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SPECIAL FEATURE: SCIENCE FOR OUR NATIONAL PARKS' SECOND CENTURY

Ecological monitoring and evidence-based decision-making in America's National Parks: highlights of the Special Feature

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Abstract. In this Special Feature, we celebrate 100 years of National Park Service science by highlighting contributions from the agency's Inventory and Monitoring Division. This broad body of work coalesces into several themes, including the role of protected areas in understanding rapid global change and the growing interest in place-based ecological insights that contextualize scientific information from protected areas across broader scales. Finally, we illustrate progress on the long-sought integration of science into the resource management strategies implemented within "America's Best Idea," now more important than ever given the many challenges our nation's parks face.

Key words: biodiversity; conservation; ecological monitoring; evidence-based decision-making; global change; national parks; protected areas; Special Feature: Science for our National Parks' Second Century.

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Introduction

Welcome to the Ecosphere Special Feature, "Science for our National Parks' Second Century." The 20 papers included here highlight scientific contributions from the National Park Service's (NPS) Natural Resources Inventory and Monitoring Division (IMD) and collaborators from within and outside the agency. The NPS 2016 Centennial provides an opportunity to reflect on scientific accomplishments by the agency and its partners as we prepare for an increasingly uncertain future for protected areas around the world (Hobbs et al. 2010). Often called "America's best idea," the collection of landscapes, people, and historic events that make up the U.S. National Park System faces enormous challenges, including rapid global change and shortfalls in organizational capacity. The long-sought integration of science into NPS policy and resource protection (Sellars 1997, Soukup 2004) is now more important than ever. Capitalizing on this investment in science capacity will be crucial to the success of the NPS mission in its next 100 years. The 1916 NPS Organic Act established that national parks must remain "...unimpaired for the enjoyment of future generations." This mandate is unique among U.S. land and water management agencies, requiring comprehensive scientific information about the condition of a diverse array of resources across aquatic, terrestrial, and atmospheric ecosystems (Fancy et al. 2009). Although this presents the agency with a tremendous challenge, it also provides an opportunity and motivation for meaningful collaborative research and applications of science to decision-making via long-term ecological monitoring.

Almost 20 years ago, the NPS established the IMD and launched its Vital Signs Monitoring Program (Fancy et al. 2009), one of the centerpieces to the agency's 1999 Natural Resources Challenge (Parsons 2004). The Challenge responded to the congressional mandate of the 1998 National Parks Omnibus Management Act to rebuild NPS science capacity and improve science-based management decisions. In addition to the Vital Signs Monitoring Program, the Challenge established 18 Cooperative Ecosystem Studies Units in universities across the country and 19 Research Learning Centers in parks. These networks have helped to institutionalize strategic linkages to academia and outside governmental and non-governmental partners. Thanks to the Challenge, the Natural Resource Stewardship and Science directorate, which oversees IMD and other natural resource divisions, increased scientific staffing to more than 350 permanent positions and established new pipelines to recruit and engage visiting scholars. From 2000 to 2016, several hundred peer-reviewed publications have appeared in scientific journals authored or co-authored by IMD scientists and their collaborators (NPS 2016). This activity suggests that the "intellectual backlog" of ecological knowledge in national parks (Soukup 2004) is being filled; however, only time will tell how this evolves into a culture of improved park stewardship. It is one thing to conduct and publish research in parks, but achieving science-informed decision-making, what Fancy and Bennetts (2012) referred to as "institutionalizing" the science, can be surprisingly difficult (e.g., Cook et al. 2009).

Special Feature Highlights

For this Special Feature, we solicited contributions from across the Vital Signs Monitoring Program. We have published 20 of those contributions in this feature. This makes for an unusually large Special Feature, underscoring the current pace and enthusiasm of scientific activity in NPS. We begin with Ray Sauvajot's editorial (Sauvajot 2016), which elaborates on why the investment in science is so important and supported at the highest levels of the agency. The subsequent collection of papers shows the breadth and depth of the program after 16 years of development. The NPS is entrusted with stewarding a rather astounding array of natural resources, that, as reflected here, often span very broad geographic (e.g., Miller et al. 2016, Monahan et al. 2016, Rodhouse et al. 2016) and temporal scales (e.g., Ketz et al. 2016, Paulsen et al. 2016, Roland et al. 2016), and multiple levels of ecological complexity (e.g., Coletti et al. 2016, Fakhraei et al. 2016). The assembled papers reflect the growing interest in and capacity to generate place-based ecological insights (sensu Billick and Price 2010*a*), and many have replicated studies across multiple parks. This ability to contextualize scientific information for park decision-makers by scaling up among multiple parks and with surrounding landscapes is a particularly important aspect of long-term monitoring and research in protected-area networks. It was our goal that the Special Feature would contain papers that explored this topic.

