Ecological Applications, 14(1), 2004, pp. 14–15

A CAREERIST'S PERSPECTIVE ON "SUPPORTING BASIC ECOLOGICAL RESEARCH IN U.S. NATIONAL PARKS"

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Parsons (2004) accurately summarizes the treatise by Richard Sellars (Sellars 1997) regarding the uncertain role afforded science in the National Park Service (NPS) over its history. By most standards the NPS has succeeded in providing basic resource protection and high levels of visitor services to an approving public. However, the investment in science necessary to manage 34×10^6 ha (84 million acres) of park lands has not been made by an agency that is chronically underfunded but given great latitude to juggle funds to meet the most pressing needs of the moment. The result is not only a deferred maintenance backlog but also an "intellectual backlog" in understanding the resources the bureau manages. While intuitive decision-making may have sufficed in the 20th century, it certainly will not ensure that the natural systems (the wildlife and scenery) of national parks will be maintained unimpaired throughout the 21st century.

The primary proponents (a "fifth column" of sorts) of science-based decision making in national parks were NPS's research scientists, until their removal to the U.S. Geological Survey, as Parsons references. Since that loss, a very good sign of a broadening agency culture that embraces the necessity of science in achieving its mandate has been the unflinching support of the Natural Resources Challenge (NR Challenge) by career and politically appointed leadership. The NR Challenge will provide $100 million annually to expand the scientific tools available to park managers. This effort will serve the 270 natural-resource-based parks with 12 basic data layers in a GIS format, including an inventory of vascular plants and vertebrate animals. Some parks like Great Smoky Mountains National Park with its All Taxa Biodiversity Inventory (funded largely with donated funds) are taking it upon themselves to go faster and further. National Parks like Yellowstone and Everglades have important science programs, but because of decentralization there is wide variability in the priority given to investments in science among parks by managers who often have limited backgrounds in both science and the applications of science in difficult resource-protection issues.

With other NR Challenge programs aimed at providing science for parks, like the Cooperative Ecosystem Studies Units, monitoring networks, and others mentioned by Parsons, parks will be able to identify issues, get technical support and research, resolve resource issues successfully, and talk with visitors and interest groups with better information.

Other important NR Challenge efforts such as Learning Centers (which provide housing and workspace for researchers) and the Sabbatical-in-the-Parks Program are intended to support the concept of "parks for science." The future for national parks will be bright when parks are seen by the research community (and the National Science Foundation among others) as optimal basic research sites where results not only appear in the peer-reviewed literature but also are directly applied for the societal benefit of natural-system/national-park preservation. Such an outcome will require a larger, long-term effort with parks filling the environmentally equivalent role played by the fruit fly for geneticists. Understanding vast complex systems requires no less. If this mutualism between park management and scientists is fully understood, the future of parks will indeed be brighter and parks will fulfill another very important role in the future American landscape.

The responsibility of the NPS is not only to recognize this need and potential, but also to ensure that park management's knowledge of their natural systems grows—even slowly—year after year. Integrative capacity is essential to achieving the Service's challenging mission, but an accumulating understanding and institutional (science-based) memory of the resources the NPS manages remain sorely absent. Many studies are provided to parks by academe, private contractors, and other agencies each year. Many resource-management projects are initiated in parks without full integration of the experience into an adaptive-management protocol that increases a park's understanding of its resources. No other entity than NPS has the role or responsibility to consistently assemble park-specific working models of resource relationships, resilience, and vulnerability that stand the test of real-life application in daily management. To be successful in its

Manuscript received and accepted 21 April 2003. Corresponding Editor: J. S. Baron.

For reprints of this Forum, see footnote 1, p. 3.

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mission, NPS must become systematic not only in encouraging the acquisition of large volumes of information but also in actively accreting and integrating information into a functional understanding—one that is refined, applied, and tested in the academic, civic, and legal arenas. Because parks are stable fixtures on the landscape, these models can be refined year after year until they become valuable not only to parks but to science and to regional decision makers. This requires investment in staff scientists who are integrators, modelers, and systems thinkers. A sufficient array of highly trained park scientists with salaries based on research achievements, site fidelity, and professional excellence must be available to assemble all the available studies—all those reports on the shelves provided by external sources—into a growing understanding. A big part of their jobs must be to provide park managers with ever-increasing credibility and authority when they tackle issues that deal with the long-term viability of national parks.

The NPS has been honored with the role of steward of the nation's natural heritage. It must be equal to the task. Managing national parks in the modern landscape is an intellectually challenging task that calls for facility with systems ecology and hands-on application of its tenets. While there are political and institutional barriers to accepting that challenge, national parks will not be truly protected until those barriers are overcome.

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Ecological Applications, 14(1), 2004, pp. 15–17

PROMOTING ECOLOGICAL RESEARCH IN NATIONAL PARKS BY INVESTING IN THE NEXT GENERATION OF SCIENTISTS

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The adoption of the National Resource Challenge (NR Challenge) as an action plan for preserving natural resources in national parks represents a monumental shift in the attitude toward and commitment to scientific research by the National Park Service (NPS) (Kaiser 2000). Historically, the attitude toward scientific research (and scientists) in national parks has varied widely among parks, and was determined largely by the priorities of the park superintendent (NRC 1992, Sellars 1997, Parsons 2004). While there are notable exceptions (see Parsons 2004), for the most part national parks have been an under-exploited resource for ecological research. Now that there is a national mandate to attract scientists to conduct and science in the properties managed by the NPS (see NPS web site)[2] (also see Kaiser 2000), many of the logistical constraints and administrative obstacles that limited or prevented ecologists from working in the parks are being removed. For example, the permitting process has become streamlined and is now accessible over the web. Information about park resources, including the availability of and links to data on biological, geopmorphological, climatological, and cultural resources in the national parks are now easily accessible over the web.[3] These are important and necessary steps in making the parks, and data about park resources, more accessible to researchers. They also provide the framework for the establishment of rigorous, scientific research programs that can take advantage of the diversity of habitats and broad spatial scales over which many patterns and processes occur in our national parks.

