioblitzes and biodiversity discovery activities have gained momentum across the National Park System and beyond. Published in 2012, the NPS Call to Action articulated numerous goals to guide the work of the National Park Service in the time leading up to the bureau's 100th anniversary in 2016. One of those goals is to conduct 100 bioblitzes in national parks by 2016, a goal that has already been exceeded, with park participation growing rapidly over the past few years. Nevertheless, these events are still relatively rare in comparison with the overall number of park visitors and interpretive and research programs that take place in a given year. Thus it is unsurprising that most respondents in this study had limited experience with other bioblitzes. Yet we also note that a number of respondents at each park had previously participated in bioblitzes, either at other national parks or elsewhere at local natural areas. Anecdotal accounts also indicate the potential for developing bioblitz "groupies" as prevalence of these opportunities increases.

Conclusion

Given the growing popularity of bioblitzes, it will be important to ensure that these events continue to meet expectations of participants. Future bioblitzes can use lessons from this study to capitalize on the strong community and environmental ethic of visitors attracted to these events and to emphasize to a greater degree the role that participants play in contributing to park science and stewardship. Offering species inventories and other experiential research opportunities should remain an important and visible component of these kinds of events. In addition, providing central access to information about planned events could help bioblitz aficionados learn about upcoming opportunities and continue to spread interest via their own social networks. Finally, an effort should be made to reach out to underserved audiences to broaden the diversity of participants.

Although only adults were surveyed in this study, many attended the bioblitz in family groups and likely imparted their stewardship ethic to their children, many of whom also attended the bioblitz in school groups. Because an additional goal of NPS bioblitzes relates to creating the next generation of park stewards, our future research will examine the social outcomes of participation for teachers and students, the other major audience participating in NPS-NGS BioBlitzes.

Acknowledgments

The authors would like to thank the Texas A&M graduate students who assisted with data collection, and reviewers for their comments and suggestions during preparation of this manuscript. This study was approved by park research permit programs, the Office of Management and Budget in compliance with the Paperwork Reduction Act, and the Texas A&M University Institutional Review Board as part of the Human Subjects Protection Program.

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About the authors

Kirsten M. Leong *is program manager, Human Dimensions of Biological Resource Management, National Park Service, in Fort Collins, Colorado. She can be reached at kirsten_leong@nps.gov.* ***Gerard T. Kyle*** *is a professor in the Department of Recreation, Park, and Tourism Sciences, Texas A&M University, in College Station, Texas. He can be reached at gerard@tamu.edu.*

"CAMERA TRAPS" CONTINUED FROM PAGE 105

In addition to community monitoring, the technology associated with camera traps and data analysis techniques continues to develop rapidly; a second international conference on this topic was held in Sydney, Australia, in September 2012. Developing approaches include use of camera traps to monitor rodents, other small mammals, and herpetofauna, and to estimate abundance of unmarked animals (the Random Encounter Model; Rowcliffe et al. 2008).

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About the author

Don Swann *is a biologist with Saguaro National Park in Tucson, Arizona. He can be reached at don_swann@nps.gov.*

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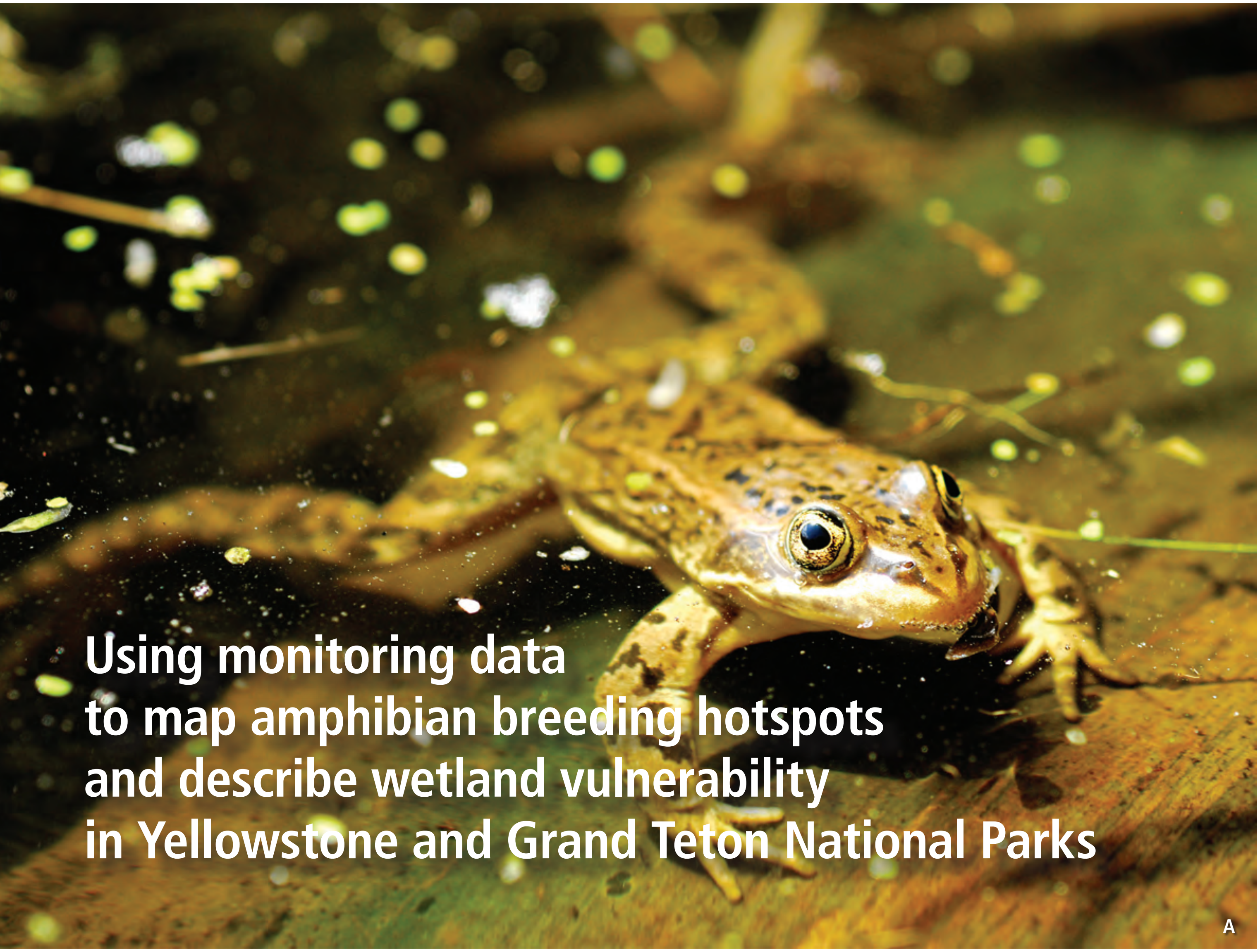

