FINAL REPORT

Vulnerability of U.S. National Parks to Land Use and Climate Change

Principal Investigators: Andrew Hansen  
Landscape Biodiversity Lab  
Ecology Department  
Montana State University  
Bozeman, MT 59717  
hansen@montana.edu  
http://www.homepage.montana.edu/~hansen/hansen/lab/  

Steven Running  
Numerical Terradynamic Simulation Group (NTSG)  
College of Forestry and Conservation  
University of Montana  
Missoula, MT 59812  
swr@ntsg.umt.edu  
http://www.ntsg.umt.edu/

Team Members  
Cory Davis – PhD student, Montana State University  
Jessica Haas – MS student, University of Montana

Collaborators:  
David Theobald, Colorado State University  
John Gross, National Park Service

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Abstract from Proposal

The U.S. National Park Service (NPS) faces the challenge of maintaining ecosystem function and biodiversity within National Parks in the face of climate and land use change. New satellite and other technologies have increasingly allowed reconstruction for past decades of climate and land use at fine spatial scales with associated consequences for ecosystem processes such as net primary productivity (NPP) and fire risk. These reconstructions reveal high levels of spatial heterogeneity across the U.S. in directions and magnitude of change in climate, NPP, fire risk, and stream flows. The goal of this study is to assess park vulnerability to current and near-term future climate and land use based on detailed reconstructions and analyses of change and ecological response over the past 50-100 years. Specific objectives are:

1. Quantify change from 1900 to present in land use and climate (mean and variability), ecosystem response, and biodiversity during 1900-2003 (coarse spatial resolution) and 1982-2003 (fine spatial resolution).
2. Evaluate the vulnerability of parks to current and near-term future land use and climate based on past change and ecosystem and biodiversity response.
3. Evaluate statistical patterns of association between land use, climate, ecosystem function, and biodiversity during this time period as a means of validating vulnerability indices.
4. Derive guidelines for mitigating the primary vulnerabilities of each park.

The study includes 60 National Parks in the U.S. that are relatively large in area (>27,000 ha) and that represent the full range of regions across the U.S. The study defines and includes the larger ecosystem surrounding each park. Potential drivers (climate and land use), ecosystem response (NPP, stream flow, fire risk, and habitat area), and biodiversity response (representation of native species guilds, exotic species, and species richness) are being quantified across the 60 national parks during the 1900s using NASA and other imagery, data, and models. Statistical patterns of association will be used to evaluate the plausibility of cause and effect relationships between the potential drivers and response variables. The vulnerability of each of the parks to current and near-term future climate and land use change will be assessed based on the Rapid Assessment and Prioritization of Protected Area Management (RAPPAM) methodology. The results will be used to suggest to the NPS which parks are high priority for mitigation, and the primary issues that threaten the parks, and to develop mitigation strategies.
Primary Publications Resulting from the Project

Davis, C.R. and A.J. Hansen. In Press. Trajectories in land-use change around US National Parks and their challenges and opportunities for management. Ecological Applications. Delineates protected area centered ecosystems around 57 NPS units, analyzes land use change for 1940-2000 (19 measures) within each, develops a land-use typology of park units and assigns each to wildland undeveloped, wildland developable, agriculture, exurban, or urban categories, and derives management guidelines for each.


Hansen, A. J., C. Davis, N. B. Piekielek, J. Gross, D. Theobald, S. Goetz, F. Melton, R. DeFries. 2011. Delineating the ecosystems containing protected areas for monitoring and management. BioScience 61(5) 363-373. Uses objective ecological criteria to map the ecosystems surrounding 13 national park units, analyzes change in land use within these, identifies the benefits of broader application of this approach to enhance research and conservation.


Primary Publications In Review or Preparation


Davis, C. In Prep. Vulnerability of U.S. National Parks to Current and Future Land Use and Climate Change. Ph.D. Dissertation, Montana State University, Bozeman. Includes the chapters on delineating protected area centered ecosystems, land use change within 57 of these, and on consequences of trends in land use for native and exotic biodiversity.
Davis, C. In Prep. Consequences of land use change in and around U.S. National Parks for biodiversity. Ecological Applications.
Tests hypotheses on the effects of past land use change in and around NPS units on native birds, native mammals, and exotic species.

Analyzes change in monthly and annual temperature, precipitation, and drought index in and around 57 NPS units for 1895-2005

Related Publications

Offers methods for mapping areas of strong interaction between protected areas and surrounding human communities.

Develops an approach for monitoring land cover and land use change around protected areas and applies the method to the Greater Yellowstone Ecosystem.

Uses change in land cover and land use as a basis for identifying the species and habitat types most at risk of land use change around Greater Yellowstone.

Proposals Funded


**Professional Development**

This project contributed to the professional development of the project team as follows.

