Using NASA Resources to Inform Climate and Land Use Adaptation

Ecological Forecasting, Vulnerability Assessment, and Evaluation of Management Options Across Two US DOI Landscape Conservation Cooperatives
Team

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Goals and Objectives

**Goal**
Demonstrate the four steps of a climate adaptation planning strategy in two LCCs using NASA and other data and models.

**Objectives**
1. Hindcast and forecast future climate and land use scenarios.
2. Assess the vulnerability of ecological processes and key habitat types.
3. Evaluate management options.
4. Design and deliver management adaptation strategies.
5. Inform decision support.
Approach

Approach

1. Identify Conservation Targets
2. Assess Vulnerability to Climate Change
3. Identity Management Options
4. Implement Management Options

Vulnerability Assessment

Framework for Climate Change Adaptation (Glick et al. 2011)

Monitor, Review, Revise

Evaluate Management Options

Prioritize Importance and Feasibility of Management

Low Risk, Manageable, High Cost/Low Benefit

Exposure: None, Moderate, High
Vulnerability: High, Moderate, Low
Adaptability: High, Moderate, Low

Implement, Management

Managing for Resilience, Managing for Change

Hindcasting (1980-2010) and Forecasting (2010-2100)

Ecosystem Processes (TOPS, BIOME-BGC & LEF models)

Habitat Type Distribution
Climate envelope models
Habit suitability models
Disturbance models
Connectivity/dispersal models

Adaptive Capacity

Exposure
Sensitivity
Potential Impact

Wildfire, Lodgepole pine, Douglas fir, Aspen, Sagebrush

Prioritize Current patterns of vulnerability (decade)

Mosaic and mosaic patterns of management

Prioritize management strategies: species and populations, Ecosystems, Landscapes

From: Tyler Framework
Step 1. Identify Management Targets

<table>
<thead>
<tr>
<th>STEPS</th>
<th>Purpose</th>
<th>Outputs</th>
<th>Tools</th>
</tr>
</thead>
</table>
| 1. Select Specific Conservation Targets | - Conservation Targets are species, ecosystems, ecological processes, and cultural resources that are climate sensitive, iconic, keystone, or umbrella  
- This again reduces complexity by focusing on the priority resources that need to be analyzed as Conservation Targets for this exercise | Define 5-10 Conservation Targets                      | - Enabling Legislation;  
- Existing Priorities from Mgt Documents I&M Networks;  
- Exiting research on Climate Sensitive Resources or workshops to define Science needs  
- Scenario Planning Workshops  
- Natural Resource Condition Assessments |
Step 2. Assess vulnerability

- Exposure = magnitude & extent of change experienced
- Sensitivity = degree to which fitness/process is affected
- Adaptive capacity = coping responses of species/process
Step 2. Assess Vulnerability

Hindcasting (1980-2010) and Forecasting (2010-2100)

- Downscaled Climate (CMIP5 / AR5)
- Land use (SERGoM model)

Ecosystem Process
(TOPS BIOME-BGC & LPJ models)
(Snow, runoff, soil moisture, fire, NPP, phenology)

Habitat Type Distribution
Climate envelope models;
Habitat suitability models;
Disturbance models;
Connectivity/dispersal models

Habitat Types: GNLCC
- Whitebark Pine
- Lodgepole pine
- Douglas Fir
- Aspen
- Sagebrush

Habitat Types: APLCC
- Spruce/Fir
- Oak/Hickory
- Oak/Pine
- Maple/Beech/Birch
Step 2. Assess Vulnerability

Downscaled Climate Scenarios

Max temp, PRISM, July, 1950

Max temp, Downscaled 800m CMIP5 GFDL-CM3, RCP 8.5, July, 2099 (Bridget Thrasher)
Step 2. Assess Vulnerability

SERGoM Land Use Change Model

Classes have been expanded to better represent land use.
**Step 2. Assess Vulnerability**