Using monitoring data to map amphibian breeding hotspots and describe wetland vulnerability in Yellowstone and Grand Teton National Parks

By Andrew Ray, Adam Sepulveda, Blake Hossack, Debra Patla, and Kristin Legg

THE NUMBER OF SPECIES THAT OCCUR IN A location (hereafter "species richness") is a basic measure of species or biological diversity (Hamilton 2005). This simple measure of diversity is often used to guide conservation strategies and make inferences about resource condition. Areas with many species (hotspots) are often prioritized for protection, while declines in species richness may indicate environmental change. Monitoring efforts in the National Park System that provide knowledge of patterns of species richness, particularly related to breeding or other vital activities, can therefore assist park administrators with identifying management actions for sustaining or improving natural resource conditions (Fancy et al. 2009).

Here, we use multiyear monitoring data on amphibian breeding to examine amphibian richness patterns in Yellowstone (Wyoming, Montana, and Idaho) and Grand Teton National Parks (Wyoming) (hereafter "Yellowstone and Grand Teton"). Amphibians have been selected as a "vital sign" by several National Park Service (NPS) Inventory and Monitoring (I&M) networks, including the Greater Yellowstone I&M Network. Selection was based on the understanding that amphibians can be sensitive to environmental and land use change and provide an indicator of

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Figure 1. The native amphibians of Yellowstone and Grand Teton National Parks comprise (A, facing page) Columbia spotted frog (*Rana luteiventris*), (B) western tiger salamander (*Ambystoma mavortium*), (C) boreal toad (*Anaxyrus boreas*), (D) boreal chorus frog (*Pseudacris maculata*), (E) northern leopard frog (*Lithobates pipiens*), and (F) Plains spadefoot (*Spea bombifrons*).*

*Plains spadefoot shown, but the taxonomic species of spadefoot in Yellowstone has not yet been determined.

Abstract
Amphibians have been selected as a "vital sign" by several National Park Service (NPS) Inventory and Monitoring (I&M) networks. An eight-year amphibian monitoring data set provided opportunities to examine spatial and temporal patterns in amphibian breeding richness and wetland desiccation across Yellowstone and Grand Teton National Parks. Amphibian breeding richness was variable across both parks, and only 4 of 31 permanent monitoring catchments contained all four widely distributed species. Annual breeding richness was also variable through time and fluctuated by as much as 75% in some years and catchments. Wetland desiccation was also documented across the region, but alone did not explain variations in amphibian richness. High annual variability across the region emphasizes the need for multiple years of monitoring to accurately describe amphibian richness and wetland desiccation dynamics.

Key words
amphibians, Grand Teton, wetlands, Yellowstone

wetland ecosystem and landscape condition (Guzy et al. 2012). A recent analysis documented that North American amphibian populations are declining at a rate of approximately 4% annually and that some of the greatest declines in amphibian occurrence were observed on lands administered by the National Park Service (Adams et al. 2013).

Only six native amphibian species, representing five different families, have been recorded in Yellowstone and Grand Teton: western tiger salamanders, boreal toads, boreal chorus frogs, northern leopard frogs, Columbia spotted frogs, and a spadefoot species (Koch and Peterson 1995; table 1 and fig. 1). This limited species richness is characteristic of montane regions of northern latitudes; consequently, the loss of one amphibian species represents a large proportion of the total species pool. The northern leopard frog has apparently vanished from Grand Teton, with only one confirmed sighting since the 1950s. Boreal toads used to be common in this region, but are now relatively rare. Spadefoots have been documented just a few times in Yellowstone's history (Koch and Peterson 1995), and the taxonomic species of spadefoot remains unclear. Species loss and declines are surprising given that the Greater Yellowstone Area (GYA) is renowned as the largest relatively intact temperate ecosystem in the conterminous 48 states.

Table 1. Native amphibians of Grand Teton and Yellowstone National Parks

Common Name	Family	Scientific Name
Western tiger salamander	Ambystomatidae	*Ambystoma mavortium*
Boreal toad	Bufonidae	*Anaxyrus boreas*
Boreal chorus frog	Hylidae	*Pseudacris maculata*
Northern leopard frog	Ranidae	*Lithobates pipiens*
Columbia spotted frog	Ranidae	*Rana luteiventris*
Spadefoot species	Scaphiopodidae	*Spea* sp.

While the reason for amphibian declines on protected lands varies, climate-related changes to available wetland breeding habitat have been identified as a potential driver of the decline (McMenamin et al. 2008). Higher air temperatures and decreased precipitation can lead to wetland desiccation, reducing the surface water required for amphibian breeding and larval development. In 2007, a hot and dry year, up to 40% of all monitored wetlands in Yellowstone and Grand Teton lacked surface water by midsummer (Ray et al. in press). Climate-related declines in available wetland habitat could reduce amphibian distribution and abundance (Matthews et al. 2013) and affect amphibian richness in even the most protected places. Documenting the spatial and temporal patterns of amphibian breeding richness along with patterns of wetland desiccation in Yellowstone and Grand Teton is an important first step in determining amphibian vulnerability.