Cory Davis
Will complete a Ph.D. in ecology at Montana State University in fall 2011;

Has secured a job as Monitoring Coordinator for the Southwestern Crown of the Continent CFLRP at the University of Montana.

Jessica Haas
Obtained a Master’s of Science degree from the University of Montana (2010);

Has serving as a NASA Goddard Space Flight Center Visiting Scientist (2009); and

Was hired as a Data Services Specialist at the USDA Rocky Mountain Research Station, Human Dimensions: (2009 - present)

**Steve Running**
Co-recipient, Nobel Peace Prize 2007 for work on IPCC climate change assessment.

**Andrew Hansen**
P.I. of a $1.8M grant to study biological response to climate change across federal lands in the Northern Rockies and the Appalachian Mountains;

Senior Scientist on a $30M NSF EPSCoR grant to Montana to build capacity to understand Montana’s vulnerability to climate change.
**Presentations and Posters**

**2011**
Hansen, A.J. Delineating the ecosystems containing protected areas for monitoring and management. American Association of Geographers Annual Meeting, Seattle.

**2010**

**2009**
Hansen, A.J. Discovering park-centered ecosystems. Monitoring and Reporting Landscape Change in and around Protected Areas: From Good Science to Operational Monitoring and Reporting Systems. 2009 George Wright Society Biennial Conference on Parks, Protected Area, and Cultural Sites. Portland, Oregon.
Hansen, A.J.. Land use change in the Greater Yellowstone Ecosystem: A context for setting a science agenda. Climate Change, Invasive Species, and Land Use Change as Drivers of Ecological Change in the Greater Yellowstone Area: A workshop to identify priority science and implementation strategies. Bozeman, MT.
2008

2007
Summary of Accomplishments

This project is the first to analyze both land use and climate change across a network of US National Parks (Davis et al. in press). The land use analyses lead to an innovative classification of park units based on rates and types of land use change and land allocation (Fig 1 and 2). This typology allows the unique management challenges and opportunities of each class to be identified (Table 1).

Through robust quantification of the rates of change for key climate variables (temperature, precipitation), and ecosystem health indicators (available water and net primary productivity; NPP) we identified the National Park System units that are rapidly changing with respect to climate and ecosystem productivity (Fig 3) (Haas 2010). Additionally, we compared the NPS units with the surrounding, protected area centered ecosystem (PACE), to identify which parks were undergoing different changes from their surroundings and vice versa. At these local scales, recent trends in NPP are being driven by land use change, disturbances or sever climate changes (drought) therefore the analysis of NPP trends can be used to monitor changes in disturbance patterns. This study provides key insight into relative rates and drivers of change for 60 national parks and their surrounding ecosystems (e.g., Fig 4).

We also used the core results to develop important applications for conservation and management including delineation of protected area centered ecosystems (Hansen et al. 2011a), the mapping of carrying capacity of species richness as a basis for preservation and restoration (Hansen et al. 2011b), and a framework for prioritizing conservation among ecosystems across the terrestrial biosphere based on ecosystem energy (Hansen in review).

The results of this project were widely disseminated through presentations and posters at scientific meetings and via the peer-reviewed literature. Moreover, Nobel-laureate Running has given countless presentations to citizen groups on climate change during the period of study. The project contributed substantially to the professional development of the research team and lay the basis for important new projects on climate and land use change.
### Figure 1. Classification rules, distribution of means, and final park typological assignments.

<table>
<thead>
<tr>
<th>Wildland Protected</th>
<th>Wildland Developable</th>
<th>Agricultural</th>
<th>Exurban</th>
<th>Urban</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. &gt; 65% public</td>
<td>1. &lt; 65% public</td>
<td>1. &lt; 65% public</td>
<td>1. &lt; 65% public</td>
<td>1. &lt; 65% public</td>
</tr>
<tr>
<td>2. private &gt; 60% undeveloped</td>
<td>2. private &gt; 60% undeveloped</td>
<td>2. private &gt; 60% undeveloped</td>
<td>2. private dominated by exurban or urban &lt; 15%</td>
<td>2. private &gt; 60% undeveloped</td>
</tr>
<tr>
<td>3. private &gt; 16% agriculture</td>
<td>3. private &gt; 16% agriculture</td>
<td>3. private &gt; 16% agriculture</td>
<td>3. private dominated by urban or urban &gt; 15%</td>
<td>3. private &gt; 16% agriculture</td>
</tr>
</tbody>
</table>

- Arches
- Colorado River parks
- Crater Lake
- Craters of the Moon
- Death Valley
- Dinosaur
- Glacier
- Great Basin
- Joshua Tree
- Mojave
- Mount Rainier
- North Cascades
- Rocky Mountain
- Voyageurs
- Yellowstone/Grand Teton
- Yosemite/Kings Canyon-Sequoia
- Zion

