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Science for Natural Resource Management under Climate Change

Emerging applications of climate change research to natural resource management show how science provides key information for agencies to take action for vulnerable ecosystems.

Climate change poses a fundamental challenge for natural resource management: Climate patterns are shifting in space and time, but national parks, national forests, and other natural areas remain at fixed locations. Research shows that climate change has shifted the ranges of plant and animal species and biomes (major vegetation types). Warming has also altered the timing of events such as plant flowering and animal migration. Climate change has even driven some frog species to extinction. Intergovernmental Panel on Climate Change (IPCC) assessments and other research indicate that unless we substantially reduce greenhouse gas emissions from motor vehicles, power plants, and deforestation, the resulting warming may overwhelm the ability of many species to adapt. Climate change could convert extensive land areas from one biome to another, increase wildfire, transform global biogeochemical cycles, and isolate or drive more species to extinction.

Climate change affects the 2.6 million square kilometers of land owned by the people of the United States and managed by the federal government. This is nearly a third of the country's total land area and managed mainly by, in order of land area, the Bureau of Land Management (BLM), the Forest Service (FS), the Fish and Wildlife Service (FWS), and the National Park Service (NPS). The missions of these agencies all seek to manage ecosystems for future generations. They are stewards of places of national and often global significance, ranging from Yellowstone National Park (NPS) to the Arctic National Wildlife Refuge (FWS) to Tahoe National Forest (FS) to Grand Staircase-Escalante National Monument (BLM).

Presidential Executive Order 13514 (October 5, 2009) directed Executive Branch agencies to develop adaptation approaches. Department of the Interior Secretarial Order 3289 (September 14, 2009) established department-level climate change response programs that include the BLM, FWS, and NPS. Each of those agencies and the FS has issued a climate change strategy or plan.

Natural resource managers are attempting to move from general written strategies toward specific field actions to improve the resilience of species and ecosystems to climate change. Because the Executive and Secretarial orders have established strong enabling conditions and because existing agency policies generally support actions that promote resilience, policy does not constitute the primary obstacle for resource management agencies to take action on climate change. Rather, existing workloads, limited budgets, and lack of targeted climate change science information con-

DANA FRITZ, *Rain Forest Mist, Bisphere 2*, Archival pigment print, 16 x 24 inches, 2009.

strain full integration of climate change into natural resource management. Concerning the last factor, emerging experience at the NPS offers insight on how science can provide key information for agencies to manage natural resources under climate change. Certain specific science activities merit continued emphasis.

Focus on adaptation

Climate change science should ideally aim to answer resource management questions and contribute to scientific knowledge. Answering resource management questions will directly support the stewardship of land and water. Contributing to scientific knowledge will improve the rigor of the information. In the case of climate change, questions from resource managers and gaps in scientific knowledge point to the need to analyze the vulnerability of species and ecosystems to climate change and to develop and implement adaptation measures.

Adaptation, as defined by the IPCC, is an adjustment in natural or human systems in response to climate change in order to moderate harm or exploit new conditions. The IPCC identifies three types of adaptation: anticipatory (proactive adjustment before climate change occurs), autonomous (spontaneous, unplanned response to climate change), and planned (deliberate adjustment to observed or projected climate change). Adaptation occurs through diverse mechanisms. Natural selection of plants and animals with resilient characteristics will, as individuals pass their genes to offspring, drive the evolution of species more adapted to changed climate conditions. Agencies and individuals can adapt management practices at specific sites to help individual species undergo the first type of adaptation. Also, agencies can adapt management plans across broad landscapes.

Numerous general reports on adaptation exist. For U.S. natural resource management agencies, the most relevant is the U.S. Global Change Research Program 2008 report *Preliminary Review of Adaptation Options for Climate-Sensitive Ecosystems and Resources*, which reviewed the experience and policies of each agency. Although this and other reports describe numerous case studies of work in progress, it seems that resource management agencies have only implemented a small number of adaptation measures that were developed using climate change science information and specifically targeted to respond to climate change. Also, only a very small number of the official management plans for operational field units explicitly examine climate change and adopt climate change adaptation measures.

NPS is advancing through a process of resource management with modifications that take account of climate change. Science supports the entire process. Although the NPS manages natural, cultural, and historical resources, infrastructure, and visitor experiences and seeks to develop adaptation measures for each, this article focuses on natural resources. The steps of the resource management process under climate change move end to end from science to specific adaptation actions.