Promoting the research agenda outlined in the NR Challenge and achieving the goal of getting the ''good science and scientists'' to work in national parks present some serious challenges. Foremost among them is communicating this new philosophy to the scientific community, encouraging and facilitating initial research that will lead to the development of new programs, and providing the funding to get new investigators to develop research projects in national parks. To meet these challenges, the NPS has initiated an ac-

Manuscript received 27 March 2003; accepted 30 March 2003. Corresponding Editor: J. S. Baron.

For reprints of this Forum, see footnote 1, p. 3.

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[2] URL: ⟨http://www.nature.nps.gov/challengedoc/index.htm⟩

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tive outreach program to the scientific community to attract researchers to the parks. These include programs that target more senior scientists, such as Cooperative Ecosystem Studies Units (CESUs) and the Sabbatical-in-the-Parks program and research fellowships for pre- and postdoctoral research in national parks. Both the CESU and Sabbatical-in-the-Parks program are funded by the NPS. One goal of the NR Challenge is to provide financial support for these programs both directly and indirectly by enhancing the research infrastructure in the parks. However, as Soukup (2004) points out, there is a huge ''intellectual backlog'' in the understanding of how the ecological systems that occur in the parks operate. Even with the additional investment of funds provided by the NR Challenge, more funding will be needed both to meet the needs of resource managers (''science for parks'') and to develop a better understanding of the rich and diverse biological legacy that is preserved and protected in the natural areas of our national park system.

The biggest challenge—and largest potential payoff for the parks—will be to promote and encourage opportunities that provide funding to attract new, young scientists to conduct research in the Parks. Both the Canon Scholars and National Parks Ecological Research (NPER) Fellowship Program are designed to meet this challenge. Both programs are funded by grants from private foundations (Canon and A. W. Mellon, respectively) and importantly involve collaborations with professional scientific societies (American Association for the Advancement of Science [AAAS] and Ecological Society of America [ESA], respectively). The involvement of these professional scientific societies in the selection of fellows for these programs is important for two reasons: (1) it increases the visibility and impact of these programs within the NPS and (2) it increases the awareness of the scientific community of the potential of the ''parks for science.'' When the Canon Scholars program was established in 1997 it was designed to enhance the ''science for parks'' program and did this by soliciting proposals in four focal areas identified in collaboration with park superintendents. Today, it funds research in all areas of biological, physical, social, and cultural science and technology innovation in support of conservation science and is not limited to issues important to park management.

The NPER Fellowship Program has a narrower scientific focus than the Canon Scholars program in that it currently only funds projects in basic ecological sciences that focus on the flora of the parks. However, the Mellon Foundation is supporting efforts by the National Parks Foundation to acquire additional support for the NPER program from other donors so that the taxonomic scope of the work supported by this program can be broadened. The third cohort of NPER fellows was selected in 2002 (a total of nine have been funded) and these individuals are working on a broad range of questions ranging from understanding controls on the biogeochemistry and N cycling of grasslands in Sequoia National Park to reconstructing historical patterns of plant invasions in the Cape Cod National Seashore to testing models of the evolution of mutualism with Senita cactus at Organic Pipe National Monument.[4]

One aspect of the NPER program that distinguishes it from the Canon Scholars, Sabbatical-in-the-Parks, and CESU programs is that the focus is explicitly on ''parks for science,'' not ''science for parks.'' The proposals are evaluated primarily on the scientific merit and creativity of the proposed work and credentials of the applicant. The applicant's argument about the importance of the natural resources or ecological features of the proposed park (or parks) to the proposed research is also considered, but the importance or relevance of the work for park management is not. In fact, the application explicitly states: ''Applicability of (the) research for park management needs is *not* a criterion for selection.'' The intent of this criteron is not to exclude proposals that could be done elsewhere (a reason frequently given in the past for rejecting research permits by some parks), but rather to raise the awareness of the value of our national parks for ecological research. This is a program in which the explicit intent it to support and encourage the use of national parks as sites for ecological research by new young investigators—and by doing so to change the culture of support for basic research in both the parks and agencies that support ecological research.

Two measures of the success of the NPER and Canon Scholars programs will be: (1) Do the fellows continue to conduct research in national parks when they move into full-time research or academic positions? and (2) Are individuals (and mentors) who have not previously worked in national parks being attracted to this program? While both these programs are still too young to evaluate them on these criteria, their ultimate value to the parks will not be achieved until these goals are met. Both the AAAS and ESA are providing logistical support to promote these programs by distributing information and hosting opportunities at national meetings for the prospective applicants to learn more about research opportunities in national parks. These activities will certainly help meet the goal of attracting new people to consider working in national parks, but without support from funding sources the primary goal of both these programs—and the NR Challenge—will not be met.

Fantastic as the Canon Scholars and NPER fellows programs are in providing opportunities for ecological research in national parks, by themselves they are too small to achieve a marked increased in research activ-

[4] URL: ⟨http://www.esa.org/nper⟩

ities in national parks in the near future. The Canon Scholars program currently has expanded its scope to include research in national parks in all of the Americas, which is a valuable addition to the scope of the program.[5] But as a consequence, only four scholars per year will now be funded to work in U.S. National Parks, and biology (broadly defined) is only one of the four areas supported. Similarly the NPER program is likely only to fund 2–3 fellows per year for the next 3–4 years. Consequently, the combined ''intellectual yield'' from these programs of young scientists pursuing ecological research in U.S. National Parks in the near future is likely to be small. Both these programs rely on private funds and their potential for growth is dependent on either the increased generosity from current funders or identifying additional sources of private funds.

