PROJECT PLAN

Title: 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

NRA: NNH10ZDA001N - BIOCLIM

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Introduction

Over the coming century, change in climate may exceed the resilience of ecosystems and lead to major disruptions of habitats and species. Such potential changes present a profound challenge for natural resource managers globally, including in the US. Accordingly, the US Department of Interior (DOI) has initiated various programs to meet these management challenges. The DOI launched in 2009 the creation of Landscape Conservation Cooperatives (LCCs) across networks of the federal lands (US DOI Secretarial Order 3289 2009). The goal of the LCCs is to craft practical, landscape-level strategies for managing climate-change impacts, with emphasis on: 1) ecological systems and function, 2) strengthened observational systems, 3) model-based projections, 4) species-habitat linkages, 5) risk assessment, and 6) adaptive management.

A promising framework for climate change adaptation was recently developed by an interagency working group (Fig. 1). The four steps of the framework are to: 1) identify conservation targets; 2) assess vulnerability; 3) identify management targets; and 4) implement management options. An important component of assessing vulnerability involves forecasting biological responses under alternative future scenarios. The Terrestrial Observation and Prediction System (TOPS) is increasingly used for ecological forecasting. Sponsored by NASA, the TOPS framework integrates operational satellite data, microclimate mapping, and ecosystem simulation models to characterize ecosystem status and trends. Through past NASA support, our team has used the TOPS as a basis for understanding land use trends and impacts in national parks and for enhancing the decision support systems of the NPS I&M Program.

Fig. 1. A framework for climate change adaptation planning. From Glick et al. 2011.

Using the framework above, the proposed project will develop and apply decision support tools that use NASA and other data and models to assess vulnerability of ecosystems and species to climate and land use change and evaluate management options. Objectives are:

1. Quantify trends in ecological processes and ecological system types from past to present and under projected future climate and land use scenarios using NASA and other data and models across two LCCs.
2. Assess the vulnerability of ecological processes and ecological system types to climate and land use change by quantifying exposure, sensitivity, adaptive capacity, and uncertainty in and around focal national parks within LCCs.
3. Evaluate management options for the more vulnerable ecosystem processes and types within these focal parks.
4. Design multi-scale management approaches for vulnerable elements to illustrate adaptation strategies under climate and land use change.
5. Facilitate technology transfer of data, methods, and models to LCCs and federal agencies to allow the decision support tools to be applied more broadly.

The primary collaborators with this project are LCCs and selected national parks (and surrounding park centered ecosystems or PACEs) within the LCCs. The LCCs aim to support the development and delivery of conservation solutions through: providing inter-jurisdictional data; developing data, models and tools for informed decision making; providing decision support for habitat connectivity, climate change and wildlife impacts; and enabling coordinated action among their partners. The National Park Service is initiating climate vulnerability assessments of parks within the NPS Intermountain Region. We will collaborate with the LCCs and NPS in conducting climate and land use vulnerability assessments

Our project is aimed at providing a direct means for the LCCs and the NPS to incorporate NASA data and products into their adaptation strategy planning during the initial and formative years of the LCCs. More specifically, the project will: help to develop an operational framework for adaptation strategy planning; compile key data sets such as downscaled climate scenarios, land use, and time series of historic biodiversity data; use ecological forecasting tools to project past and potential future trends in key indictors; assess vulnerability of ecosystem processes and ecological system types to climate and land use change; and demonstrate the development and implementation of management options for NPS PACEs. The transfer of the technology underlying the project should enhance the decision support capabilities of the NPS during the project and subsequently. The project may also serve as a model for adaptation by additional LCCs as they develop.

Project Scope

Study Areas and Approach

The project will focus on the Rocky Mountains ecoregion of the Great Northern Landscape Conservation Cooperative (GNLCC) and the mountainous portion of the Appalachian LCC (ALCC) (Fig 2).

In addition to the LCCs, the project will address two additional and highly relevant spatial scales: (1) potential dispersal zones, which are larger than LCCs and designed to capture the geographic range of expected biological movements under future climates, and (2) National parks and surrounding PACEs, which will provide effective case studies for vulnerability assessment and management applications. These parks may include Glacier, Yellowstone, and Rocky Mountain National Parks in the GNLCC and Delaware Water Gap NRA and Shenandoah and Great Smoky Mountains National Parks in the ALCC.