- Badlands
- Big Bend
- Big Thicket
- Big Horn Canyon
- Cayon de Chelly
- El Malpais
- Great Sand Dunes
- Guadalupe Mts.
- Lassen Volcanic
- Olympic
- Organ Pipe Cactus
- Ozark
- Petrified Forest
- Pictured Rocks
- Redwood
- White Sands

- Buffalo River
- Lake Roosevelt
- Missouri River
- Saint Croix
- Theodore Roosevelt

- Big South Fork
- Blue Ridge Parkway
- Delaware Water Gap
- Great Smoky Mts.
- New River Gorge
- Saguaro
- Shenandoah
- Sleeping Bear Dunes

- Everglades/Big Cypress
- Point-Reyes/Golden Gate
- Santa Monica Mts.
Figure 2. Protected area centered ecosystems around NPS units color-coded by typological membership.
Table 1. Potential conservation challenges and opportunities for each park land-use class.

<table>
<thead>
<tr>
<th>Potential Conservation Challenges</th>
<th>Wildland Protected</th>
<th>Wildland Developable</th>
<th>Agricultural</th>
<th>Exurban</th>
<th>Urban</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wildland Protected</td>
<td>Maintenance and/or restoration of apex predators</td>
<td>Wildlife human conflicts</td>
<td>Resource extraction on public lands</td>
<td>Loss of crucial habitats to development</td>
<td>Resource extraction on adjacent private lands</td>
</tr>
<tr>
<td>Wildland Developable</td>
<td>Loss of crucial habitats to development</td>
<td>Resource extraction on adjacent private lands</td>
<td>Little protected land leads to loss of connectivity</td>
<td>Invasive species spread from fallow/abandoned farmlands and along rivers</td>
<td>Water/air pollution from fertilizers, pesticides, and insecticides</td>
</tr>
<tr>
<td>Agricultural</td>
<td>Invasive species spread from fallow/abandoned farmlands and along rivers</td>
<td>Water/air pollution from fertilizers, pesticides, and insecticides</td>
<td>Conversion of agricultural land to low-density housing development</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exurban</td>
<td>Mesopredator release following loss of apex predators</td>
<td>High exurban development leads to loss of connectivity</td>
<td>High road density leads to fragmentation of remaining natural lands</td>
<td>Invasive species introductions and spread through roads and development</td>
<td>High levels of recreation disturbance in remaining natural lands</td>
</tr>
<tr>
<td>Urban</td>
<td>Loss of connectivity among remaining natural lands</td>
<td>Disrupted food webs after loss of apex predators</td>
<td>Invasive species introductions and spread</td>
<td>High levels of recreation disturbance in remaining natural lands</td>
<td>Water and air pollution from urban run-off and smog</td>
</tr>
<tr>
<td></td>
<td>Invasive species introductions and spread</td>
<td>High road density leads to fragmentation of remaining natural lands</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Potential Conservation Opportunities</th>
<th>Wildland Protected</th>
<th>Wildland Developable</th>
<th>Agricultural</th>
<th>Exurban</th>
<th>Urban</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wildland Protected</td>
<td>Maintain intact food chains (including apex predators)</td>
<td>Cooperative management with adjacent federal land agencies</td>
<td>Expansion of protected area through transfer of adjacent federal land</td>
<td>Land swaps or purchases of private land in crucial areas</td>
<td>Conservation easements to protect corridors and crucial habitats</td>
</tr>
<tr>
<td>Wildland Developable</td>
<td>Land swaps or purchases of private land in crucial areas</td>
<td>Conservation easements to prevent development in crucial areas</td>
<td>Purchase of unproductive/abandoned farmland (by private or governmental)</td>
<td>Restorations of abandoned agricultural land</td>
<td>Land-use planning to condense future development and leave open space</td>
</tr>
<tr>
<td>Agricultural</td>
<td>Purchase of unproductive/abandoned farmland (by private or governmental)</td>
<td>Restorations of abandoned agricultural land</td>
<td>Conservation easements to protect corridors and crucial habitats</td>
<td>Land-use planning to condense future development and leave open space</td>
<td>Active, well-funded conservation organizations</td>
</tr>
<tr>
<td>Exurban</td>
<td>Conservation easements to protect corridors and crucial habitats</td>
<td>Land-use planning to condense future development and leave open space</td>
<td>Endangered species conservation plans</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urban</td>
<td>Endangered species conservation plans</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 3: Climate trends for NPS units by analysis period for (top) Mean Annual Temperature, (middle) Total Annual Precipitation and (bottom) Moisture Index
Figure 4. Example of the graphical outputs generated for each part unit.
Appendix 1: Abstracts of Primary Publications