Is this the only way to promote ecological research in our national parks? Shouldn't it be feasible for federal programs that fund ecological research—particularly at the pre- and post-doctoral level—to promote research opportunities in national parks? For example, what prevents the National Science Foundation (NSF) Dissertation Improvement Grants and postdoctoral fellowships in BioInformatics and Microbial Biology programs from including mention that our national parks (and other federal lands) provide unique opportunities for research? Similarly, collaboration and cooperation with private foundations that support research in conservation biology should be encouraged. A potentially important collaboration that could be facilitated by members of the ESA is with the David H. Smith Conservation Research Fellowship Program.[6] Established by The Nature Conservancy (TNC) in 1998, the Smith Fellows program funds 5–7 fellows each year to conduct applied research in biological conservation in the United States. TNC's ''Conservation by Design'' program explicitly focuses on the need to develop conservation tools that can be applied at scales great enough to impact the viability of species, communities, and ecosystems.[7] Wouldn't our national parks be ideal laboratories for such research? While no preference need be given to applications to the NSF or Smith Fellows programs that use national parks and their resources (though this might be something to consider in the future), simply identifying national parks as potential sites for research might go a long way in promoting ''parks for science'' and bring both good science and good (young) scientists to the parks. The inventory and monitoring data on biological, cultural, and physical features of the national parks that are being expanded and made available on the web under the NR Challenge program could provide a fantastic resource for research questions that require consideration of how patterns vary across spatial scales.

Our national parks provide a living legacy of the natural resources and biological features of this country. Research to promote better understanding of how to preserve, protect, and manage these lands and to take advantage of the living laboratories that they provide should be promoted at all levels. The ESA is taking a small role in this by being involved in the NPER Fellowship Program, but opportunities may exist for us as a Society, and certainly as individuals, to do more to promote ecological research in our national parks. This should include working to break down the cultural barriers that may in the past have prevented coordination of efforts among agencies and private and public organizations, to support ecological research in national parks. At the very least, we should encourage students to pursue these opportunities and facilitate their efforts to work in national parks. What we do now, will certainly pay off in the future.

[5] URL: ⟨http://www.nature.nps.gov/canonscholarships/⟩
[6] URL: ⟨http://www.smithfellows.org/⟩
[7] URL: ⟨www.nature.org⟩

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Ecological Applications, 14(1), 2004, pp. 18–21

NEEDED: A UNIFIED INFRASTRUCTURE TO SUPPORT LONG-TERM SCIENTIFIC RESEARCH ON PUBLIC LANDS

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We have gone from the early day philosophy that ''if national parks were simply left alone they would survive forever'' (Botkin 1990, Sellars 1997, Parsons 2004) to the current situation where parks are jeopardized by serious environmental threats both within and outside of their borders (e.g., Pringle 2000). While science alone cannot solve the environmental problems facing public lands, it can lead us to ask the right questions and result in critical information for management and policy needs (e.g., National Research Council [NRC] 1992, Sellars 1997). Unfortunately, we lack a unified infrastructure that supports *long-term* scientific research on public lands and facilitates application of that science to management. We believe that long-term scientific research would provide essential knowledge for management of public lands, a viewpoint expressed by others as well (Callahan 1984, Likens 1989). Our goals in this commentary are to highlight: (1) the scope and magnitude of environmental problems facing U.S. public lands; (2) the lack of long-term scientific information available to identify and address these problems; and finally (3) the value of long-term research, by using a few examples from the National Science Foundation's (NSF) Long-term Ecological Research Program.

U.S. public lands are facing environmental problems of increasing scope and magnitude. The National Parks Conservation Association (NPCA) recently began issuing an annual list of ''America's Ten Most Endangered National Parks'' to draw public attention to the endangered status of many park units (NPCA 2002*a*). Environmental challenges include air pollution, threats to water resources, and recreational impacts of snowmobiles. NPCA's third annual listing of endangered parks includes Big Bend National Park, Big Cypress National Preserve and Everglades National Park, Glacier National Park, Glacier Bay National Park and Preserve, Great Smoky Mountains National Park, Mojave National Preserve, Ocmulgee National Monument, Valley Forge National Historical Park, and Yellowstone National Park. To highlight the impacts of air pollution, which are evident throughout the national park system, NPCA also established its ''Code Red'' list of ''America's Five Most Polluted National Parks'' using an air-pollution index based on haze, ozone, and acid precipitation (NPCA 2002*b*). Regional nitrate deposition in Great Smoky Mountains National Park in the southeastern United States is the highest of any monitored site in North America, with ozone pollution rivaling that of Los Angeles and violating federal health standards more than 175 times since 1998. Similarly, ozone levels surpassed human-health standards on 61 summer days in 2001 in Sequoia and Kings Canyon National Parks in the western United States Other parks making the *list of five* most polluted parks include Mammoth Cave National Park in Kentucky, Shenandoah National Park in Virginia, and Acadia National Park in Maine.

Parks are clearly not the only category of U.S. public lands that face serious environmental problems. National Wildlife Refuges (NWRs) are particularly vulnerable to development pressures from outside of their boundaries because of their small size. Competition for water resources between refuges and adjacent human populations is particularly acute in arid western regions where many refuges report that they do not have enough water in an average year to support wildlife needs (summarized by Pringle [2000]). The Audubon Society (2001) concluded that the NWR system is in a state of crisis and is failing to protect bird species that are federally listed as threatened or endangered. To emphasize this crisis, the Society released its list of ''*Ten Wildlife Refuges in Crisis*'' (each of which is a major national or international conservation priority) because of imminent threats to their biological integrity. Examples span a wide geographic range and include the Sonny Bono Salton Sea NWR in California's Imperial Valley, the White River NWR in Arkansas, the Blackwater NWR in Maryland, and the Kenai NWR in Alaska. To detail just one example of problems faced by a given NWR: the Sonny Bono Salton Sea NWR is one of the few remaining locations in southern California where many birds can rest and feed during their migration along the Pacific flyway. This refuge is plagued by high mortality of fishes and avifauna resulting from water quality and quantity problems, to the extent that an on-site incinerator is routinely op-

Manuscript received and accepted 10 April 2003. Corresponding Editor: J. S. Baron.

For reprints of this Forum, see footnote 1, p. 3.

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erated for disposal of dead birds—including endangered species such as brown pelicans.

The lack of long-term scientific information that can be used to identify and address the increasing number of environmental threats to public lands is problematic. How can we systematically assess the biotic integrity of public lands on regional or national levels if data are nonexistent for many land units? All too often, ''piece-meal data'' are used in local management decisions (see Kaiser 2000) and in attempts at more regional syntheses of environmental problems and trends. As just one example, the NPCA's report ''Code Red: America's Five Most Polluted National Parks'' is based on data from only 10 national parks (out of 270 major park units)—selected because they had sufficient monitoring data to permit a comparative analyses of data from 1991–2001. In contrast, most of the park units within the National Park System (NPS) lack monitoring programs, precluding systematic assessment at a regional or national level.