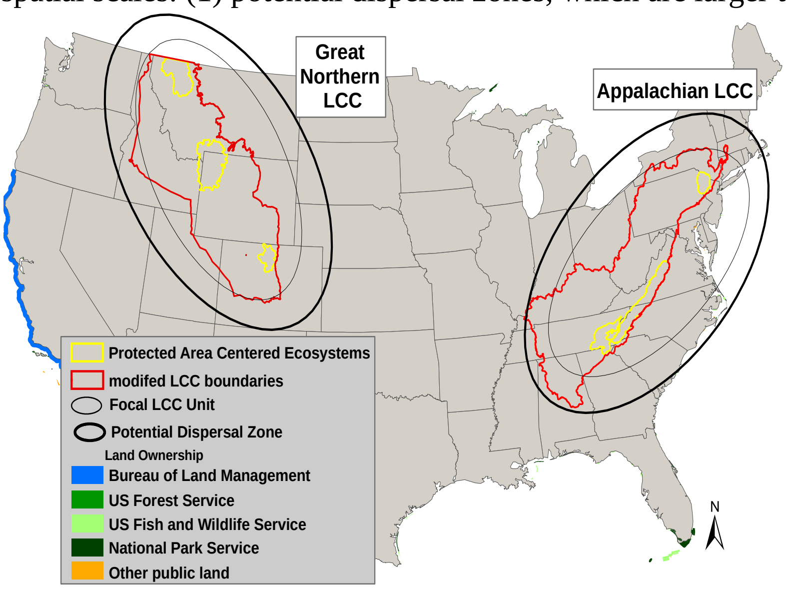

Fig. 2. Study areas depicting Landscape Conservation Cooperatives, Protected Area Centered Ecosystems, potential dispersal zones and federal ownerships.

The project is designed to enable progress on the start-up activities of the LCCs (e.g., years 1-4), by developing and testing a process on NPS lands that will inform NPS climate adaptation planning and serve as a model for the LCCs. The approach is a telescoping one where more primary steps are done across the LCCs and higher order steps are done for the focal NPS PACEs. We will first develop basic biophysical data sets. Ecological and statistical models will then be used to hindcast and forecast drivers and ecological responses. These ecological responses will include ecological processes and "coarse filter" aspects of biodiversity. Uncertainty in these predictions will be included in the vulnerability assessments for the NPS PACEs. Both vulnerability and management feasibility will be used to guide the assessment of management options. An illustrative adaptation strategy will be developed for each NPS PACE for response variables deemed of high priority. The data, methods, models, and results will be transferred to the collaborators to enhance the decision-support capacities of the NPS and LCCs.

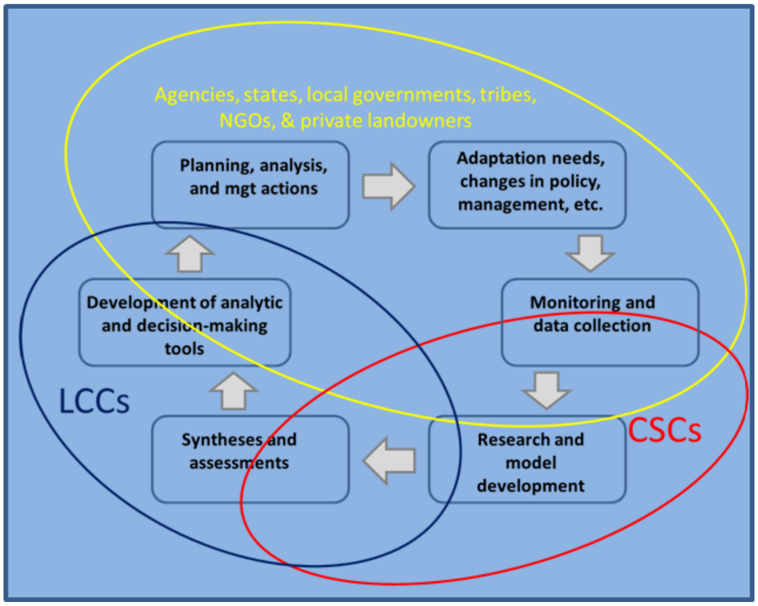

Fig. 3. The role of the Landscape Conservation Cooperatives in the Adaptive Management framework in relationship to the DOI Climate Science Centers and land management entities.

