Exposure of US National Parks to Land Use and Climate Change 1900-2100

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The basic role of protected areas is to separate elements of biodiversity from processes that threaten their existence in the wild (Margules and Pressey 2000. *Nature*.)
State of Protected Areas

Many protected areas are undergoing loss of function:

- Land use intensification in surroundings
- Invasive species
- Human caused climate change
State of Protected Areas

Protected-area Centered Ecosystem (PACE) - areas critical to the persistence of native species and wherein human activities may negatively influence ecological processes and the viability of native species within the PA.
The rates of global change and sensitivity to these changes differ among protected areas.

There is a need to assess vulnerability across networks of protected areas to determine which are most at risk and to lay the basis for adaptation strategies that are tailored to local conditions.
Vulnerability Assessment

Vulnerability Assessment

Exposure = magnitude & extent of change experienced

Sensitivity = degree to which fitness/process is affected

Adaptive capacity = coping responses of species/process
Challenges of Vulnerability Assessment

• Difficult for managers to focus on threats from surrounding lands.

• Defining the surrounding ecosystem is difficult.

• Protected areas lack the data and tools for regional to subcontinental analysis.

• Protected areas are seldom considered elements in a broader network.

• Management philosophies aimed at maintaining “naturalness” may not be consistent with the high rates of global change.
Goals and Objectives

Goal: Illustrate the initial steps in an assessment of vulnerability to land use and climate change for the network of US National Parks

Objectives:
1. Define the surrounding Protected Area Centered Ecosystem (PACE)
2. Quantify past exposure

Diagram:
- Exposure
- Sensitivity
- Potential Impact
- Adaptive Capacity
- Vulnerability

Factors:
- Land use change
- Climate change
- Invasive species

Timeline: 1900-2010
Goals and Objectives

Goal: Illustrate the initial steps in an assessment of vulnerability to land use and climate change for the network of US National Parks

Objectives:
3. Quantify potential future exposure and potential impact

4. Consider implications for management
Ecological processes such as nutrient flows, organism movements, disturbance regimes, and population dynamics may operate over areas larger than the park.

Protected Areas as Parts of Larger Ecosystems

Land use intensification outside of nature reserves may disrupt these flows and alter ecological processes and biodiversity within reserves.

The Concept of Protected Area–centered Ecosystems

Obj. 1: Define PACE

Delineating Protected-Area Centered Ecosystems

The area essential to maintaining natural processes and native populations within each park.

Delineate PACEs based on five criteria:

1. Contiguity of surrounding natural habitat
2. Watershed boundaries
3. Extent of human edge effects
4. Disturbance initiation and run-out zones
5. Crucial habitats outside the park

Obj. 2: Past Exposure

PACES for 57 Larger NPS Units in the Contiguous U.S.

Past global change may have pushed some protected areas closer to sensitivity thresholds and increased their vulnerability.

Thus, it is important to summarize past land use and climate change for the US PACES.
Land Use Variables

Present metrics:
1. Population density
2. Housing density (SERGoM)
   - Undeveloped/low density
   - Rural
   - Exurban
   - Suburban/urban
3. Land allocation (public vs. private)
4. Land in agriculture
5. Area of impervious surface
6. Percent developed
   (roads, housing, agriculture)

Change-over-time metrics:
1. Population density (1900 – 2007)
2. Housing density (1940 – 2000)
3. Land in agriculture (1900 – 2005)

### Cluster Analysis: Land Use Typology

<table>
<thead>
<tr>
<th>Wildland Protected</th>
<th>Wildland Developable</th>
<th>Agriculture</th>
<th>Exurban</th>
<th>Urban</th>
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<tbody>
<tr>
<td>&gt;65% Public</td>
<td>&lt;65% public, private &gt; 60% undeveloped, private &lt; 15% agriculture</td>
<td>&lt;65% public, private &gt; 60% undeveloped, private &gt; 15% agriculture</td>
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<td>&lt;65% public, private &lt; 60% undeveloped private urban</td>
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#### 1940 to 2000
Population density +224%

Housing density: +329%

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Obj. 2: Past Exposure

PRISM Climate Data

Spatially and temporally interpolated weather data
- United States at 4km
- 1885-2010 annual data
- Mean daily temperature
- Total precipitation
- Used to derive Water Availability (Moisture Index)

Haas 2011.
100 yr
- 80% warming (Most 1.0°C / 100 yr)
- 17% ↑ ppt
- 30% wetter
- 12% drier (temp driven)
Obj. 2: Past Exposure

Invasive Species

Percent Non-native Vascular Plants

- ANOVA, n=48, F=12.9, P<.001
## Combined Land Use and Climate Change

**Obj. 2: Past Exposure**

### Temperature Trend, Developed Lands, Invasive Plants

<table>
<thead>
<tr>
<th>Location</th>
<th>Non-native Plants (% of max)</th>
<th>% Developed in 2000</th>
<th>Temp Trend (% of max)</th>
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Obj. 2: Past Exposure

Home Density, Temperature, Non-Natives

1900-2000
Potential Biome Type Shifts

Climate change can cause the loss of dominant vegetation, leading to the potential for colonization by a new vegetation type suited to the new climate condition.