The strength of science–management connections is highly variable both within and among different types of public land units. This is a reflection, in part, of the high variability in how natural resources are managed in different regions of the United States, between states, and between different categories of public lands. While detailed discussion of the causal factors behind these disparities is beyond the scope of our commentary, here we emphasize the variability in connections between science and management and the need for a unified infrastructure to promote the gathering and application of long-term scientific information. As just one example provided by Parsons (2004), NPS science-based management in some parks (e.g., Yellowstone, Great Smoky Mountains, Everglades) has been disproportionate relative to others. Research in Yellowstone, Great Smoky Mountains, and Everglades National Parks has benefitted from fairly substantial within-park research centers staffed by NPS research scientists and largely driven by ''individual personalities and circumstances rather than a unified, national agenda'' (Parsons 2004). Recent attempts to establish an independent research arm within the U.S. Department of the Interior (DoI)—i.e., the National Biological Survey (NBS)—fell prey to a political agenda, regardless of the potential value of the NBS to management of biological integrity on our nation's public lands. Nonetheless, over the past 10 years, the DoI has continued to encourage and support research in some flagship parks, such as Yellowstone National Park. However, the DoI's support of research does not necessarily imply that this research will be directly applied to management in these flagship parks or elsewhere. To do so requires a culture shift in the attitude and training of park managers (Parsons 2004), and the understanding by scientists that policy and management decisions will not be based solely on research data. Instead, scientists must learn to sit at the table as active discussants in order to provide advice and interpretation to managers as they weigh multifaceted policy decisions.

An important mechanism to arm scientists with information for management and policy is integrated, long-term, question-driven ecological research. An example of the prospective utility of this approach is the NSF-sponsored Long-term Ecological Research (LTER) program. The mission of the LTER network is to establish a well-documented legacy of experiments and observations to gain an ecological understanding of a diverse array of ecosystems at multiple spatial and temporal scales. Coupled with this mission is the goal of creating well-designed, well-documented databases that are accessible to the broader scientific community. The LTER network has achieved these goals with varying degrees of success. Certainly, LTER is not the only option, and several non-LTER sites (e.g., Walker Branch Watershed [eastern Tennassee]) have successfully conducted long-term and integrated research of national significance. Nevertheless, a coordinated network of research programs with broadly defined goals would provide invaluable information at multiple spatial and temporal scales to enlighten policy and management decisions on public lands.

As part of the DoI's attempts to foster scientific research, repeated requests were made to NSF to sponsor LTER sites in National Parks. To us, this reflects a favorable directive from the DoI that LTER-like research would benefit park management. Parsons (2004) states that NSF has refused to fund LTER sites in national parks because of a ''lack of trust in the NPS's commitment to the long-term protection of study areas''; however, we are unaware of any current policy at NSF to explicitly or implicitly exclude national parks from the LTER Network. In fact, during the last round of competition for Land–Coastal Margin LTER sites, an LTER program managed by scientists at Florida International University was established in Everglades National Park. Moreover, the LTER network has a long history of research partnerships with federal scientists working on federal lands, including USDA Agricultural Research Service stations (Jornada [New Mexico], Shortgrass Steppe [Colorado]), USDA Forest Service Experimental Watersheds (Bonanza Creek [Alaska], H. J. Andrews [Oregon], Baltimore Ecosystem Study [Maryland], Coweeta Hydrological Laboratory [Georgia], Hubbard Brook [New Hampshire], and Luquillo [Puerto Rico]), DoI's Bureau of Land Management property (Toolik Lake [Alaska]) and the DoI's National Wildlife Refuge system (Sevilleta National Wildlife Refuge [New Mexico]). Thus, 11 of the current 24 LTER sites are on public lands where academic and federal scientists conduct integrated research. Indeed, many of these sites are part of the LTER network because they already had long-term research programs in place prior to LTER.

LTER and other long-term research programs have shown repeatedly how question-driven fundamental research yields unbiased knowledge about complex systems that can be applied directly to management issues. Since many ecological processes have high levels of year-to-year variability, long-term research is often essential to separate pattern from noise (Franklin 1989). As a classic example, studies at the Hubbard Brook Experimental Forest in New Hampshire demonstrated the occurrence of acid precipitation (Likens and Bormann 1995), distinguishing relatively subtle changes in the acidity of rainfall through time. These studies led to amendments to the Clear Air Act of 1990, illustrating the importance of long-term studies in identifying and resolving environmental issues from regional to global scales (Blair et al. 2000). Similarly, research at the Sevilleta LTER site in New Mexico provided the background understanding to determine linkages between the 1993 El Niño episode, small-mammal population dynamics, and Hantavirus Pulmonary Syndrome in the southwestern United States. This information was then used to warn the public about a possible Hantavirus outbreak during the 1997–1998 El Niño event (Yates et al. 2002). On a more local level, research on the migratory behavior of riverine shrimps at the Luquillo LTER site (i.e., the Caribbean National Forest) in Puerto Rico was ultimately used to make recommendations for mitigation of negative environmental effects caused by massive water abstraction from streams draining the national forest. Field measurements of the mortality of migratory shrimp larvae, combined with a 30-year discharge record, allowed modeling of the long-term ecological impacts of different water intake management strategies (Benstead et al. 1999) and were instrumental in the Puerto Rican Aqueduct and Sewage Authority's decision to alter the design of two new water withdrawal systems to minimize the mortality of migratory stream biota.

In a visionary evaluation of the LTER network, the ''Risser Report'' (Risser et al. 1993) recommended an expansion of the LTER network and network activities to include federal lands and federally sponsored research programs. The premise behind these recommendations was that integrated, long- and short-term research would provide the understanding needed to address many management issues on public lands. In addition, presaging NSF's National Ecological Observatory Network (NEON) initiative, the Risser Report recommended that existing LTER sites increase their spatial domain via a sub-network of regional satellite sites, including public landholdings, such as parks and wildlife refuges. The objective of NEON is to build an integrated national network of environmental observatories to address critical questions about changes in ecological systems and to evaluate the impacts of those changes at regional to continental scales. This network would include an intensively instrumented core site and a variety of satellite sites. NEON explicitly includes publicly managed lands as potential core and satellite sites, providing another opportunity to create a legacy of research that will inform land managers.