The GNLCC has continued to refine its mission and structure since our proposal was submitted and during these initial months of the project we have refined our approach accordingly. The APLCC was funded a year later than the GNLCC and is thus earlier in its development. We will thus phase our activities to focus on the GNLCC in years 1-3 and the APLCC in years 2-4. The goal of the GNLCC is to "Coordinate, facilitate, promote, and add value to large landscape conservation to build resource resilience in the face of climate change and other landscape-level stressors through: science support; coordination; informing conservation action; monitoring and evaluation; and outreach and education." The relationship with the newly formed DOI Climate Science Centers and land management entities with regards to adaptive management is depicted in Fig. 3.

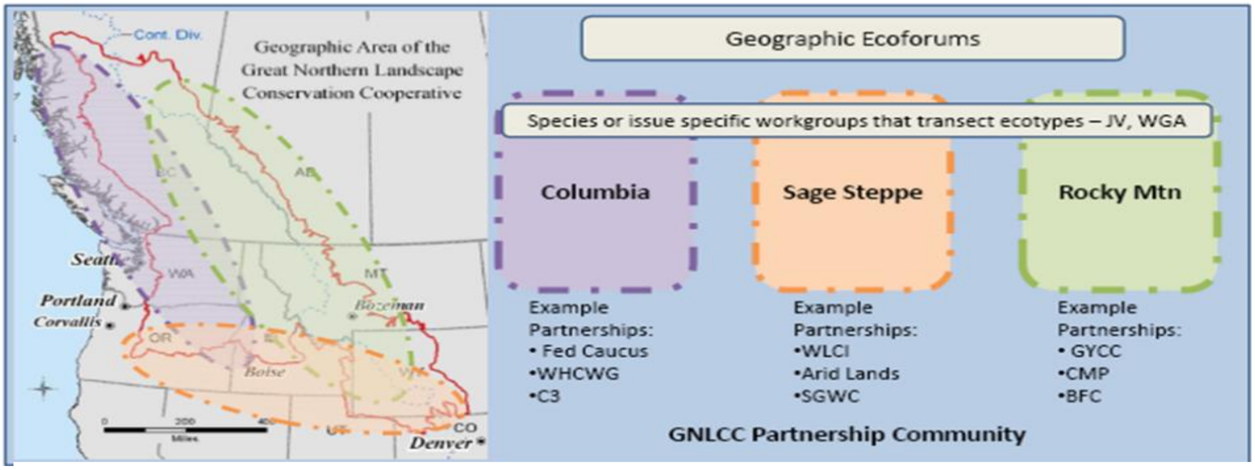

Fig. 4. Geographic organization of the GNLCC.

Our project will include activities in each component of the adaptive management model outlined in the figure. The GNLCC is hierarchically organized. The overall LCC includes three geographic regions, which are called “Ecoforums”, that relate to the major biomes in the LCC. The Ecoforums each have unique ecologies, priorities, and management partnerships (Fig. 4). Our LCC study area includes the U.S. portion of the Rocky Mountain Ecoforum. The products of our ecological hindcasts and forecasts (outlined below) will be done across the U.S. portion of the LCC. Assessment of vulnerability of ecological processes and ecological system types will be done within the U.S. portion of the Rocky Mountain Ecoforum. Management evaluation will be done within the specified national parks and surrounding PACEs. Management implementations will be done in collaboration with individual federal management units (e.g., Yellowstone National Park). We will assess outcomes through surveys of key collaborators at each of these levels in Years 1 and 4 of the project.

Ecological Hindcasting and Forecasting

We will simulate change in ecosystem processes and elements of biodiversity under climate and land use change using an approach that combines the TOPS ecosystem model and the SERGoM land use model (Fig 5). The TOPS runs will use both the Biome-BGC and LPJ component ecosystem models. Biome-BGC will be used primarily to assess impacts on vegetation productivity, phenology, runoff, and snow dynamics, while LPJ will be used to model potential changes in plant lifeforms under climate change. These ecosystem models will be driven by climate scenarios prepared for the IPCC Fifth Assessment Report (AR5). All AR5 scenarios will be downscaled to a 1-km spatial resolution via a bias correction spatial disaggregation (BCSD) approach following the same methods employed by Maurer et al. (2007) to produce the 1/8 degree downscaled WCRP CMIP3 scenarios. Ensemble averages will be calculated from all available models from each of the representative concentration pathways (RCPS): 2.6, 4.5, 6.0, and 8.5. Land use scenarios from SERGoM will also be used to modify the land cover and soil data inputs to TOPS to account for land use change and associated increases in impervious suface area. SERGoM SRES scenarios will be crosswalked to the corresponding RCPs. The SERGoM model is being updated (2010 census, TIGER 2010, NLCD 2006, LEHD, PAD-US, and wells and the classes will more fully reflect land use (rather than housing density) (Table 1). The data provided by these modeling experiments will provide