**TOPS Ecosystem Process Model**

### Input Parameter | United States (1km)
--- | ---
Impervious surface area | SERGoM (Theobald et al., 2009)
Climate (baseline run) | TopoMet Meteorological Surfaces (NTSG)
Climate (forecast) | Downscaled AR5 Scenarios, 1km resolution ensemble averages (Maurer et al., 2007) RCPs 4.5, 6.0, 8.5
Elevation | National Elevation Dataset (resampled)
Leaf Area Index (baseline run) | MODIS MOD15A2 LAI (Myneni et al., 2000)
Leaf Area Index (forecast) | Simulated by BIOME-BGC
Soils | U.S. STATSGO2 database
Land Cover | MODIS MOD12Q1 Land cover (Friedl et al., 2002)

### Vegetation Outputs
- Water stress factor
- Gross primary productivity
- Net primary productivity

### Hydrology Outputs
- Outflow
- Evapotranspiration
- Soil water potential
- Snow water equivalent
- Soil moisture (VWC)

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Step 2. Assess Vulnerability

TOPS Results

2100 Runoff

2100 GPP

Coupled climate and land use change impacts over urban areas

- Impervious Area (km²)
  - +110%
  - +54%

- Total Runoff (mm)
  - +90%
  - +60%

- Loss in GPP (kg C)
  - -25%
  - -40%
Step 2. Assess vulnerability

Linking Vegetation and Process Models

- TOPS Models
  - Biome-BGC
  - LPJ

- Ecological System / Key Species Models
  - Climate Envelope
  - Habitat Suitability
    - land facet
    - elevation
    - soil
  - Disturbance
  - Dispersal/Connectivity

Aggregate ES Types to BGC classes

Lifeform change
Step 2. Assess vulnerability

Linking Vegetation and Process Models

- Climate Envelope
  - Habitat Suitability
    - land facet
    - elevation
    - soil
  - Disturbance
  - Dispersal/Connectivity

Niche-based Approach

- Establishment
- Growth
- Reproduction
- Survival
- Reproduction
- Growth
- Survival
- Presence
- Climate niche
- Realized niche
- Environmental Gradient
Step 2. Assess Vulnerability

Crosswalk Forecasting Results in Vulnerability Assessment

<table>
<thead>
<tr>
<th>Component of Vulnerability</th>
<th>Species / Communities</th>
<th>Ecological System (ES)</th>
<th>Biomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exposure</td>
<td>Climate (TOPS) and land use (SERGoM) projections</td>
<td>Climate (TOPS) and land use (SERGoM) projections</td>
<td>Climate (TOPS) and land use (SERGoM) projections</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>Bioclimatic modeling; Dynamic vegetation modelling</td>
<td>Climate space modeling; TOPS projections</td>
<td>Biome BGC projections; controls of NPP; ecosystem model responsiveness</td>
</tr>
<tr>
<td>Adaptive Capacity</td>
<td>Species &amp; habitat traits</td>
<td>Landscape facets; ecosystem modifications; connectivity; protection</td>
<td>Diversity at Ecological System level; conservation context</td>
</tr>
</tbody>
</table>
Step 2. Assess vulnerability

Adaptive Capacity

Vulnerability Assessment

- High vulnerability
- Low vulnerability
- Adaptive capacity
- Exposure
- Sensitivity

Hindcasting (1980-2010) and Forecasting (2010-2100)
- Downscaled Climate (WRCP CMIP5)
- Land use (SE/GoM model)
- Ecosystem Process (TOPS BIOME-8G & LFJ models)
  (Snow, runoff, soil moisture, fire, NPP, phenology)

Habitat Type Distribution:
- Climate envelope models;
- Habitat suitability models;
- Disturbance models;
- Connectivity/dispersal models

Habitat Types:
- On/CC:
  - Whitebark Pine
  - Lodgepole Pine
  - Douglas Fir
  - Aspen
  - Sagebrush

Habitat Types:
- AP/CC:
  - Spruce/fir
  - Oak/Hickory
  - Oak/Pine
  - Maple/Beech/Birch