Reduce emissions and naturally store carbon. Eliminating the cause of a problem is the most effective way to attack it. Reducing the greenhouse gas emissions that cause climate change will reduce the need for adaptation. Human activities have raised carbon dioxide (CO_2), the principal greenhouse gas, to its highest level in the atmosphere in 800,000 years. The accumulation of greenhouse gases has raised global temperatures to their warmest levels in 1,300 to 1,700 years. IPCC analyses confirm that orbital cycles and other natural factors account for only 7% of observed warming. Motor vehicles, power plants, deforestation, and other hu-

DANA FRITZ, *Rain Forest Back Room, Biosphere 2*,
Archival pigment print, 16 x 24 inches, 2007.

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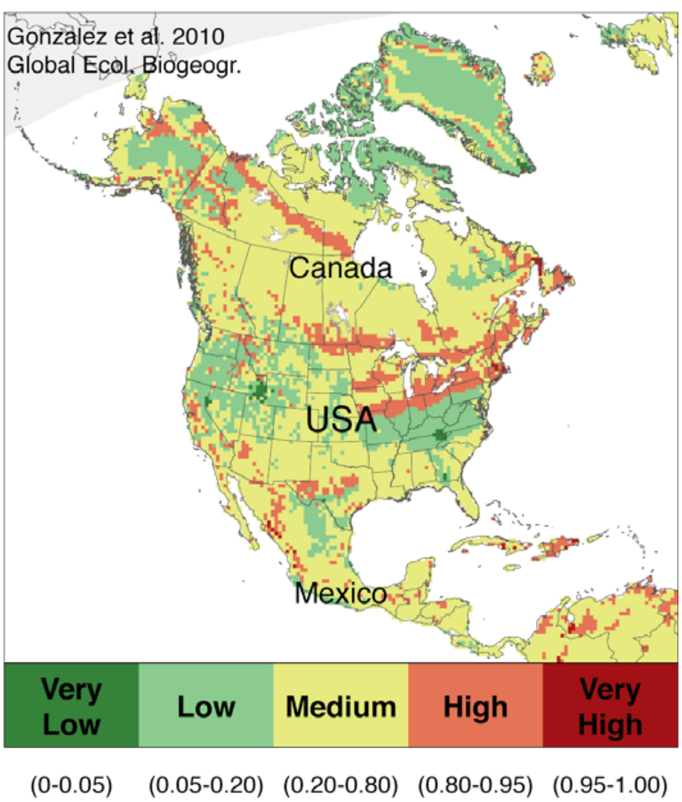
man sources emit twice the amount of greenhouse gases that vegetation, soils, and the oceans can naturally absorb. That is the fundamental imbalance that causes climate change.

The world can avoid the worst impacts of climate change by improving energy efficiency, expanding public transit, installing renewable energy systems, conserving forests, and using other currently available measures to reduce greenhouse gas emissions. The important science component of any emissions reduction effort is the use of the IPCC *National Greenhouse Gas Inventory Guidelines* to quantify emissions. These guidelines provide the scientific methods that parties to the United Nations Framework Convention on Climate Change use to report their emissions.

The NPS Climate Friendly Parks program is reducing greenhouse gas emissions from park operations. As a first step, NPS staff have been conducting emissions inventories using methods based on the IPCC *Guidelines*. These show that visitors' cars account for two-thirds of estimated emissions within parks. Many national parks and other federal

FIGURE 1

Confidence that the biome of a location may change due to climate change, 1990-2100



areas have increased shuttle bus services and installed renewable energy systems.

Vegetation naturally reduces global warming by removing CO_2 from the atmosphere and storing it in biomass. Forests in Redwood National Park and Sequoia National Park contain carbon at some of the highest densities in the world. To assess the carbon balance (the difference between storage and emissions) of fire management and other resource management actions, managers need information on the spatial distribution of carbon across the landscape over time. Scientific research that integrates field measurements of trees and satellite remote sensing data can map the spatial distribution of vegetation carbon. The United States, however, currently does not have a time series of spatial data that shows the distribution of vegetation carbon over time across the country.

The FS Forest Inventory and Analysis program has estimated forest carbon in individual plots at 5 to 10-year intervals since the 1980s. An experimental FS effort has also combined field inventory and MODIS remote sensing data to map U.S. forest carbon in 2001. The U.S. Geological Survey (USGS) land cover maps of the United States for 2001 and 2006 potentially provide the basis of a vegetation carbon change estimate. The lack of spatial data on vegetation carbon over time for the entire United States contrasts with Australia, where the National Carbon Accounting System has produced 17 nationwide Landsat mosaics and analyzed data from hundreds of field plots to generate a time series of vegetation carbon across the country since 1972. Such a system in the United States would enable land managers to estimate carbon implications of resource actions.