We used eight years of amphibian monitoring and wetland data from Yellowstone and Grand Teton to explore patterns of amphibian breeding richness and wetland desiccation dynamics. Our primary goals were to describe the spatial and temporal patterns

Climate-related declines in available wetland habitat could reduce amphibian distribution and abundance and affect amphibian richness in even the most protected places.

of amphibian breeding richness across both parks. Moreover, we were interested in identifying monitored catchments that are vulnerable to wetland desiccation in relation to catchments with the highest amphibian richness. To that end, we asked the following three questions: Where are hotspots for amphibian breeding richness? Are hotspots constant through time? Do amphibian breeding hotspots exist in regions where a high proportion of wetlands are susceptible to drying?

Methods

The Greater Yellowstone Network, in collaboration with the U.S. Geological Survey's Amphibian Research and Monitoring Initiative, has organized annual amphibian monitoring in a set of randomly selected catchments distributed across Yellowstone and Grand Teton since 2006 (Gould et al. 2012). Catchments (or watersheds) are defined by topography as it relates to the flow and collection of water sources and averaged approximately 200 hectares (494 ac) in size. On average, 30 catchments are revisited annually; we report results from 31 catchments that have more than five years of monitoring data. All wetlands within the selected catchment are visited in summer, when two independent observers search for evidence that amphibians bred there (i.e., eggs, larvae, or recently metamorphosed individuals). We also describe the presence of surface water observed during the surveys: wetland sites without surface water are described as "dry," while sites with an expanse of surface water greater than 1 m^2 (1.2 yd^2) in size and exceeding 2 cm (approximately 1 in) in depth are described as "inundated." We used results from annual surveys completed from 2006 to 2013 to examine spatial and temporal variation in amphibian richness and to describe wetland status for monitored catchments. Because elevation is a potentially limiting factor of amphibian richness in montane landscapes (Sergio and Pedrini 2007), we also used correlation analysis (a technique to examine the association between two variables) to examine the relationship between average amphibian breeding richness and average wetland elevation in catchments.

To identify catchments that are amphibian breeding hotspots, we plotted the total number of breeding amphibian species that were observed at least once from 2006 to 2013 (fig. 2). We did not correct for detection probabilities because detection for breeding amphibians at the catchment scale is high and constant over years (>75%; Gould et al. 2012). Nevertheless, improved methods for identifying rare species like boreal toads, spadefoots, and northern leopard frogs are needed. We are testing DNA-based monitoring tools, which are now being used widely to survey for rare or secretive amphibian species (see the sidebar on page 118 and specifically Pilliod et al. 2013b for more information about environmental DNA).

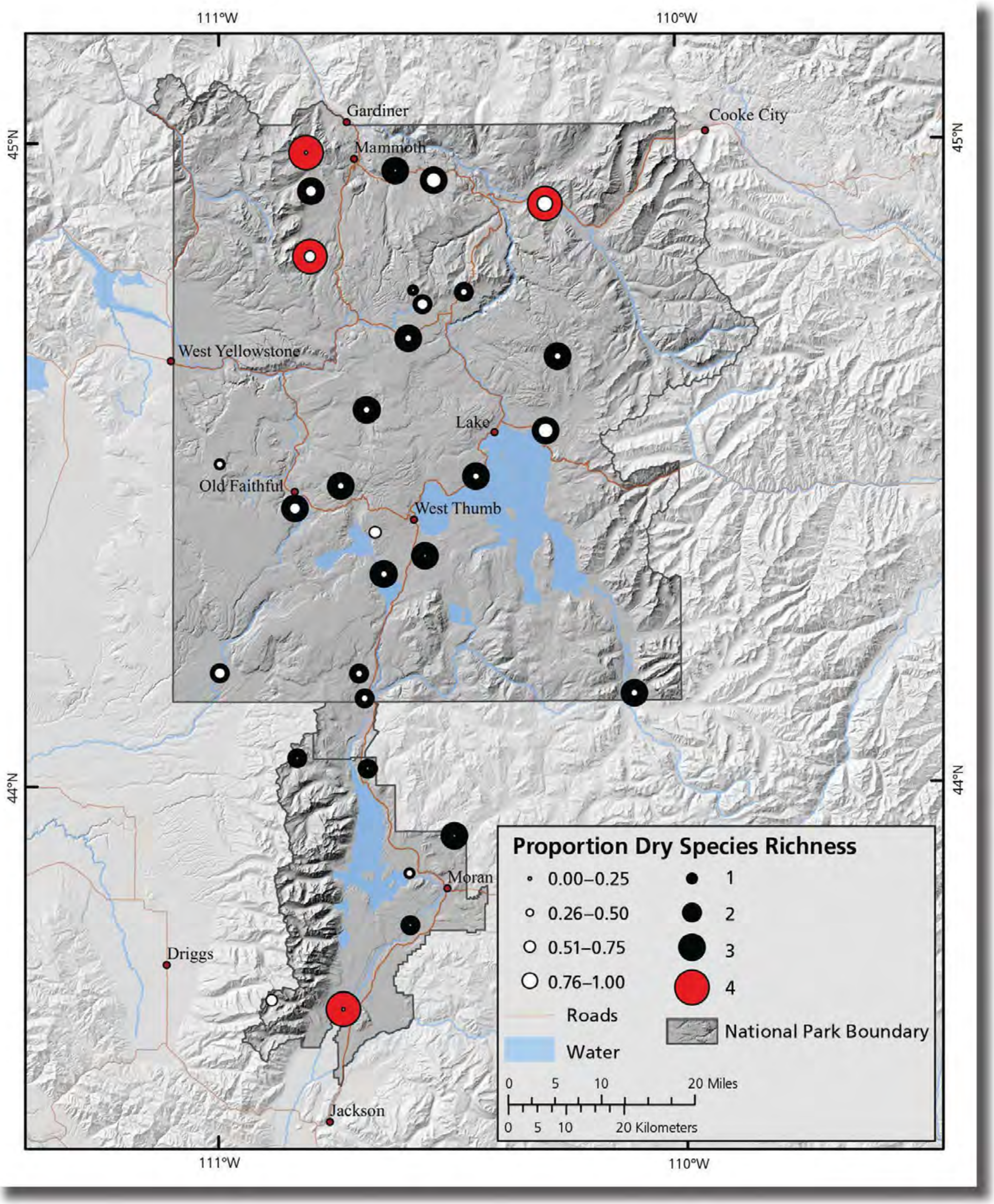
To examine whether amphibian breeding hotspots exist in regions where a high proportion of wetlands are susceptible to drying, we plotted the maximum number of breeding amphibian species observed in a catchment with the proportion of dry wetlands (fig. 2). We calculated the proportion of dry wetlands within a catchment by summing the number of wetlands reported as dry at least once from 2006 to 2013 and dividing by the total number of wetlands visited. Catchments with a high proportion of wetlands susceptible to drying indicate areas where amphibians are vulnerable to climate-related declines in available breeding habitat.