Without a doubt, long-term research has led to management applications even when that research was not driven initially by management needs (e.g., Krishtalka et al. 2002). We believe that long-term basic research coupled with targeted, problem-based research will go a long way in informing policy decisions on public lands. We strongly recommend that an LTER-like network be established and supported by relevant agencies to promote integrated, regionally based understanding of ecosystems. This network should be linked to existing regional and national programs (e.g., LTER, National Water Quality Assessment Program, AmeriFlux Network, etc.). This would provide a much-needed ''network of networks'' on a continental scale that would yield a deeper understanding of ecological systems and provide better information to guide management of our endangered public lands.

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Ecological Applications, 14(1), 2004, pp. 21–24

PROMOTING ECOLOGICAL RESEARCH IN NATIONAL PARKS—A SOUTH AFRICAN PERSPECTIVE

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Background

South African National Parks (SANParks) has its own unique and favorable science dispensation, particularly in its first and biggest holding, the Kruger National Park (KNP). SANParks is a parastatal organization currently administering 20 parks over a wide range of South African biomes. Finances accruing from tourism revenue are recirculated within the organization, but with the central government still subsidizing some mainstream SANParks activities to a level of less than 20% of corporate budget in the last decade. A sustained track record of institutional support for science has been the result of a general desire to link science and management, of some good parks–academic partnerships, and of a legal mandate since a modification introduced into the National Parks Act:[2]

> *The object of the constitution of a park is the establishment, preservation* ***and study therein*** *of wild animal, marine and plant life and objects of geological, archaeological, historical, ethnological, oceanographic, educational and other scientific interest* . . . .
> [emphasis added]

Scientists have been part of the staff at KNP since 1950 and deployed in other parks since the early 1970s, and their work has been expected to inform management through generating relevant basic ecological understanding. Initially, the science emphasis throughout SANParks was more on applied and descriptive topics (especially relating to charismatic fauna), on inventorying, and on setting up what have become long-term monitoring programs. Over time, park scientists have come to act mainly as science facilitators. Since the early 1990s staff scientist numbers in SANParks have stayed more or less constant at around 20 persons, including several veterinarians. They are assisted by technicians, field assistants, secretaries, game guards, and laborers. Apart from a long history of science activity at KNP, some excellent and sustained science initiatives have also been conducted in the Kalahari Gemsbok and Mountain Zebra (both arid savanna parks), Tsitsikamma (mainly marine research), and Wilderness (a freshwater lake system) National Parks (Biggs and Novellie 2003). In an ongoing drive towards biome representivity, much expansion of conservation estate is currently taking place in the unique fynbos (a globally renowned separate floral kingdom) and succulent karoo, and SANParks are increasingly using state-of-the-art structured conservation planning techniques (Margules and Pressey 2000) to select these reserve networks. In particular, science activities in the recently acquired Cape Peninsula National Park, although largely outsourced, include strong elements of what was available through the plethora of organizations that previously controlled the nonresidential parts of the Cape Peninsula. This park also has a strongly developed integrated environmental-management system, making formalized provision for science–management links. Outside of this and the KNP (the two ‘‘institutionally large’’ parks with their own scientific community), a key issue was the clustering of scientists into a few viable centers serving wider areas, rather than placing one scientist at each ‘‘smaller’’ park.

The application of science, and the relationship between science and management is thus uneven across both the existing and the proposed park system (McKinsey and Company, 2002). This is part of a wider challenge, going beyond science and conservation

Manuscript received 24 March 2003; accepted 30 March 2003. Corresponding Editor: J. S. Baron.

For reprints of this Forum, see footnote 1, p. 3.

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[2] First introduced in Act 42 of 1962, Section 4, and carried forward in subsequent revisions.

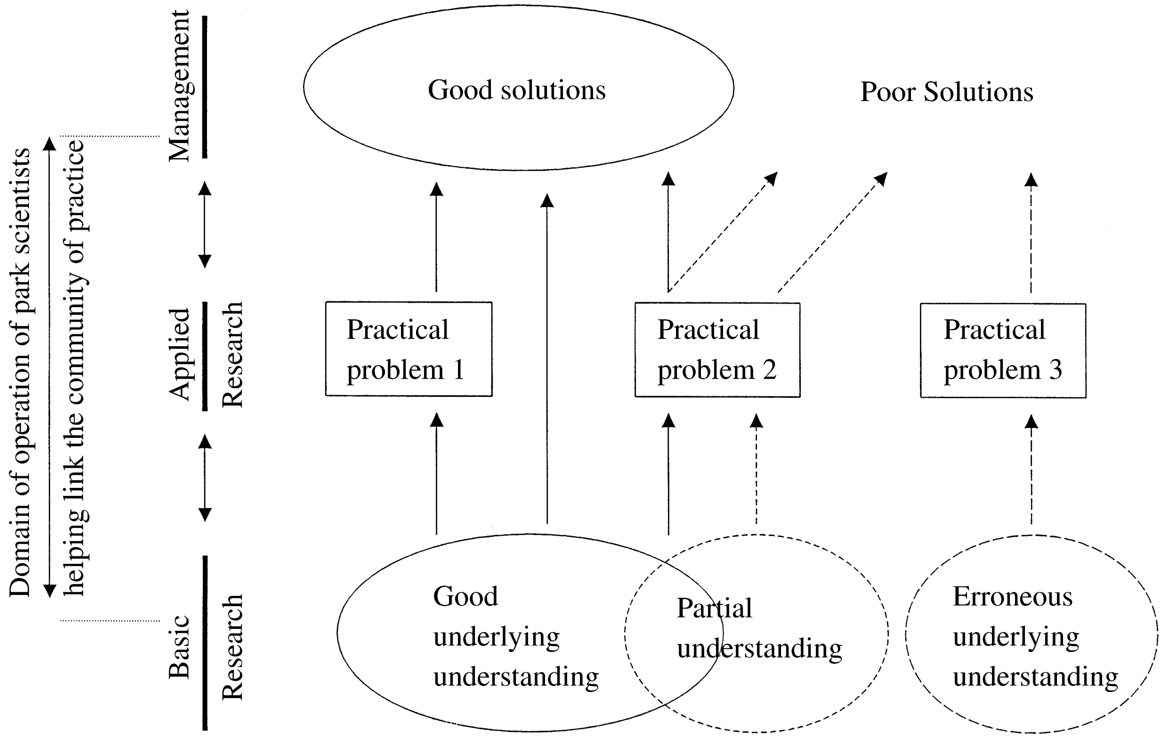

FIG. 1. Schematic representation of basic and applied research, and their relationship with park management. Park researchers should facilitate the implementation and linkage of these components, rather than being experts at basic research, applied research, or management.