Identify management questions. The importance of national parks, national forests, and other natural areas should prompt scientists to conduct research that answers questions on the effective management of those areas. Each NPS unit has identified management questions that require scientific input, either implicitly in a General Management Plan (the official master plan for a park) or explicitly in Resource Stewardship Strategies, Wilderness Plans, or other management plans for specific resources.

Individual NPS units often form direct relationships with individual scientists and discuss management questions with them. For example, Saguaro National Park works with University of Arizona researchers on the management of buffel grass, an invasive species that may be favored by climate change. In addition, a consortium of government agencies operates Cooperative Ecosystem Studies Units, a network of universities directly connected to resource managers. The Department of the Interior, through USGS, its

Dana Fritz, *Tethered Saguaros and Netted Magpies*, Archival pigment print, 16 x 24 inches, 2007.

main science agency, is establishing eight Climate Science Centers to connect agencies with universities specifically to conduct climate change research.

Academic research can successfully connect theoretical science and resource management applications. For example, Anthony Westerling of the University of California, Merced, and colleagues (*Science*, 2006) conducted statistical analysis of climate and fire that documented an increase in fire across western federal lands since 1970, coincident with warming. This work advanced scientific knowledge and contributed to resource managers' understanding of wildfire. Peer review for scientific publication improves the rigor of information that is also used for resource management.

Detect changes and attribute causes. Detection of changes and attribution of causes provide basic information on whether or not a species or ecosystem is changing and whether or not climate change is the cause. Detection is the measurement of historical changes that statistically are significantly different from natural variability. Attribution is the determination of the relative importance of different factors in causing detected changes. Field measurements from national parks have contributed to the detection and attribution to climate change of warmer winters, decreased snow, and earlier spring snowmelt in western U.S. parks, upslope shifts of vegetation and small mammal species in Yosemite National Park, and northward shifts of vegetation in Alaska and winter bird ranges in the lower 48 states.

Attribution can guide resource management toward the predominant factor that is causing change. Whereas resource managers have developed many measures that address invasive species, overharvesting, urbanization, wildfire, and other nonclimate factors, ecological changes because of climate change might require the development of new adaptation measures.

Analyze vulnerabilities. Vulnerability to climate change is the degree to which a system is susceptible to and unable to cope with adverse effects. Design features of robust vulnerability analyses include:

Existing workloads, limited budgets, and lack of targeted climate change science information constrain full integration of climate change into natural resource management.

DANA FRITZ, *Intensive Agriculture Sunset, Biosphere 2*, Archival pigment print, 16 x 24 inches, 2007.

Dana Fritz, *Painted Clouds, Biosphere 2*,
Archival pigment print, 16 x 24 inches, 2009.

- Examination of all three components of vulnerability: exposure, sensitivity, and adaptive capacity. Exposure is the extent of climate change experienced by a species or ecosystem: for example, degrees of annual temperature change per century. Sensitivity is the change in a species or ecological variable for each increment of change in climate: for example, increased tree mortality of 5% per degree of average temperature increase. Adaptive capacity is the ability of a species or ecosystem to adjust: for example, increased germination to compensate for the increased tree mortality.
- Detection and attribution of historical changes.
- Analyses of observed and projected data. Because of time lags between the emission of greenhouse gases, the expression of changes in climate, and ecological responses, vulnerability is a function of historical and future climate changes.
- Quantification of uncertainties. Computer model errors, future emissions scenario assumptions, field measurement errors, and statistical variation all combine to create a range or probability distribution of possible values for any calculation.
- Identification of vulnerable areas and potential refugia. Spatial analyses that map patterns of vulnerability will identify the locations of the most vulnerable areas and potential refugia. This provides the scientific data needed to prioritize areas for adaptation.

In a published analysis of the vulnerability of ecosystems around the world to vegetation shifts because of climate change (see figure), colleagues and I employed these design features. We conducted a meta-analysis of published research literature for cases of biome shifts detected in the field and attributed to climate change. We examined exposure through spatial analyses of 20th century observed and 21st century projected climate. We analyzed sensitivity and adaptive capacity through spatial analyses of observed and projected vegetation biomes. Using IPCC criteria, we quantified uncertainties and classified areas into five vulnerability classes. We found 15 historical cases of biome shifts detected and attributed to climate change. Spatial analyses indicated that one-tenth to one-half of global land is highly vulnerable to further vegetation shifts.