Abstract
Most protected areas are part of a larger ecological system and interactions with surrounding lands are critical for sustaining the species and ecological processes present within them. Past research has focused on how development rates around protected areas compare to development rates across a wider area as measured within varying sizes of buffer areas or at the county level. We quantified land-use change surrounding the 57 largest US National Parks in the contiguous US for the period 1940 to the present and grouped the parks based on patterns of change. Land use was analyzed within the area considered essential to maintaining natural processes within each park, the protected-area centered ecosystem (PACE). Six variables were measured to determine the current level of development: population density, housing density, land in agriculture, area with impervious surfaces, percent covered by roads, and percent in public land. Time series of population density, housing density, and land in agriculture were used to analyze changes over time. Cluster analysis was used to determine if patterns in major land use typologies could be distinguished. Population density within PACEs increased 224% from 1940 to 2000 and housing density increased by 329%, both considerably higher than national rates. On average, private land in PACEs contained a combined 24% exurban and rural housing density and these increased by 19% from 1940 to 2000. Five distinct land-use classes were identified indicating that groups of parks have experienced differing patterns of development on surrounding lands. The unique management challenges and opportunities faced by each group are identified and can be used by managers to identify other parks to collaborate with on similar challenges. Moreover, the results show park managers how severe land-use changes are surrounding their park compared to other parks and the specific locations in the surrounding landscapes that influence ecological function within the parks. This is the first effort to develop a typology of protected areas based on land-use change in the surrounding ecosystem. Other networks of protected areas may find this methodology useful for prioritizing monitoring, research, and management among groups with similar vulnerabilities and conservation issues.

Abstract.
The U.S. National Parks are an integral part of our National Heritage. They are now, more than ever, experiencing threats from outside forces that are difficult to evaluate, such as climate change. The magnitude and direction of change will vary spatially across the landscape, making it difficult for park managers to adopt just one approach to managing for climate change. Therefore, there must be a systematic way to analyze climate trends and the subsequent effects on ecosystems, which is unbiased and useful in varying climates and landscapes. Through robust quantification of the rates of change for key climate variables (temperature, precipitation), and ecosystem health indicators (available water and net primary productivity; NPP) we identified the National Park System units that are rapidly changing with respect to climate and ecosystem productivity. Additionally, we compared the NPS units with the surrounding, protected area centered ecosystem (PACE), to identify which parks were undergoing different changes from their surroundings and vice versa. At these local scales, recent trends in NPP are being driven by land use change, disturbances or sever climate changes (drought) therefore the analysis of NPP trends can be used to monitor changes in disturbance patterns. This study provides key insight into relative rates and drivers of change for 60 national parks and their surrounding ecosystems.


Abstract.
Park managers realized more than 130 years ago that protected areas are often subsets of larger ecosystems and are vulnerable to change in the unprotected portions of the ecosystem. We illustrate the need to delineate protected area–centered ecosystems (PACEs) by using comprehensive scientific methods to map and analyze land-use change within PACEs around 13 US national park units. The resulting PACEs were on average 6.7 times larger than the parks in upper watersheds and 44.6 times larger than those in middle watersheds. The sizes of these PACEs clearly emphasized the long-term reliance of park biodiversity on surrounding landscapes. PACEs in the eastern United States were dominated by private lands with high rates of land development, suggesting that they offer the greatest challenge for management. Delineating PACEs more broadly will facilitate monitoring, condition assessment, and conservation of the large number of protected areas worldwide that are being degraded by human activities in the areas that surround them.

Abstract.
**Aim** To demonstrate that the concept of carrying capacity for species richness (SK) is highly relevant to the conservation of biodiversity, and to estimate the spatial pattern of SK for native landbirds as a basis for conservation planning.

**Location** North America.

**Methods** We evaluated the leading hypotheses on biophysical factors affecting species richness for Breeding Bird Survey routes from areas with little influence of human activities. We then derived a best model based on information theory, and used this model to extrapolate SK across North America based on the biophysical predictor variables. The predictor variables included the latest and probably most accurate satellite and simulation-model derived products.

**Results** The best model of SK included mean annual and inter-annual variation in gross primary productivity and potential evapotranspiration. This model explained 70% of the variation in landbird species richness. Geographically, predicted SK was lowest at higher latitudes and in the arid west, intermediate in the Rocky Mountains and highest in the eastern USA and the Great Lakes region of the USA and Canada.

**Main conclusions** Areas that are high in SK but low in human density are high priorities for protection, and areas high in SK and high in human density are high priorities for restoration. Human density was positively related to SK, indicating that humans select environments similar to those with high bird species richness. Federal lands were disproportionately located in areas of low predicted SK.