Results

Species summary

The boreal chorus frog was the most common species encountered during this eight-year period and breeding was detected in an average of 23 (range 19–26) catchments annually. The Columbia spotted frog was also widely distributed and breeding was detected in 20 (18–22) catchments each year. The western tiger salamander and boreal toad were less widespread and breeding was

Figure 2 (facing page). The map shows the locations of catchments (i.e., watersheds) in Yellowstone and Grand Teton National Parks that are used for long-term monitoring of amphibians. The maximum number of breeding amphibian species observed in a catchment (species richness) is shown by the outer circles, with the proportion of dry wetlands (proportion dry) indicated by the inner circles. The circles summarize results from surveys conducted from 2006 to 2013. Red circles indicate amphibian "hotspots," where four amphibian species have been documented as breeding in a catchment.


111°W
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Old Faithful
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Jackson
Proportion Dry Species Richness
0.00–0.25
0.26–0.50
0.51–0.75
0.76–1.00
1
2
3
4
Roads
Water
National Park Boundary
0 5 10 20 Miles
0 5 10 20 Kilometers

Our eight-year data set on amphibians underscores the importance of multiyear monitoring for making inferences about amphibian status. . . . Basing inferences about amphibian status on only 2007 data . . . would provide an underestimate and a potentially incorrect interpretation of amphibian breeding richness.

detected in 10 (7–14) and 4 (3–6) catchments annually, respectively. No northern leopard frogs or spadefoots were observed.

Amphibian breeding hotspots

Just fewer than half (15 of 31) of all catchments surveyed contained three breeding amphibian species for at least one year of monitoring (fig. 2). Surprisingly, all four widely distributed species were documented only in four catchments (fig. 2, shown in red). Three of these catchments were located in Yellowstone's Northern Range and one was in Grand Teton's Snake River Valley. Across all years, higher-elevation regions (>2,500 m or 8,200 ft) had the lowest amphibian richness. In general, we discerned a weak but significant inverse relationship ($r = -0.373$, $P = 0.030$) between elevation and average annual amphibian breeding richness.

Variations in amphibian breeding richness through time

Amphibian hotspots (catchments with four species breeding in at least one year) in Yellowstone's Northern Range fluctuated from two to four breeding amphibian species during this eight-year period (fig. 3). A synchronous drop in breeding richness occurred in 2007 at these hotspots; however, the identity of species that did not breed varied by catchment. The 2007 drop was followed by a synchronous increase in 2008. After 2008, breeding species richness varied annually but lacked synchrony among these hotspots. The only hotspot in Grand Teton varied from two to four breeding amphibian species. In this catchment, breeding richness declined to two species in 2007, returned to three species in 2008, and increased to four species in 2012 when boreal toad breeding was detected for the first time (fig. 3).

Wetland desiccation

The proportion of dry wetlands ranged from 0 to 1 in monitored catchments. The median proportion of dry wetlands within a catchment was 0.40, indicating 40% of available wetlands within that catchment were dry at least once in the 2006–2013 period. Catchments in the Northern Range contained few wetlands altogether (6.0 ± 0.9; mean ± 1 SD), and four of six Northern Range catchments had a high proportion of dry wetlands (≥0.57; fig. 2). In contrast, catchments in lower-elevation regions (<2,250 m or 7,380 ft) of Grand Teton generally contained more wetlands (five of six catchments contained ≥14 wetlands) and a much lower proportion of dry wetlands (≤0.36). Catchment elevation and the proportion of dry wetlands were not correlated ($r = -0.097$, $P = 0.591$).

Amphibian breeding hotspots and wetland desiccation

The proportion of dry wetlands in documented amphibian hotspots ranged from 0.17 to 0.83. The catchments that had the highest proportion of dry wetlands (0.57 and 0.83) also exhibited the most frequent fluctuations from two to four breeding species (figs. 3B and 3C).

Discussion

We identified amphibian breeding hotspots in Yellowstone's Northern Range and in the Snake River Valley of Grand Teton. These areas supported breeding populations of boreal chorus frogs, Columbia spotted frogs, western tiger salamanders, and boreal toads. The latter two species had the patchiest distributions, suggesting that breeding hotspots may be tied to special habitat conditions or may be associated with particular biogeographic conditions (e.g., proximity to glacial refugia).