In another vulnerability analysis, Kenneth Cole of the USGS and colleagues analyzed observed and projected climate and vegetation data on the Joshua tree in the U.S. Southwest. They identified potential refugia for Joshua trees but found high vulnerability in Joshua Tree National Park. In addition, NPS and its partners are conducting other vulnerability analyses across the country for species such as pika and bristlecone pine and ecosystems such as salt marshes.

The use of computer models and simulations in vulnerability analysis requires care. In the design stage, the accurate calibration of models, especially climate downscaling models, depends on observed field data. After the generation of results, the validation of the accuracy of models requires an independent set of field data.

Scenario planning. Scenario planning is a method to consider potential future effects of uncertain driving forces that affect a system and to determine which decisions may offer a better chance of meeting future goals. Herman Kahn of RAND Corporation developed the method in the 1960s for military planning. Pierre Wack of Royal Dutch Shell, Peter Schwartz of Global Business Network, and others refined the method for oil-company planning. The Global Business Network is assisting NPS in applying the method to resource management planning for climate change.

Scenario planning starts with the organization of interdisciplinary groups of resource managers and scientists who work in a specific landscape. Using data from vulnerability analyses and other scientific sources, the group examines pairs of climate variables that are important for resource management and exhibit large uncertainties. Each pair of climate variables defines four possible future management scenarios that are plausible, divergent, and challenging. Groups formulate qualitative descriptions so that each management scenario becomes a story about the future that can help with decisions today. Ideally, groups develop adaptation measures that can respond to each situation, generating a set of options available for managers as conditions unfold.

NPS has conducted scenario planning training work-

DANA FRITZ, *Rowboat and Beach Window, Biosphere 2*, Archival pigment print, 16 x 24 inches, 2007.

DANA FRITZ, *Green Ductwork*, Archival pigment print, 16 x 24 inches, 2007.

shops in landscapes covering most of the 50 states. Assateague Island National Seashore in Maryland and Sequoia National Park in California are developing adaptation options for key ecosystems based on scenario planning results.

Develop adaptation measures. Applied scientific research provides important information to guide the development of new adaptation measures. Some adaptation measures in development include:

• Propagation of coral for reef restoration in the Florida Keys. The Coral Restoration Foundation, University of Miami, and partners have established staghorn coral nurseries in Biscayne National Park and other parts of the Florida Keys National Marine Sanctuary. The nurseries propagate coral that has survived recent ocean warming and bleaching episodes. Experimental planting of resilient corals at two dozen sites seeks to restore bleached areas and increase reef resilience.

• Fire management in the southern Sierra Nevada. The Southern Sierra Conservation Cooperative, which involves the NPS, FS, USGS, University of California, Davis, and others, is developing adaptation measures for fire management. Vulnerability analyses of observed and projected climate, fire, and vegetation data are identifying areas vulnerable to future wildfire regime changes and potential refugia. Scenario planning is providing management response options. The group will provide scientific information that NPS and FS fire managers will use to modify official fire management plans and to implement measures such as wildland fire and prescribed burning based partly on climate change information.

• Resource management on the Olympic Peninsula. Olympic National Forest, Olympic National Park, and the University of Washington conducted vulnerability analyses and scientist-manager discussions. As an adaptation measure to maintain fish habitat, road culverts are being enlarged or replaced with bridges to reduce erosion and prevent road failure from possible increases in storms. Possible adaptation measures to manage forest ecosystems include creation of forest gaps for the generally shade-intolerant species projected to increase under climate change and reforestation

DANA FRITZ, *Banana Conveyor, Eden Project*, Archival pigment print, 16 x 24 inches, 2009.

with seed selected for resistance to bark beetles, also projected to increase.

- General Management Plan for Assateague Island National Seashore. NPS, in consultation with the FWS and the state of Maryland, has drafted a General Management Plan with one alternative designed specifically for climate change. IPCC sea-level rise estimates and a scenario planning workshop provided information for the plan. Proposed adaptation measures include flexible placement and light construction of infrastructure threatened by sea-level rise and adjustment of visitor zones in case of increases in storms.