management, one that SANParks has dubbed the ''one organization, twenty parks'' problem. Through SANParks history, certain individual park managers have been wary of science, though usually morally obliged to allow research or monitoring to continue. Lack of institutionalized adaptive-management processes with shared learning, has allowed this rift to persist in certain parks. Scientists can aggravate the condition by treating their knowledge as the only valuable source of information for management. Managers have a need for fairly immediate action, and then often go ahead trusting their experience, rather than waiting for an abstract hypothesis to be tested. Even when a scientific study is completed, lack of explicit feedback loops can result in non-application.

Considerable role overlap between researchers and managers occurs, park wardens often being drawn from research ranks. In the KNP, ex-researchers have held the posts of either warden and/or head of conservation since 1961. This overlap has generally promoted the science–management partnership.

A key strength of the SANParks science promotion initiative since 1958 has been its peer-reviewed science journal *Koedoe*, which has published more than 600 articles across a wide range of subjects relating to national parks.

OBJECTIVES AND PHILOSOPHY OF SCIENCE IN KNP

A science partnership between Kruger National Park (KNP) and any institute or individual is based primarily on a sufficient degree of joint interest. This demand is articulated from the KNP side via a well-developed wide-ranging set of objectives (Braack 1997). Its breadth stems from an aspirational mission statement balancing biodiversity with human benefits and wilderness demands. The biodiversity component reads: ''. . . to maintain biodiversity in all its natural facets and fluxes'' following the biodiversity definition of Noss (1990) where ''facets'' refers to structure, composition, and function under scales ranging from genetic to regional and even subglobal. ''Fluxes'' refers to heterogeneity over space and time. The contentious word ''natural'' pins the desired set of conditions to a wide envelope bounded by the extremes one expects over millennia, minus (wherever possible) the effects of post-technological humans. The objectives generated from such a mission statement create many applied and fundamental research opportunities.

Basic research underlies and guides applied research, allowing application a greater chance of success because the fundamental understanding is in place (Fig. 1). Park scientists, one of whose main tasks is research facilitation, need to stretch their capabilities across these domains and the linkages between them. In this way they help connect up a largely self-organizing value-added chain, called in business literature a ''virtual community of practice'' (Wenger et al. 2002). The chain may stretch from pure math at the far basic end, through many intermediaries (modelers, basic scientists, applied scientists, science-literate managers), to perhaps opening a waterhole for animals in the park, at the extreme tip of the management end. Partial role overlap along the links in the chain obviously promotes communication and the chance of success. There is place for curiosity-driven research if an appropriate win–win situation for academic and park objectives can be identified.

To give explicit expression to objectives, and to connect research, monitoring and management fluently, KNP utilizes a construct called ''thresholds of potential concern'' (TPCs), which are ''worry levels'' set up to ring an alarm bell before undesirable ecosystem endpoints are reached (limits of allowable flux). These TPCs (Rogers and Biggs 1999) also act as viable ongoing research hypotheses, tracers to drivers of change in the ecosystem, and achievable environmental goals. The setting into which this concept fits is a forward-looking, objectives-oriented, adaptive-management system. Researchers, managers, and those who monitor use this TPC system rather like relay runners in a (for purposes of this analogy, everlasting) relay race would use a baton, and research is both justified and focused by this approach. Research must produce the understanding to choose, calibrate, and interpret useful TPCs, the monitoring initiative selects and measures appropriate indicators for these, and management is elicited by an exceedance (or better still, modeled anticipated exceedance) of a TPC.

Partnerships and KNP Science

Genuine partnership is the cornerstone of science–management and parks–science linkages. The University of Pretoria (the first one in South Africa to offer postgraduate wildlife-management courses) was the main original science partner for SANParks, with a few individuals from the University of the Witwatersrand also making key contributions in KNP (Kruger National Park). Until the 1990s very few other academics participated, and the KNP developed a reputation of being inbred. This changed considerably under the influence of the KNP Rivers Research Program (RRP) (Water Research Commission 2000). The RRP was a multi-institutional interdisciplinary program to address poor flow and quality in rivers entering the park, a major biodiversity threat. A set of factors (including a political window of opportunity during democratization in South Africa, and changes in ecological paradigms of practicing scientists around the same time) favored the success and diffusion of their ideas across to the KNP in general. The new National Water Act of 1998, also indirectly influenced by this program, makes provision for guaranteed environmental reserves. Additional tools for science engagement in parks, discussed below, emanate directly or indirectly from the RRP. The RRP also developed frameworks for equitable participation of stakeholders in catchments, thus fulfilling the wider social contract in which science delivers tools to secure ecosystem services in a ''desired state'' (Rogers and Bestbier 1997).

KNP offers a negotiated project registration process, aimed at creating a joint learning platform in the science partnership. Currently there are about 200 registered research projects operating in KNP, and researcher accommodations are fully used. KNP has GIS capacity and an organized set of digital databases, with clear meta-file access. An intellectual property-rights policy offers limited lead-time protection on certain data sets for which SANParks are custodians, after which most become public domain. KNP has two new large-scale field-exclosure sets to test fire and two levels of herbivory effects. This rigorous design is expected to prove to be a major research resource, as are a flux-measurement tower, and the 50-year-old experimental burnplots (Trollope et al. 1998).

At this time most partners bring their own funds, with KNP supporting them in kind. Some activities and services are subsidized by KNP. The in-house KNP research budget is used mainly for salaries and operational costs of the major monitoring programs. Donor funding for various specific needs has become a major source of revenue in the last decade.