Our eight-year data set on amphibians underscores the importance of multiyear monitoring for making inferences about amphibian status. We found that annual breeding richness variability can be very high and fluctuated by as much as 75% in some years and catchments. Importantly, annual fluctuations in the number of species breeding were common among Northern Range catchments, a region where wetland desiccation has been well documented (McMenamin et al. 2008; Schook and Cooper 2014). Basing inferences on amphibian status on only 2007 data, for example, would provide an underestimate and a potentially incorrect interpretation of amphibian breeding richness. The high annual variability across the region emphasizes the need for mul-

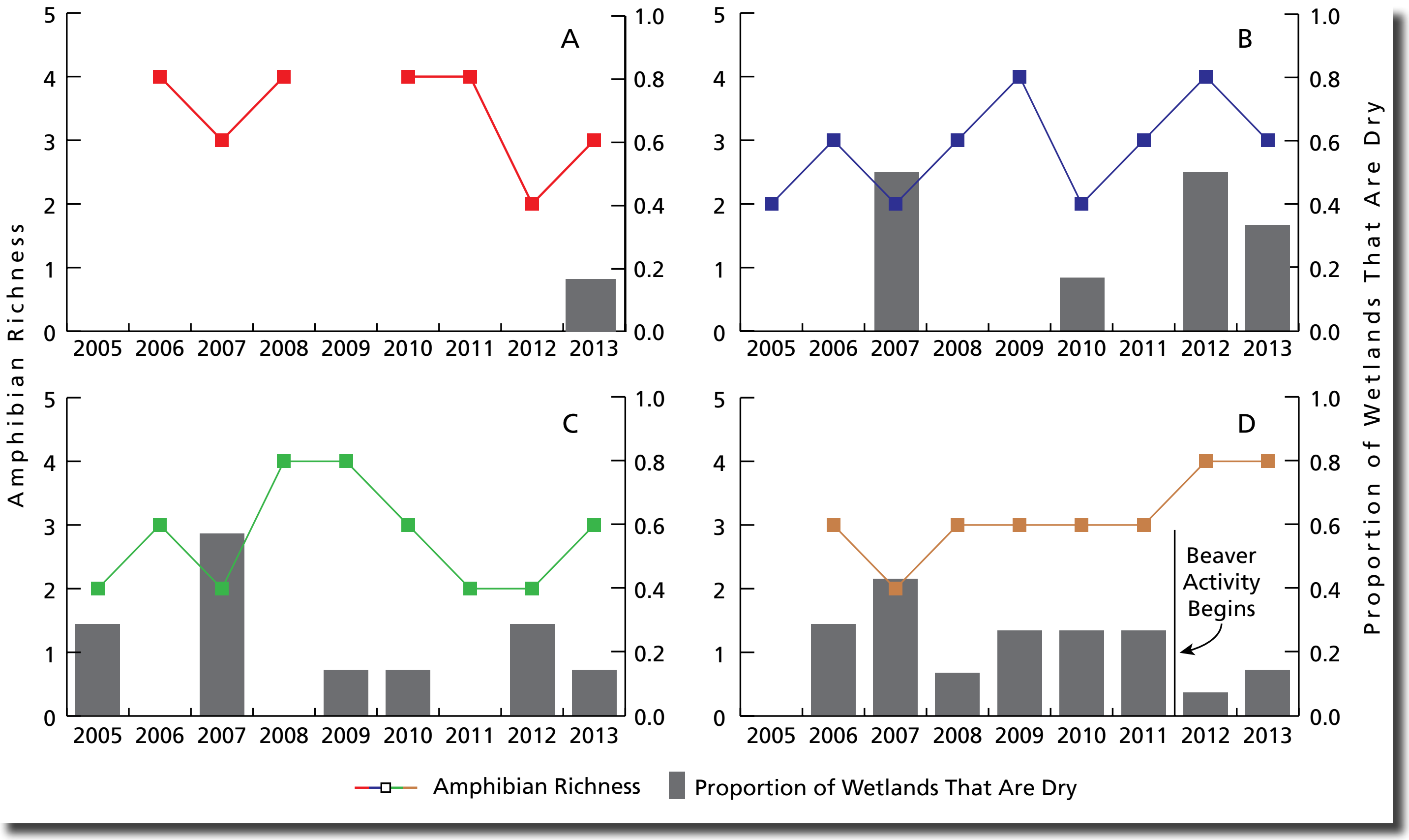

Figure 3. The graphs show the annual variation in amphibian breeding richness (left vertical axis) for four amphibian hotspots (colored lines). Hotspots are long-term monitoring catchments that contained four breeding amphibian species in at least one year (see fig. 2). Also shown is the proportion of dry wetlands (right vertical axis) in each catchment summarized by year (gray bars). Catchments summarized in panels A, B, and C are located in Yellowstone's Northern Range. The catchment shown in panel D is located in the Snake River Valley of Grand Teton National Park. New beaver activity was documented in this catchment in 2012.

tiple years of sampling to accurately describe amphibian richness and, potentially, overall biodiversity.

Climate-driven wetland desiccation has been implicated in changes to amphibian richness in Yellowstone's Northern Range (McMenamin et al. 2008). In Wyoming, low-elevation wetlands have the greatest desiccation risk because they typically have higher air temperatures and lower precipitation than higher-elevation wetlands (Copeland et al. 2010). We found that wetland desiccation is proportionally high in the Northern Range and is widespread across Yellowstone and Grand Teton (Ray et al. in press), but that elevation alone did not explain differences in the proportion of those that were dry among catchments. This is likely because some wetlands may be connected hydrologically to permanent water sources (e.g., the Snake River) or are made resistant to desiccation by beaver activity, which can impound and store water even during dry years. Interestingly, beaver activity was documented in two catchments since 2012, and in both catchments boreal toad breeding occurred at the newly created or expanded wetlands.