Prioritize locations. To identify geographic priorities under climate change, managers can broadly consider three options: areas of high, medium, or low vulnerability. For acquisition of new areas, it may be prudent to prioritize areas of low vulnerability, known as refugia, and avoid areas of higher vulnerability. Conversely, for management of existing areas, it may be necessary to prioritize places of higher vulnerability because those locations may require more intensive management. Areas of unique ecological or cultural value may continue to merit high priority.

Implement actions. Resource management agencies have reached this step in only a few cases. For example, Blackwater National Wildlife Refuge in Maryland is using local sediment to raise and restore wetlands inundated by rising sea level. Alligator River National Wildlife Refuge in North Carolina is building up oyster reefs and planting flood-tolerant trees in coastal areas vulnerable to sea-level rise. Examples of other possible site-specific adaptation measures include wildland fire and prescribed burning to avert catastrophic wildfires, natural regeneration and enrichment planting of adapted plant species, and reforestation of native riparian tree species along stream banks to provide shade and cool water for fish. At the landscape scale, agencies can adjust large area management plans, establish corridors to facilitate species dispersal and migration, and plan land acquisitions in potential climate change refugia.

The Northwest Forest Plan demonstrates how cooperative efforts can manage for habitats across a landscape rather than managing for individual species at specific sites. In the context of climate change, managing for habitats rather than individual species would involve the identification and conservation of functional groups, such as perennial grasses in a grassland ecosystem, or habitat types, such as a subalpine forest. Assuring the vibrant functioning of an ecosystem could perhaps more effectively conserve more species than dedicating scarce resources to the conservation of a few individual endangered species.

Recognizing the importance of conservation planning based on ecological landscapes rather than administrative boundaries, the Department of the Interior is now establishing 21 Landscape Conservation Cooperatives across the country to bring resource management agencies together to develop adaption strategies.

Because national forests surround many national parks, the FS is one of the most important partners for the NPS in many landscapes. The two agencies collaborate closely on six landscape-scale science and adaptation projects in the Cascade Range, Olympic Mountains, Rocky Mountains, and the Sierra Nevada.

Monitor effects. Monitoring permanent ecological plots can provide essential data to track the effectiveness of adaptation measures. The NPS inventory and monitoring program tracks key physical and ecological characteristics of parks, such as glacier extent and animal populations. NPS did not establish its system to trace effects of individual management actions at specific locations. Also, most sites do not have the 30 years of data needed for a statistically significant sample to examine temporal trends. Agencies will need to address these types of issues in existing monitoring programs, or in some cases establish new monitoring programs, to track whether or not adaptation measures increase the resilience of species and ecosystems.

Adjust adaptation measures. Adaptive management uses the lessons of the past to redesign management for the future. As NPS pursues end-to-end science and adaptation projects in Sequoia National Park, Assateague Island National Seashore, and other areas, changes in climate, ecological response, and future emissions will necessitate changes in adaptation measures.

Policy implications

General reports on adaptation are informative but not adequate for the management of specific natural areas. The most effective approach for natural resource management agencies is to work through a complete process of science and adaptation in specific landscapes. Policy initiatives on climate change can facilitate this work by supporting particular types of applied science. These include detection and attribution of historical change, analysis of vulnerability of species and ecosystems, and quantification of vegetation carbon over time across the United States using field and remote-sensing data. Detection and attribution of historical change guide resource management toward the predominant factor that is causing change. Analyses of vulnerability provide the scientific data needed to prioritize areas for adaptation. Spatial data on vegetation carbon over time could enable land managers to estimate carbon effects of resource management actions.

The Executive and Secretarial orders that established greenhouse gas emission reduction and climate change adaptation as priorities have set strong enabling conditions for future action. Other policies could further facilitate action. For example, integration of climate change information into Resource Management Plans (BLM), National Forest Plans (FS), Comprehensive Conservation Plans (FWS), and General Management Plans (NPS) would adapt these official management plans for operational field units to future change. Moreover, because separate agencies in the Departments of Agriculture, Commerce, Defense, and Interior manage substantial natural areas, further collaboration within and outside of the Department of the Interior Landscape Conservation Cooperatives would facilitate landscape-scale adaptation. Also, the National Climate Assessments of the U.S. Global Change Research Program are useful analyses of climate change science whose continuation is essential for adaptation.

Science and policy are only two of many factors determining resource management decisions. Resource managers combine scientific information and national policies with other considerations: financial costs, human resource requirements, community needs, ethics, and values. Natural resource management under climate change will balance exigencies of the present and the needs of future generations. Science must provide robust and objective information. Ultimately, people will use climate change science to help make decisions on the survival of species and ecosystems.

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