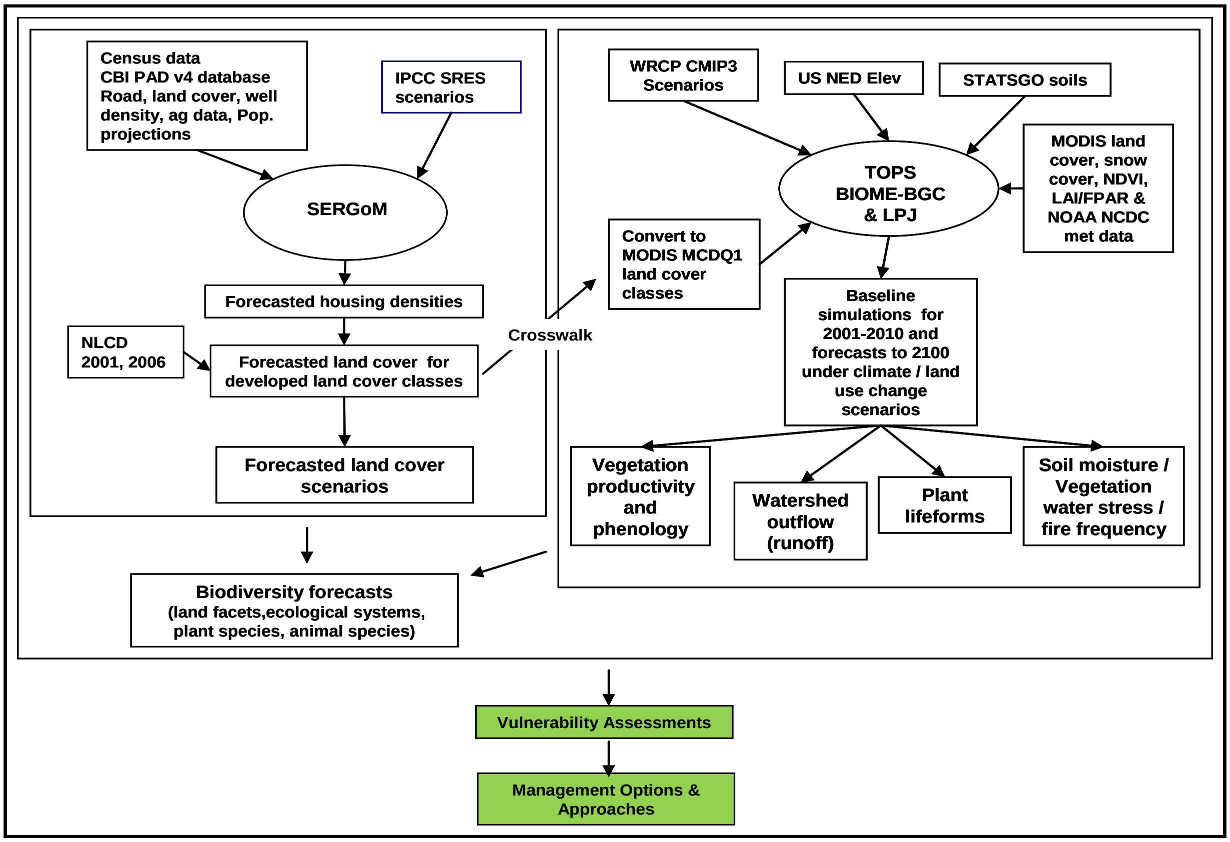

Fig. 5. Overview of the components and data flow for the proposed modeling effort and project.

quantitative measures of current and future ecosystem processes, lifeforms, and ecological system types that will be used in the vulnerability assessments. The models will be run for a hindcast/forecast period from 1950-2099 using the climate and land use scenarios (Table 2), and

Table 1. Land use classes in the new version of SERGoM (ICLUS/SERGoM v2).