Conclusion

Our amphibian and wetland monitoring efforts indicate that amphibian breeding hotspots in the Yellowstone Northern Range are vulnerable because they occur in a region with few wetlands and high susceptibility to wetland drying. Breeding hotspots in Grand Teton are less vulnerable to wetland drying because they occur in the Snake River Valley, where there are more wetlands per catchment, where some wetlands have a hydrological connection to permanent waters, and where beavers have been active recently. In the Northern Range and other areas that are susceptible to wetland drying, monitoring and vulnerability modeling can be helpful strategies to increase awareness of the potential for climate effects on amphibians and wetlands. In addition, adaptation strategies, including the removal of other stressors in permanent wetlands (e.g., nonnative fish; Ryan et al. 2014), can help increase amphibian resiliency. Another management option that may increase wetland resiliency is protection of beaver

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Environmental DNA: Can it improve our understanding of biodiversity on NPS lands?

By Andrew Ray, Adam Sepulveda, Blake Hossack, Debra Patla, and Kristin Legg

TRADITIONAL BIODIVERSITY MONITORING APPROACHES require large investments in field time, are based largely on visual observations, and require significant taxonomic expertise. New survey techniques using DNA collected from aquatic habitats may provide a cost-effective, repeatable approach to sampling a large number of sites for many taxonomic groups (Thomsen et al. 2012b; Bohmann et al. in press).

Environmental DNA (eDNA) monitoring enables the detection of organisms from DNA present and collected in water samples (Darling and Blum 2007; Darling and Mahon 2011). Detection of organisms can be confirmed because aquatic and semiaquatic organisms release DNA contained in sloughed, damaged, or partially decomposed tissue, gametes, and waste products into the water. In fact, recent evidence suggests that DNA survey techniques may be considerably more sensitive than traditional surveys for rare species (Jerde et al. 2011; Dejean et al. 2012; Pilliod et al. 2013a) and offer the ability to identify multiple species simultaneously (Minamoto et al. 2012; Thomsen et al. 2012b; Thomsen et al. 2012a) from individual water samples.

For these reasons, the Greater Yellowstone Inventory and Monitoring Network is partnering with university and agency scientists to begin testing whether eDNA monitoring can be integrated with ongoing amphibian monitoring in Grand Teton and Yellowstone National Parks. Our monitoring program is uniquely suited to evaluate the use of eDNA for amphibian richness monitoring across Grand Teton and Yellowstone for multiple reasons. First, visual encounter surveys are completed each year at approximately 250 long-term monitoring wetlands and will provide a means of testing the efficacy (i.e., determine if it is accurate and repeatable) of eDNA monitoring and potentially develop protocols for its incorporation into long-term monitoring. Additionally, these parks had two native species (e.g., spadefoot and northern leopard frog) that have not been detected in eight years of surveying. The ability to detect species at low densities with eDNA monitoring therefore offers greater potential for detecting these secretive, rare, or now-defunct species. Finally, our work and that of others suggest that some of the most biologically rich wetlands in the region occur at lower elevations; these same wetlands may be at risk for changes in climate. Cataloging the amphibian, mammalian, avian, and invertebrate assemblages or their use of these wetlands using eDNA techniques may help to more fully characterize the biodiversity of these threatened habitats (see Bohmann et al. in press).

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"AMPHIBIAN MONITORING" CONTINUED FROM PAGE 117

In Wyoming, low-elevation wetlands have the greatest desiccation risk because they typically have higher air temperatures and lower precipitation than higher-elevation wetlands.

dams and, where possible, beaver establishment (see McKinstry and Anderson 1999 for attitudes regarding beaver management). Increasing resiliency and growing awareness are just two of the primary tenets of adaptation planning (Heller and Zavaleta 2009) that can help to conserve some of the most biologically rich yet climate change–vulnerable resources.

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About the authors

Andrew Ray *(andrew_ray@nps.gov) is an aquatic ecologist and* ***Kristin Legg*** *is program manager; both are with the NPS Greater Yellowstone Inventory and Monitoring Network in Bozeman, Montana.* ***Adam Sepulveda*** *is a biologist with the U.S. Geological Survey, Northern Rocky Mountain Science Center, in Bozeman.* ***Blake Hossack*** *is a research zoologist with the U.S. Geological Survey, Aldo Leopold Wilderness Research Institute, in Missoula, Montana.* ***Debra Patla*** *is field coordinator for the amphibian monitoring program with the Northern Rockies Conservation Cooperative in Jackson, Wyoming.*

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Notes from Abroad

Restoring biodiversity in Ireland's national parks

By Daniel Sarr, Cameron Clotworthy, and Robbie Millar

Abstract

Ireland, settled since late Stone Age times, has experienced a long history of environmental change and biodiversity loss. With the establishment of its national parks, Ireland began the relatively recent process of restoring its natural heritage. These ongoing efforts, which have involved restoration of focal communities or habitats, such as oak forest and, most prominently, the restoration of focal species populations such as the golden eagle, have provided potent symbols of renewal in an ancient cultural landscape. The restoration work also has yielded insights into the challenges and opportunities that can come from applying the national park idea in long-settled lands.

Key words

anthropic, biodiversity, Ireland, national parks, restoration

ALTHOUGH NATIONAL PARK conservation arose in the wilderness landscapes of the American West, it is rooted in a strong preservation ethos and its worldwide adoption has since brought it into many long-settled lands. Such human-dominated landscapes often contain novel albeit anthropic ecosystems, distinctive biodiversity, and compelling questions for conservation science (Palmer et al. 2004). Of particular interest are historically degraded landscapes that have lost essential elements of biodiversity in the past, but through changes in land use and ecological restoration may be recovering their natural and cultural heritage. Ireland, an ancient cultural landscape, provides fascinating examples of the roles that national parks can play in biodiversity conservation and restoration, particularly in highly modified landscapes (fig. 1).