Several key factors, in conjunction with the above, are likely to keep KNP a preferred science destination:

- The fact that so many research programs are operating in KNP is a major drawcard. A science volume *The Kruger Experience—ecology and management and savanna heterogeneity* (Island Press) will appear during 2003. Several prominent South African and overseas groups now participate in research, often acting as a catalyst for more networking. KNP, in collaboration with the University of the Witwatersrand, plans to host an annual ecosystems research meeting to promote association.
- Strategic planning for SANParks and KNP favors continued prominence of research as a core function (McKinsey and Company; *unpublished report*).[3] The author believes integration of biophysical with socio-political and economic arenas will become commonplace.
- KNP is likely to be involved in the forthcoming SAEON (South African Earth Observatory Network). This local version of the Long-term Ecological Research (LTER) initiative will probably be catchment based (Van Jaarsveld and Biggs 2000), with a more pristine component of the planned site perhaps in KNP, which lies at the middle to lower end of several important rivers with high biodiversity. Proposed Af-

rican LTER sites tend to include or be in national parks.

- KNP offers prestige fellowships to South African students in plant ecology, a project currently supported by the Andrew W. Mellon Foundation.
- Affirmative action for previously disadvantaged South Africans is a major challenge in the ecological research field. Although SANParks has been able to make certain such appointments, it is currently planning organized long-term scholarship and mentorship programs, diversifying and hence safeguarding park science.
- The Great Limpopo Transfrontier Conservation Area is in the process of forming around KNP, providing further impetus as new areas open up in Mozambique and Zimbabwe, and require research and monitoring. The KNP science presence is expected to provide a nursery effect.

Conclusion

Science–management synergy in Kruger National Park (KNP) has been aided by explicit setting of objectives and a strategic adaptive-management framework in which research, monitoring, and management can collaborate fluently. The wide heterogeneity-based biodiversity mission statement enhances not only applied research on particular immediate park problems, but also promotes fundamental research supporting overall understanding of ecosystems. Logistic support is offered, along with several field facilities and biodiversity and ecosystem research opportunities characteristic of the KNP savanna. A lively future profile and emphasis on shared learning in genuine partnerships provide the most promising levers to enhance a strong science role in KNP and other South African Parks.

Acknowledgments

Thanks to several colleagues (Oonsie Biggs, Jane Carruthers, Hector Magome, Michael Knight, Peter Novellie, and Danie Pienaar) for commenting on an earlier draft, and to David Mabunda. This paper is based partly on a paper given at the symposium ''Science in national parks: basic research and application'' that was held at ESA's 86th annual meeting, 5–10 August 2001.

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Ecological Applications, 14(1), 2004, pp. 25–27

ECOLOGICAL RESEARCH AND THE COSTA RICAN PARK SYSTEM

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Natural areas are extremely important to human society for many different reasons that range from their aesthetic value to their potential use as sources of materials and services. In recognition of their value, organizations such as the National Park Service (NPS) in the United States have been assigned the responsibility of protecting governmentally set-aside natural areas for the enjoyment and benefit of present and future generations. Ecologists value natural areas because they enclose ecosystems that can be studied to learn about their functioning and interactions with the biosphere. Applied ecologists might use them as reference ecosystems against which the integrity of those that have been degraded can be assessed. However, ecologists are only one of many users of protected areas and uses can sometimes become conflicting. Parsons (2004) makes a clear point about the difficulties the U.S. NPS has faced in managing protected areas while balancing the interests of different groups. One unfortunate result is that national parks are sometimes managed without the benefit of basing decisions on sound ecological research.

In Costa Rica, more than one quarter of the land has been set aside and is under one or another form of protection against human development. Most of the area is enclosed within the system of national parks, a system that was initially modeled after the U.S. national park system. National parks in Costa Rica share many of the same objectives, users, and conflicts discussed by Parsons (2004) for U.S. national parks. However, over time the different realities the two systems face have resulted in differences in how ‘‘welcoming’’ national parks are to ecologists and how much ecological information has been included in their management. Here, I review briefly the history of Costa Rican national parks, how the system diverged from the original model, and the role that ecological research plays in park management.

Brief History of Costa Rican Parks

Initial efforts to protect areas of forest in Costa Rica had little success before the 1960s, when the first biological reserves were established. Success came just after a period of intense deforestation. During the decade of the 1950s, Costa Rica lost $\sim 10^6$ ha of forest through conversion to farms and cattle ranches (Fournier 1981, Fallas 1982, J. Monje-Najera, *unpublished report* [available on the Internet][2]). The biological reserve of Cabo Blanco was established in 1963, protecting 1172 ha, and was followed by Río Macho the following year protecting 110 000 ha (Fournier 1979). Thanks to the efforts of two biologists, Mario Boza and Alvaro Ugalde, an incipient Department of National Parks was established in the 1970s (Wallace 1992). The first national parks soon appeared: Poas National Park was first, protecting a volcano and its ecosystems, Cahuita protected a coral reef, and Santa Rosa protects the last tract of tropical dry forest in the country. The Forestry Law of 1969, based on a draft written under advice from the United Nations Food and Agriculture Organization (FAO), was the official origin of the national parks in Costa Rica. The law had a short life of 10 years, but it was enough to ensure the establishment of national parks and reserves, among other programs (Fournier 1991).

The national park system protects over $>0.5 \times 10^6$ ha of land, representing about 10% of the territory of Costa Rica (Boza 1987). In a recent change in its approach to park protection and conservation, the Ministry of the Environment developed the Sistema Nacional de Areas de Conservacion (SINAC). SINAC is the administrative and technical integration of all protected areas, including national parks, in Costa Rica into a system of 10 Conservation Areas that cover $>$25% of the country.

The most significant difference between the system in Costa Rica and other reserve systems in the world is a more scientifically sound approach to protecting ecosystems rather than a few focal species. The development of Conservation Areas represents another significant step towards the decentralization of the administration and the inclusion of local human communities in the management of parks. This is an important step to gain neighbor support and stress the value that park protection has on local communities. The initial system has diverged from the U.S. national park system over time, and the national and international scientific community played a major role in making this change.