Potential Impact
- Adaptive Capacity
- Vulnerability

Assess
Step 2. Assess vulnerability

Adaptive Capacity

Vulnerability Assessment

High vulnerability

Low vulnerability

Adaptation strategies

Sensitivity →

Adaptation capacity

Exposure →

Assess
Step 3. Management Options

Identify Management Options

Evaluate Management Options

<table>
<thead>
<tr>
<th></th>
<th>Low Risk</th>
<th>Manageable</th>
<th>Save at High Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Management</td>
<td>None needed</td>
<td>Helpful</td>
<td>High cost/Risky</td>
</tr>
<tr>
<td>Exposure</td>
<td>Low</td>
<td>Moderate</td>
<td>High</td>
</tr>
<tr>
<td>Vulnerability</td>
<td>High</td>
<td>Moderate</td>
<td>High</td>
</tr>
<tr>
<td>Resiliency</td>
<td>High</td>
<td>Moderate</td>
<td>Low</td>
</tr>
<tr>
<td>Adaptability</td>
<td>High</td>
<td>Moderate</td>
<td>Low</td>
</tr>
</tbody>
</table>

Adaptation Strategies:
- Protect current patterns of biodiversity (baseline)
- Project future patterns of biodiversity
- Maintain Ecological Process
- Maintain and restore ecological connectivity
- Protect climate refugia
- Protect the ecological stage (enduring features)
Step 4. Deliver Management Strategies
Example: Whitebark Pine in GYE

Overview
• Keystone species
• Declining dramatically
• Listed as Candidate species
• Grizzly bear relisted

Management Questions
• Range change under future climate?
• Settings allowing reproduction?
• Where to focus treatment of competitors, translocation?

Collaborators
## Decision Support

<table>
<thead>
<tr>
<th>Decision Support Product</th>
<th>Spatial Scale</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>LCC</td>
</tr>
<tr>
<td>Data layers (e.g.):</td>
<td></td>
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<tr>
<td>• downscaled climate SERGoM projections,</td>
<td>X</td>
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<tr>
<td>• TOPS and biodiversity outputs</td>
<td></td>
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<tr>
<td>Development of metrics for conservation targets (e.g.):</td>
<td></td>
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<tr>
<td>• permeability</td>
<td>X</td>
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<tr>
<td>• biodiversity index</td>
<td></td>
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<tr>
<td>Syntheses reports (e.g.):</td>
<td></td>
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<tr>
<td>• downscaled climate</td>
<td>X</td>
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<tr>
<td>• land use change</td>
<td></td>
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<tr>
<td>• Vegetation response</td>
<td>X</td>
</tr>
<tr>
<td>Test theory of V.A. at scales relevant to management</td>
<td></td>
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<tr>
<td>Development of climate adaptation options</td>
<td></td>
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<tr>
<td>Implementation of strategies</td>
<td></td>
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<tr>
<td>Demonstration of full four-step vulnerability assessment</td>
<td></td>
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<tr>
<td>Training on overall approach</td>
<td>X</td>
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</tbody>
</table>
Current Status

The project is the first year of the four-year funding period.

**Year 1:** Refine study approach; engage key collaborators; compile data sets; validate models

**Year 2:** Do ecological hindcasts and forecasts; model habitat types; assess vulnerability in GNLCC with cooperators.

**Year 3:** Do management evaluation and implementation in GNLCC; assess vulnerability in APLCC with cooperators.

**Year 4:** Do management evaluation and implementation in APLCC; technology and data transfer; final reporting.

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Funds for the project are provided by the NASA Applied Sciences Program under the Biological Response to Climate Change Initiative. In-kind support is provided by the National Park Service Inventory and Monitoring Program and the Great Northern LCC. Collaborators include: Mike Britten, NPS I&M Rocky Mountain Network; Jim Comiskey, NPS I&M Mid-Atlantic Network; Keith Langdon, Great Smoky Mountain National Park I&M Coordinator; Matt Marshall, NPS I&M Eastern Rivers and Mountains Network; Jim Schnerbl, Shenandoah National Park; David Thoma, NPS I&M Yellowstone Network.
Proposed Vegetation Modeling