Code	Group	Class Name	Description	Chip	NRI class
0	Water	River, stream	Running waters	water	Water
1	Water	Lake	Natural "standing" waters	Water	Water
2	Water	Reservoir	"Standing" water with dam or other human structure controlling flow	Water	water
3	Rec/conservation	Recreation	Parks, natural areas, campgrounds, wilderness, etc.	Undeveloped /Recreation	Federal, state, local, CRP?
4	Extractive	Extractive timber	Timber production	Resource ext	Forest
5	Extractive	Extractive grazing	Grazing (and other resource extraction e.g. oil & gas)	Resource extraction	Rangeland
6	Extractive	Extractive pastureland	Pasture	Agriculture	Pastureland
7	Extractive	Extractive cropland	Cropland	Agriculture	Cropland
8	Extractive	Extractive mining	Mineral resources	Resource ext	?
9	Urban/built-up	Urban parks/open space	Parks with structures (fields, courts, golf courses, cemeteries). No housing units.	Residential	Urban (large)
10	Urban/built-up	Residential (exurban low)	Exurban housing density 1 per 10-40 ac)	Residential	?
11	Urban/built-up	Residential (exurban)	Exurban housing density 1 per 2.5-10 ac)	Residential	Urban (large)
12	Urban/built-up	Residential (suburban)	Housing density 1 per 0.6-2.5 ac		Urban (small)
13	Urban/built-up	Residential (medium)	Housing density 1 per 0.1-0.6 ac	Residential	Urban (small)
14	Urban/built-up	Residential (high)	Housing density 1 per >0.1 ac	Residential	Urban (small)
15	Urban/built-up	Mixed residential and commercial	Residential housing medium or higher and density of employees > xx	Mixed use	Urban (small)
16	Urban/built-up	Commercial and Institutional	Commercial complexes, office buildings, schools,, churches, govt., military	Mixed use – institutional	Urban (small)
17	Urban/built-up	Industrial and utility	Industrial parks, factories, power plants, land fills, transportation	Mixed use - industrial	Urban (small)
18	Trans.	Transportation	Interstates, highways, railways, airports	Trans.	Trans.

Table 2. Hindcasting and forecasting "experiments and scenarios to be run for the 1950-2100 period. Among the ensemble of climate models evaluated, we will report the more extreme (high) and least (low) climate projections and the average across climate models.

	RCP 4.5 / B1 (avg + high + low)	**RCP 6.0 / A1** (avg + high + low)	**RCP 8.5 / A2** (avg + high + low)
No LUC	3 runs	3 runs	3 runs
SERGoM LUC	3 runs	3 runs	3 runs
SERGoM + biome shifts?	3 runs	3 runs	3 runs
SERGoM + BMPs + biome shifts?	3 runs	3 runs	3 runs

A baseline period spanning 2001-2010. Runs conducted for the baseline period will used observed climate data and will incorporate satellite observations of vegetation conditions. Results from the baseline run will be used to assess the model accuracy, and will also be used to quantify the additional uncertainty resulting from the used of modeled climate data and simulated vegetation growth.

While the LCCs will be assessing the full hierarchy of biodiversity, we will focus on the coarser biodiversity levels in order to make initial progress. These will include vegetation lifeforms, and ecological system types. Vegetation life forms distinguish broad classes of vegetation based on physiognomy (woody vs herbaceous, tree vs shrub, evergreen vs deciduous). Ecological system types are defined by Nature Serve as groups of plant community types that tend to co-occur within landscapes with similar ecological processes, substrates, and/or environmental gradients. Classes with high areal extent, for example, are Northern Rocky Mountain dry-mesic montane mixed conifer forest in the GNLCC (50%) and Appalachian (Hemlock)-Northern Hardwood Forest in the ALCC (10%). Such "coarse-filter" approaches to conservation planning are known to capture up to 80-90% of species within a planning area. Moreover, these coarser levels are often key predictors of species distributions. Ecological system types are widely used in conservation planning because they contain valuable resources and because they represent key elements of habitat for many species. Within each NPS PACE, we will select for analysis the subset of ecological systems (ca 5) that have been identified as the highest priorities by our collaborators. The GNLCC, for example, has rated as high priorities particular management questions, ecosystems, and species in various workshops and landscape assessments, including the GYCC Workshop (Nov 2009): the Crown Scenario Planning Workshop (March 2010); the NPS High Elevation Climate Response I&M Workshop (May 2010); the BLM Middle Rockies REA Management Questions and Course and Fine Filter Conservation Elements (April 2011); The BLM Wyoming Basins REA MQs, CF, and FF Conservation Elements (Jan 2012); the WGA MT-ID Divide Pilot Priority Species, Habitats, and Change Agents (March 2011); and the GNLCC Strategic Framework Conservation Targets. There is, by design, a lot of overlap and this should serve as a good initial list of priority conservation targets for this effort. We will review the outputs of these events to select our focal ecological system types.