Ice, wind, and famine: The rise and fall of Irish biodiversity

After its evolutionary stage was swept largely clean by Pleistocene glaciers, Ireland was colonized by a spare and mobile suite of species and peoples during a relatively brief time when the nation was connected to Great Britain at the tip of the British peninsula (Yalden 1999). With the rise of Holocene seas around 10,000 years ago, it assumed its current island form, and flight, wind, and water became the only routes for species to arrive. The patterns of biological colonization and persistence in Ireland suggest a story of postglacial founders and subsequent invaders that occasionally attained dominance and pushed ancient elements to marginal refugia (Searle et al. 2009). Ireland's insular setting ensured that native species would be inherently vulnerable to extinction and to the needs of a growing human population. However, the Burren and Killarney National Parks in western and southwestern Ireland contain a number of such relict species.

Figure 1. The national parks of the Republic of Ireland are marked with red stars; black triangles are major cities.

The environmental history of the British Isles has been well chronicled, especially since the late Middle Ages (Lovegrove 2007). Habitat losses began early. In both Britain and Ireland, largely forested in the early Holocene, major shifts in the fossil forest beetle fauna suggest abrupt habitat changes, most likely deforestation, around 3,000–5,000 years ago (Whitehouse 2006). This parallels the flowering of advanced megalithic cultures on both islands, suggesting that while they built such timeless structures as Stonehenge and Newgrange, late Stone Age cultures started a long trajectory of landscape change. Compounding habitat losses, persecution of many species in both Britain and Ireland accelerated until the beginning of the 20th century and still occurs in some regions (Lovegrove 2007). Losses of most large carnivores, such as wolves, eagles, and hawks, were complete, or nearly so, by the middle of the 20th century (Hickey 2000; O'Toole et al. 2002). In Ireland these abuses were compounded by the human tragedy of the Great Famine of the mid-19th century, such that a ravaged fauna became a food source of last resort.

(A) NPS/DANIEL SARR, (B) CON MORIARTY, (C) LORCAN O'TOOLE, (D): PAM BROPHY

Figure 2. Focal habitat and species restoration issues in the Irish national parks. (A) One of the last native stands of Scots pine (*Pinus sylvestris*) woodland in Ireland and Lough Veagh at Glenveagh National Park. (B) Red deer (*Cervus elaphus*) stag, one of the first and most prominent and successful species restorations in Ireland. (C) Pontic rhododendron (*Rhododendron ponticum*, flowering evergreen shrub on right bank) invades a riparian forest, displacing native species at Killarney National Park. Pontic rhododendron is possibly the greatest threat to native biodiversity in the Irish national parks, because it competitively excludes most native plant species. (D) A golden eagle (*Aquila chrysaetos*) chick at Glenveagh National Park. Golden eagle introductions are the highest-profile species restoration in the last two decades in Ireland.

Restoring biodiversity in the national parks of Ireland

The culmination of Ireland's environmental history was severe biological impoverishment. By the 20th century, only 0.5% of the nation's land remained in forest, and the last vestiges of wild forests and their inhabitants were often to be found on private estates and hunting lodges. Without a wealth of public lands, the republic was forced to purchase lands incrementally for its parks or to accept land as gifts to the state. Nonetheless, progress has been impressive. In 1970, Ireland had only one national park and no other state-owned conservation areas (Craig 2001). However, by 2000, Ireland had established its current array of six national parks (fig. 1) and other designated conservation areas, constituting approximately 14% of its terrestrial and near-marine areas and putting it in the top half of European Union nations for lands conserved.

In the management of its national parks, Ireland follows the standards set forth by the International Union for the Conservation of Nature (IUCN) in 1969, which recommends that all governments agree to reserve the term "national park" to areas sharing the following characteristics:

- Where one or several ecosystems are not materially altered by human exploitation and occupation; where plant and animal species, geomorphological sites, and habitats are of special scientific, educational, and recreational interest or contain a natural landscape of great beauty.
- Where the highest competent authority of the country has taken steps to prevent or eliminate as soon as possible exploitation or occupation in the whole area and to effectively enforce the respect of ecological, geomorphological, or aesthetic features that have led to its establishment.
- Where visitors are allowed to enter, under special conditions, for inspirational, educational, cultural, and recreational purposes.

The application of this ideal is obviously problematic in a long-settled land, and although they occupy some of the most pristine areas of the country, none of the Irish parks have escaped human impact. Consequently, Ireland's national parks have become anchors for active and passive restoration (e.g., removal of impacts such as turf cutting and allowing natural recovery, respectively) of native biodiversity. In some cases, this is because they contained remnant forests, for example the birch, oak, and pine woodlands at Glenveagh National Park (fig. 2A). In other cases, national parks have been determined to be places of stable land tenure, where hunting, grazing, and other impacts can be controlled. Nonetheless, major challenges to biodiversity restoration in the Irish parks, as elsewhere, include extirpation of foundational species, habitat change and loss, effects of native and domestic grazers, and invasive plant species.

Because many of Ireland's native predators were extirpated by the 19th century, species restorations have become a major conservation goal. National parks have been focal areas for the direct introductions of native wildlife, including the iconic red deer (*Cervus elaphus*, a close relative to the North American elk; fig. 2B). This species was restored to Glenveagh National Park in the late 19th century from populations in Britain and Ireland (GNP 2008). Raptor restoration has been a major focus in recent years, including the golden eagle (*Aquila chrysaetos*) at Glenveagh in 2001 (O'Toole et al. 2002), the white-tailed sea eagle (*Haliaeetus albicilla*) at Killarney National Park in 2007, and the red kite (*Milvus milvus*) in Wicklow Mountains National Park in 2007. To date, population recovery rates of most raptors are low. Major sources of mortality include poisoning, vehicle accidents, and illegal hunting. However, the first golden eagle chicks in more than a century fledged in 2007 at Glenveagh (fig. 2C, previous page), and scientists are hopeful that these native-born birds will fare better than introduced juveniles. Only time will tell.