Images of climate-induced forest die-off from around the world. Anderegg et al. 2012. Nature Climate Change
Obj. 3: Future Exposure and Potential Impact

Potential Biome Type Shifts

Locations of Forest Die-off

North America

Europe

Field Trip: Whitebark Pine Die-off in Greater Yellowstone
Field Trip: Whitebark Pine Die-off in Greater Yellowstone
Potential Biome Type Shifts

Spatial distribution of climate factors that limit plant growth

Future climate may exceed the tolerances of plant species leading to increased mortality.


Obj. 3: Future Exposure and Potential Impact

**Future Climate**

2030: warming of 0.9 – 2.4°C

2090: 2.5 – 4.6°C warmer than present.

Data from: Reufeldt et al. 2012. Ecological Applications
Potential Biome Type Shifts

Predicted distributions of biomes based on climate from the consensus of six scenarios.


Obj. 3: Future Exposure and Potential Impact
Obj. 3: Future Exposure and Potential Impact

Potential Biome Shifts in PACES

Data from: Rehfeldt et al. 2012. Ecological Applications
Response of vegetation to climate change reflects the interaction of exposure to climate change, sensitivity of vegetation to those changes, and adaptive capacity of the vegetation.

Data from: Rehfeldt et al. 2012. *Ecological Applications*
Obj. 3: Future Exposure and Potential Impact

Land Use and Potential Impact

Figure 6.
Cumulative and Synergistic Effects

Cumulative Effects.

The additive or cumulative effects among these elements of exposure may result in stronger negative effects than these factors individually. For example, habitat loss due to both land use and climate change.

Synergistic Effects.

Synergistic effects are those where the effects of two elements of exposure are greater than the additive effects due to interactions among them. For example, the ability of species to adapt to climate change is reduced by land use impacts.
Summary on Vulnerability

PACES differ in past and potential future exposure.

Example Trajectories:
- Little change
- High land use intensification, often with increasing invasives
- High climate change
- Both land use and climate change

PACES differ in sensitivity and potential impact.

Higher Sensitivity
- Species and communities with narrow climate tolerances
- Locations near the edge of zones of climate suitability
- Species and communities subject to higher disturbance rates (e.g. fire, pests)

Lower Adaptive Capacity
- Shallow rooting
- Short lifespans
- Dispersal limited
- Dependent on mutualists

PACES differ in vulnerability and should be managed accordingly.
### Management Philosophies

<table>
<thead>
<tr>
<th>“Naturalness”</th>
<th>“Future Conditions”</th>
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<tbody>
<tr>
<td><strong>Also called:</strong></td>
<td><strong>Also called:</strong></td>
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<tr>
<td>Historic Range of Variation or Ecological Process Management</td>
<td>First Principles</td>
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<td>Pluralistic and adaptive</td>
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<tr>
<td><strong>Goal:</strong></td>
<td><strong>Goal:</strong></td>
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<tr>
<td>Perpetuate natural pattern and function.</td>
<td>Promote ecological integrity and resilience under future changing conditions.</td>
</tr>
<tr>
<td><strong>Strategy</strong></td>
<td><strong>Strategy:</strong></td>
</tr>
<tr>
<td>Maintain landscape patterns and ecological processes within the range of variation in place prior to Euro influence.</td>
<td>Design future ecosystems based on guiding principles, including historical fidelity, autonomy of nature, ecological integrity, and resilience, as well as managing with humility.</td>
</tr>
<tr>
<td><strong>Key Reference:</strong></td>
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Tailoring Management to Nature of Change

Obj. 4: Implications for Management

<table>
<thead>
<tr>
<th>Past, Present, Future Ecological Conditions</th>
<th>Management</th>
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<td>Relevant Philosophy</td>
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<td>Restore Resilience</td>
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<td>Historic</td>
<td>Future</td>
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<td>DFC</td>
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<td>No Overlap</td>
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</table>
Case Study: Olympic National Park

**Exposure:**
- Land Use Typology: Wildland Developable
- PACE Developed: 45%
- Temp change (1900-2010): 0.5 °C
- Non-native plants: 19%
- Temp change (2100-2030): 1.37 °C

**Sensitivity**
- Low

**Potential Impact**
- Area shifting biome 2030: 22%

**Vulnerability**
- Low - Moderate

**Management Philosophy**
- Historic Range of Variation
Case Study: Santa Monica Mountains

Exposure:
- Land Use Typology: Urban
- PACE Developed: 72.4%
- Temp change (1900-2010): 1.4 °C
- Non-native plants: 27%
- Temp change (2100-2030): 1.4 °C

Potential Impact
- Area shifting biome 2030: 52%

Vulnerability
- High

Management Philosophy
- Future Conditions
Conclusions

• Protected areas potentially differ in each of the components of vulnerability to land use and climate change.

• Knowledge of these differences can be used to guide adaptation strategies.

• This partial analysis of vulnerability of US PACEs illustrates the utility of such an approach for designing adaptation strategies.

• Similar applications may help to safeguard biodiversity of protected areas in a changing world.
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