Manuscript received and accepted 7 April 2003. Corresponding Editor: J. S. Baron.

For reprints of this Forum, see footnote 1, p. 3.

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[2] URL: ⟨http://rbt.ots.ac.cr/tropiweb/conserva/control.html⟩

Park Management and Scientific Research

The national parks of Costa Rica face a wide variety of management problems that need to be addressed if they are going to be protected in the long term. Issues range from gold mining in Corcovado National Park to the impact of a highway that divides Braulio Carrillo National Park in two. Although problems and interests might be as diverse as the animal and plant species protected within their boundaries, national-park management benefits from the efforts of ecologists in understanding ecosystem functioning. Ecological research has made available information that has been used to improve park management at many different levels. Short-term projects, such as master's theses and doctoral dissertations, have been used to improve particular aspects of park management in specific parks. Life-long efforts of ecologists have resulted in major changes in the way parks are organized and managed.

In Manuel Antonio National Park student research helped park managers understand how visitors were impacting local wildlife. Manuel Antonio, on the Pacific coast, is a favorite destination for Costa Ricans. The park used to have camping areas within its boundaries that were quickly filled during holidays. Although park personnel made efforts to keep the camping areas clean, trash and poorly packed food were frequently accessible to animals. Researchers from the wildlife management program at Universidad Nacional discovered seasonal changes in raccoon behavior that was related to peaks in park visitor use. During months of low visitation, raccoons spend their time mainly in mangrove forests, searching for food during the day. During holiday season, when the park was full of campers, raccoons became nocturnal and searched for food in the camping grounds. Results of a master's thesis on raccoon behavior in Manuel Antonio National Park was convincing enough that park managers decided to close the camp grounds within the park and start a program to educate visitors and the nearby community on how to reduce the problem with raccoons (E. Carrillo, *personal communication*).

The long-term efforts of ecologists, such as Dan Janzen, have made Santa Rosa National Park the classical example of the importance of sound ecological information on park management at a large scale in Costa Rica. The park was established in the 1970s to protect a patch of tropical seasonally dry forest, ~10 600 ha. Initial efforts to protect the forest followed the traditional ''leave it alone'' approach. The main objective was to remove cattle from grazing within the park boundaries and allow natural succession to restore the ecosystem. It was soon evident that this was not the right approach. Introduced African pasture grasses fueled large wild fires, reducing the area of forest even more. Fires do not occur naturally in this ecosystem. A new approach was developed using past experiences and input from the scientific community. The plan called for active restoration of certain areas of the park, controlling forest fires, and managing cattle to control introduced grasses. The activity produced positive results and soon the focus of conservation changed from preserving the dry forest within park boundaries to developing strategies to increase the park's size and the amount of dry forest protected (Janzen 1997).

Ecological Research and the Future of National Parks

Two major contributions of ecologists to the long-term protection of national parks deserve to be highlighted here. First, the national park system evolved from a group of scattered patches of forest protected by law to a system of large conservation areas, which enclose the entire matrix of land uses that surrounds national parks. Second, some budget limitations that always threatened the future of national parks have been alleviated with the intervention of the international scientific community.

From a landscape perspective, all national parks in Costa Rica are islands embedded in a matrix of agriculture and urbanization. Ecological research in national parks started to produce a long list of ecological phenomena that linked parks with the surrounding area. Quetzals and many birds migrate seasonally from their protected high-elevation cloud forest to lowland areas dominated by agriculture. Insects migrate from the dry seasonal forest in the Pacific lowlands to wet forests in the Caribbean. Entire watersheds were not protected, disrupting the needed connectivity between upstream and downstream reaches. In summary, small isolated national parks were insufficient to maintain species diversity and ecosystem function. In response, the park system matured from isolated park units to a system of conservation areas, similar to the system of biosphere reserves developed by UNESCO (Boza 1993). Each conservation area includes several parks and reserves, which protect patches of natural forest, and the matrix of secondary forest, farmland, and urban centers that compose the landscape. Management plans are designed to integrate forest protection with community education and include the potential to offer services to the community.

Budget limitation is a major obstacle to the conservation of any natural area in developing countries. A large part of the success of the conservation movement in Costa Rica is funded from sources outside the country. The scientific community has played a key role by providing attractive examples that could be used to justify conservation projects, or by gathering resources and even fund-raising themselves.

There are probably many issues that deserve the attention of scientists in order to develop sound management plans. One of them deserves priority: assessment of the impacts of tourism in national parks. Costa Rica became a popular destination for ecotourists in the early 1990s and the industry soon became a main source of income for the country (J. Monje-Najera, *unpublished report*). Although there are a large number of private reserves, national parks are the main tourist attraction and most parks have seen large increases in visitation (Boza 1993). National parks benefit from increases in revenue from visitor fees. At the same time, private sectors benefit by providing the infrastructure needed by the tourism industry, and people and politicians are more than aware of the value of protecting national parks for the country's economy. Ecotourism is a potentially sound use of national parks. Ecologists now need to make an effort to keep up with this changing situation and provide the needed information to allow park managers to balance the costs and benefits of ecotourism. Initial impacts of increased tourist visitation are already visible in the form of trail erosion and damage. There is an urgent need to assess the vulnerability of particular ecosystems to increased visitation and to include this information in management plans.

Conservation areas are composed of one or several cores of primary forest in the form of national parks and a matrix of patches of diverse land uses, commonly secondary forest, agriculture, and some urban centers. The long-term conservation of national parks depends on an integrated understanding and management of all areas, the core and the matrix. Some areas of the matrix might need to be restored to naturally functioning ecosystems, while others might be better left for other uses. Successful ecological restoration must have a major social component (Janzen 1997). Ecologists should focus on working in interdisciplinary teams with sociologists and anthropologists to understand how conservation areas work and how they should be managed.

The national park system of Costa Rica started following the steps of the park system in the United States. However, the system faces a different socio-economic environment that has moved the system from preservation to conservation and then to integration with the surrounding environment. Ecologists have played important roles by proving information to develop sound management at different scales. Major challenges remain to assure the long-term conservation of national parks, and ecologists must be there to tackle the challenge.

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