Other restoration needs in the Irish national parks include active and passive approaches to wetland and riparian restoration, forest restoration, and control of invasive plant species. The introduced Pontic rhododendron (*Rhododendron ponticum*), which competitively excludes native plants, is perhaps the greatest threat to biodiversity in the Irish national parks, and it has proven to be a strong invader of forests, moorlands, and riparian environments (fig. 2D, previous page). In contrast, some introduced species and communities are yielding beneficial ecological surprises. Plantations of introduced conifers, such as Sitka spruce (*Picea sitchensis*), which are rightly viewed as ill-conceived by many because they are not native to the British Isles, apparently provide important surrogate habitat for some forest-dependent species, including the pine martin (*Martes martes*) and the hen harrier (*Circus cyaneus*). Such observations reinforce a need for precaution, but also provide hopeful signs that native biodiversity can be resilient.

In other cases, the restoration of native species has had substantial negative effects on some habitats. Restoration research at both Glenveagh and Ballycroy using grazing exclosures of varied sizes has demonstrated that red deer and livestock tend to decrease the abundance of ling heather (*Calluna vulgaris*) and expand the dominance of purple moor grass (*Molinia caerulea*), and that heather can recover with short-term exclusion of native grazers and introduced livestock (fig. 3). However, long-term exclusion of red deer has also been observed to favor increases in the cover of grazing-resistant purple moor grass, which forms a heavy thatch that limits recruitment of native trees (Millar, unpublished data) and has less habitat value than heather. Some of these grazing impacts may be due to the current lack of large predators (wolves) in the Irish landscape, which is unlikely to change anytime soon. Restoration of a full diversity of habitats, therefore, will likely require long-term commitments to wildlife population management as well as innovative grazing management through the use of exclosures, movement of animals, or targeted grazing with other ungulates (e.g., sheep, goats, or cattle).

CAMERON CLOTWORTHY

Figure 3. A research grazing exclosure at Ballycroy National Park enabled scientists to understand the effects of grazing on vegetation by red deer. The dark vegetation in the exclosure is ling heather (*Calluna vulgaris*) and the pale tufted grass around the exclosure is purple moor grass (*Molinia caerulea*). Ling heather is critical habitat for the native red grouse (*Lagopus lagopus scoticus*), and research into the effects of both native (red deer) and non-native grazers (sheep) on habitat availability helps the park balance rural livelihoods and native species conservation.

A marked decline in the populations of red grouse (*Lagopus lagopus scoticus*) across Ireland and in the approximately 25,622 hectares (63,313 ac) Owenduff/Nephin Complex Special Protection Area (CSPA) surrounding Ballycroy National Park is believed to have been caused by a combination of depredation and habitat loss. In particular, excessive grazing by domestic sheep has led to declines in ling heather height and cover, important dimensions of red grouse habitat (Murray et al. 2013). In 2006 the decision to remove sheep in winter for five months, split between late fall and early spring, allowed an improvement in habitat condition and a doubling in red grouse numbers (362–426 individuals in 2002 vs. 790–832 individuals in 2012) across the Owenduff/Nephin CSPA (Murray et al. 2013). The success of this innovative approach may have broad implications for red grouse habitat management in Ireland.

Ireland, an ancient cultural landscape, provides fascinating examples of the roles that national parks can play in biodiversity conservation and restoration, particularly in highly modified landscapes.

Implications for biodiversity

These examples provide only a brief sketch of the challenges of restoring biodiversity in long-settled lands such as Ireland. These are rarely settings where absolutes and complete solutions can be implemented successfully in one effort. In Ireland, initial work ranged from largely successful (red deer restoration) to highly challenging (raptor restorations). Of course, there are also unintended consequences of restoration that can be both good and bad. A critical element in such a comprehensive restoration program is the strategic pursuit of an adaptive research and long-term monitoring capacity to help park managers and partners track the success of their efforts. Current monitoring and research have focused on a subset of species (red deer) through agency and collaborative public and nongovernmental efforts (raptors). The first author conducted the field research for this article in 2008 on a Fulbright Fellowship, just before the onset of the global economic crisis. Since that time, Ireland has endured great economic challenges, and is currently struggling to rebuild and expand its conservation research and monitoring capacity in a fiscally difficult time. Professional exchanges, in which scientists share ideas for inventory, monitoring, and research, are likely to be valuable for sharing insights and techniques in biodiversity restoration across differing environmental and cultural settings.

We conclude that national parks in long-settled lands like Ireland present interesting and compelling challenges for biodiversity conservation. They serve not only as important anchors of ecological restoration but also as windows on a vanished past and catalysts for human well-being today. Reestablished wildlife species and ecosystems provide potent and inspiring symbols of conservation for present and future generations. These examples from Ireland demonstrate the importance of park-based restoration programs to foster environmental awareness and conservation commitment in an ancient yet continuously evolving landscape. They also reinforce the importance of long-term commitment to inventory, monitoring, and adaptive research to ensure that such efforts succeed and biodiversity is restored.

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About the authors

Daniel Sarr *(dsarr@usgs.gov) developed this article while working with the National Park Service's Klamath Network Inventory and Monitoring Program, Ashland, Oregon, USA, with support from the Irish American Fulbright Commission. He is now a research ecologist with the U.S. Geological Survey's Grand Canyon Monitoring and Research Center in Flagstaff, Arizona.* ***Cameron Clotworthy*** *is with Ballycroy National Park, Westport, County Mayo, Ireland.* ***Robbie Millar*** *is with Glenveagh National Park, Churchill, Letterkenny, County Donegal, Ireland.*

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