• We will focus on the coarser biodiversity levels in order to make initial progress. E.g. land facets, vegetation lifeforms, and ecological system types

• **Coarse filter**
  – Climate envelope modeling of major **ecological system types** in the ALCC (e.g. South-Central Interior Mesophytic Forest, Appalachian (Hemlock-) Northern Hardwood Forest)
  – Serves two purposes
    1) Generate scenarios of broad scale ecological reorganization in response to climate and land use change
    2) Inform **ecological process modeling** (Biome-BGC) so that process model outputs (e.g. GPP, plant water stress) reflect changes in vegetation type predicted by climate envelope models

• **Fine filter**
  – Detailed modeling of **high priority species** or ecological system types within management units. Candidate species include Fraser Fir (*Abies fraseri*), *Red Spruce* (*Picea rubens*), and *Eastern Hemlock* (*Tsuga canadensis*).

• Both levels will include an assessment of uncertainty from multiple sources including climate envelope modeling algorithms, general circulation models, vegetation traits, and sampling.
Existing Vegetation Modeling Efforts

- Potrer et al. (Clustering)
- Iverson et al. (Random forests)
- Coops and Waring (3pg -> CART)
- McKenney et al. (Filtering)
- Crookston et al. (Random forests -> FVS)
- Morin et al. (Phenofit)

The graph shows the relationship between the number of species and cell size (km) for different vegetation modeling efforts. The efforts are categorized as National or Regional based on the number of species they model.
Existing Vegetation Modeling Efforts

- Potter et al. Clustering
- Iverson et al. Random forests
- Coops and Waring 3pg -> CART
- McKenney et al. Filtering
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- Crookston et al. Random forests -> FVS
- Coops and Waring 3pg -> CART
- Morin et al. Phenofit

Cell size (km)

# of species

National

Regional

4
Potential Future Forest Type Changes

The links below allow comparison of maps of potential forest-type changes according to the various GCM scenarios.

**IMPORTANT:** Make sure you read the help file before interpreting the changes.

View Summary of Changes
Vegetation Structure - derivation of cover at multiple canopy heights / layers

Canopy cover at 10_15m
Canopy cover at

25-30m
20-25m
15-20m
10-15m
5-10m
0-5m
ALCC Science Needs

• Ecological flows
• Aquatic habitats
• Terrestrial landscapes
• Energy extraction
• Rare endemics
• Climate change
ALCC Science Needs

• Terrestrial Landscapes

• Thematic Area Goal:
  Assemble the necessary information or conduct studies necessary to
  develop and implement comprehensive regional strategies to conserve and
  manage forest/working forest communities across jurisdictions by
  inventorying significant regional forest communities, evaluating the
  condition, importance, and regional threats impacting these communities.

• Specific Science Support Need:
  Understanding representative/priority/focal species and population
  distributions across the region, their habitat relationships, and effective
  movement/dispersal linkages.
ALCC Science Needs

Terrestrial Landscapes cont.

- National and regional maps “are often at a resolution too coarse or a precision too inaccurate to be utilized at the scale of on-the-ground habitat conservation delivery”

- “need mapping products with units developed at a resolution necessary to take into account or respond predictably to successional dynamics and disturbance regimes”

- Need for products that “identify habitat structural characteristics (e.g., canopy cover, layer stratification)” which “are critical to better understanding habitat condition and determining suitability for specific species”
ALCC Science Needs

- **Climate Change**

- **Thematic Area Goal:**
  Work with partners and stakeholders to determine climate change adaptation and mitigation strategies that can be implemented and coordinated across multiple scales by applying the best available projections of how the regional climate will change and estimates of the impacts those changes will have on the region's natural and cultural resources.

- **Specific Science Support Need:**
  Support multi-scale vulnerability assessments that incorporate species-specific physiological data to identify habitats and species that would be most vulnerable to climate change in the LCC, especially range-limited/endemic species.