The collaborative multi-park approach to monitoring and information delivery is a hallmark of the network organizational structure of the NPS Vital Signs Monitoring Program but a significant departure from the agency's traditional orientation toward individual park autonomy. This was in part a practical decision to build economies of scale among parks within networks (Fancy et al. 2009), but it created a tremendous architecture for place-based ecological study as well. By replicating common monitoring and research protocols in many parks, unique insights can be gained about ecological variation in parks over space and time, the "idiosyncrasies of place" as described by Billick and Price (2010*b*). Instead of a search for generality, the place-based approach steeps itself directly in the messy, idiosyncratic details of real ecosystems. For the NPS, this can mean park-specific insights (e.g., Jeffress et al. 2013) and customized conservation strategies. For example, Brown et al. (2016) applied a common protocol to coral reefs in four parks that revealed among-park variation in stressors and subsequent management recommendations. Ashton et al. (2016) replicated vegetation surveys among prairie parks and found previously undescribed cyclical variation in invasive brome grass dynamics that will greatly benefit park weed management. Witwicki et al. (2016) described a complex dynamic among ecological sites in parks on the Colorado Plateau between annual fluctuations in precipitation and C_3 and C_4 grass cover, also with implications for invasive species management. Also in one of those Colorado Plateau parks, Arches National Park, Weissinger et al. (2016) revealed place-based idiosyncrasies over 14 years in the apparent climatic influences on discharge rates of groundwater springs. Finally, Fakhraei et al. (2016) provide assessment points for the management of nutrient concentrations in aquatic resources scaled to the Great Smoky Mountains National Park and its unique landscape context. These kinds of studies give confidence to park resource staff that they are making decisions specific to the ecology of their place of interest.

Parks have long been seen as more natural than surrounding landscapes, protected from the crush of humanity and places where visitors can find solitude and respite (Sellars 1997). Indeed, the concept of "naturalness" is central to the NPS mission (Cole et al. 2008). It is clear, however, that parks are not by default protected from outside-in anthropogenic stressors such as climate change, biological invasion, and land-use changes (Cole et al. 2008, Hobbs et al. 2010). A new paradigm for protected-area conservation has emerged that recognizes the highly dynamic and vulnerable nature of park ecosystems and emphasizes active interventions (e.g., restoration; Hobbs et al. 2010). All of the Special Feature contributions reflect this paradigm and the increasingly precarious conditions of parks. This is particularly evident in the papers about global change impacts on parks. Monahan et al. (2016) show us that the onset of spring is advancing in most parks, as Monahan and Fisichelli (2014) have demonstrated previously that the entire NPS system is actively experiencing temperature increases. Rodhouse et al. (2016) present this alternatively as climate change velocity, in the context of bat conservation, which has the potential to shift species distributions and depress fecundity in parks of the arid west. Ray et al. (2016) describe climate change impacts on amphibian wetland occupancy vital rates in the Greater Yellowstone Ecosystem, and Weissinger et al. (2016) describe drought-induced losses in groundwater recharge and springs in Arches National Park.

Biological invasions are now ubiquitous in NPS parks and are one of the most common Vital Signs Monitoring topics identified by IMD (Fancy et al. 2009). As noted previously, invasive annual grasses are the subject of study by Ashton et al. (2016) and Witwicki et al. (2016). But NPS is confronted with tremendous conservation challenges presented by other invasions. The 6 years of monitoring in high-elevation whitebark pine stands of the Greater Yellowstone Ecosystem by Shanahan et al. (2016) revealed alarming rates of pine mortality and shifting tree age class dynamics caused by the Eurasian fungal disease, white pine blister rust. They also describe novel insights about the interactions between rust, mountain pine beetle outbreaks, and water availability that can guide conservation. Rodhouse et al. (2016) evaluated the current and projected pace of spread of the invasive fungal bat disease white-nose syndrome, also from Eurasia (Warnecke et al. 2012), across the NPS system and concluded that well over 100 parks will soon be directly impacted by this disease. Heard and Sickman (2016) provide compelling evidence that oligotrophic mountain lakes in Yosemite and Sequoia and Kings Canyon National Parks are experiencing elevated rates of atmospheric nitrogen deposition and phytoplankton blooms, despite strict California state water quality standards.

Yet, regardless of the many outside-in stressors affecting the NPS system, parks can still provide meaningful reference conditions against which changes in adjacent systems can be measured, as demonstrated in several papers. Miller et al. (2016) showed that parks in the eastern United States provide significantly older forest structure and different demographic rates than forests outside of parks. Similarly, Kirschbaum et al. (2016) used remote sensing techniques to reveal nuances about disturbance processes in forested parks and adjacent landscapes in the Great Lakes region and Upper Mississippi Valley. Also in the Great Lakes region, Paulsen et al. (2016) provide a long view comparing contemporary forest species composition patterns in parks with those recorded during 19th-century public land surveys. This study not only provides a perspective on historic land-use impacts across the entire region, it also establishes the long-lasting legacy of these land-use impacts still affecting contemporary park ecosystems and constraining management options for these systems. Schweiger et al. (2016) also addressed the question of legacy land-use and management decision impacts on contemporary wetland ecological integrity in

Rocky Mountain National Park within a causal inferential framework using structural equation models. Their study revealed that a substantial proportion of that park's wetlands do not meet established reference conditions but their analysis provides a robust integrity-based framework to guide strategic wetland conservation and restoration. Finally, the papers by J. Alexander et al. (*unpublished manuscript*) and Ladin et al. (2016) demonstrate two alternative approaches with avian point count data that provide perspectives on the contribution of NPS-protected areas to regional biodiversity conservation strategies.

Where Do We Go From Here?

How does the NPS Vital Signs Monitoring Program, and indeed any ecological monitoring program, remain relevant and sustainable in the coming decades? We highlight three themes that emerge from the Special Feature papers and from our collective experience with NPS monitoring that appear to be essential ingredients to successful ecological monitoring. First, a successful program is one that is relevant to stakeholders (Cash et al. 2003, Cook et al. 2013, Roux et al. 2015) and a central tenet of success must be the degree to which monitoring provides information that actually facilitates decision-making and improves the efficacy of conservation activities. Certainly, the NPS investment in science can only be sustained if there is a broad perception within the agency and by the taxpaying public that it strengthens resource stewardship (Sauvajot 2016). This is an intuitive bar to set for monitoring, but it has been surprisingly difficult for most monitoring programs to achieve (Olsen et al. 1999, Stoddard et al. 2008, Baker 2015).

Second, the papers in this Special Feature demonstrate the catalyst role that NPS IMD and other science staff increasingly play in building collaborations with academics, subject-matter experts, and park managers. To be effective catalysts, NPS scientists must translate research findings for managers and management needs for scientists. This is the role of the "embedded scientist" within science–management boundary-spanning organizations advocated for by Cook et al. (2013) and others (e.g., Roux et al. 2015). The cadre of embedded scientists accelerates the uptake and utilization of scientific information and adds significant value to recent NPS investments in science. Embedded scientists will become increasingly sought-after in the coming decades as the socio-ecological landscape of NPS becomes more complex, requires more sophisticated cross-boundary collaborations, and necessitates deeper investments into the translation of research and monitoring information.

Third, organizational flexibility will be required for NPS to capitalize on increased scientific investments. Flexibility does not come easy for a bureaucracy as large as NPS, but the accelerated rates of environmental and socio-political changes underway will demand this flexibility. Within the context of the Vital Signs Monitoring Program, flexibility must emerge from a willingness to adapt to changing organizational needs and as ecological understanding evolves (Lindenmayer and Likens 2010). Vital Signs priorities may need to be revisited, resources be re-allocated from surveillance monitoring to more focused hypothesis-driven studies (Paulsen et al. 1998, Nichols and Williams 2006, Wintle et al. 2010, Ketz et al. 2016), and scopes of inferences be more causal (Grace et al. 2012, 2016, Schweiger et al. 2016) than is currently the case. Several papers in this Special Feature demonstrate that this need not be an either/or decision but rather an evolution from initial inventory and surveillance to the generation of hypotheses that can be tested within the same monitoring framework. This will be most effective when rapport and dialogue between the embedded scientist and the manager is high. However, management must respond in kind and be willing and able to adapt to new scientific understanding in real time, nimbly revise management plans, and even recast park thematic identities and missions (Cole et al. 2008, Hobbs et al. 2010, Powell et al. 2013).

Conclusion

Relative to its long-term ambition (Fancy et al. 2009), the NPS Vital Signs Monitoring Program is still in early stages of its development. The next several years of the Vital Signs Monitoring Program will be crucial to its long-term success, for example, by completing the approximately 330 monitoring protocols initially outlined in Network plans over the next several years.

Concerns about adequate institutional capacity and flexibility notwithstanding, from our vantage point, we expect that it will be successful. The growing environmental challenges facing the National Park System and the availability of extensive earth observational datasets within and among park units would suggest an expanded rather than diminished role for Vital Signs Monitoring. However, success is far from certain and need not be taken for granted. It is instructive at this point to reflect on the achievements, lessons learned, and challenges encountered by the program to date and to push ourselves, as a community of science and management practitioners, to honestly answer the central question of relevancy: "would we be missed…?" It is our hope that this Special Feature will help to ensure that the answer will unequivocally become "Yes!"

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