We originally proposed to model the potential future locations of these ecological system types using statistical models parameterized through analyses of the “biophysical envelope” of current locations of these ecosystems. We anticipate that in addition to climate variables, TOPS products such as phenology, snow cover, runoff, soil moisture and primary productivity, which have not been previously widely available at a resolution of 1 km, will improve the strength of the statistical models. This modeling of ecological system types will be done in a nested design where habitat suitability, disturbance, and connectivity are added to the biophysical-envelope models to increase realism (Fig. 6).

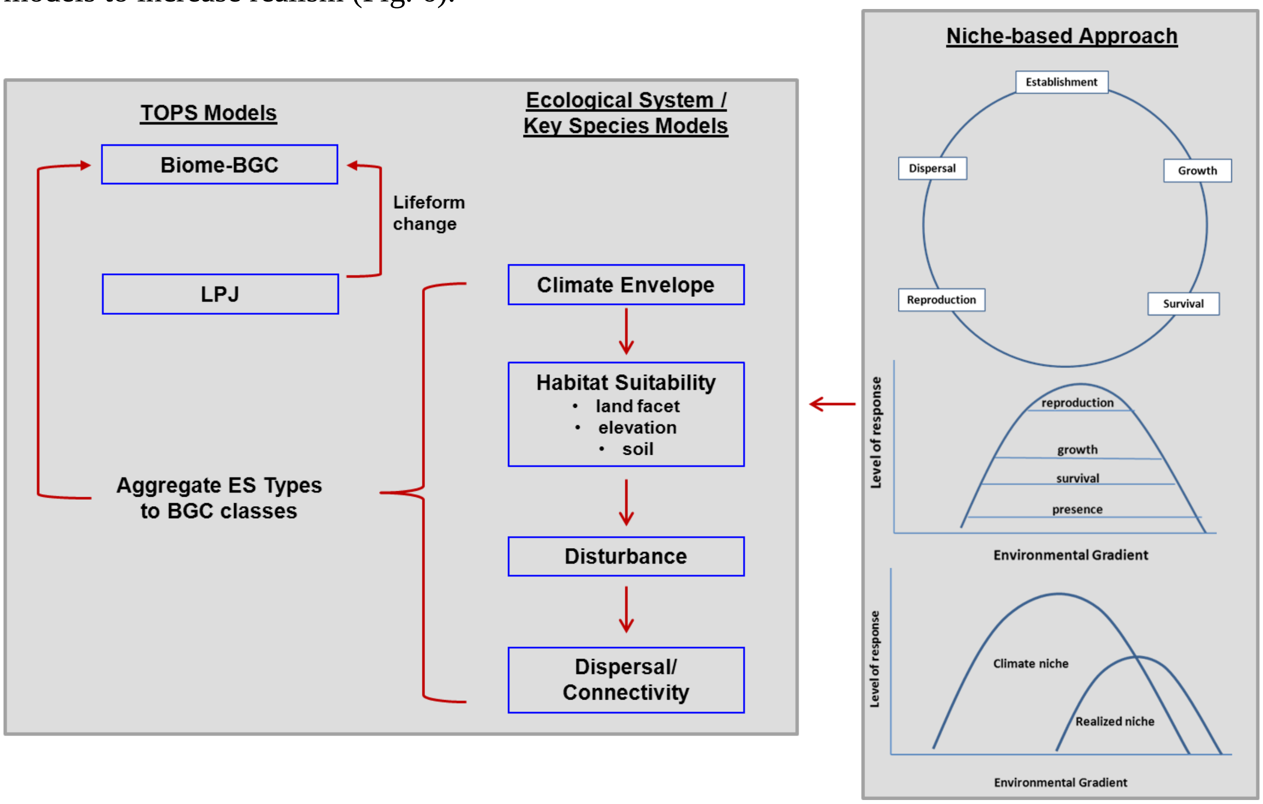

Fig. 6. Framework for modeling vegetation. Ecological system types are modeled with nested models of increasing realism and outputs are used to inform change in vegetation lifeform for the BGC ecosystem process model. Land facets are defined based on parent material, landform, and aspect. Key species models will be done under a niche-based approach where constraints are considered separately for establishment, growth, mortality, and/or reproduction. The results will be used to identify the fundamental niche where the species may occur based on abiotic constraints and where it actually occurs based on competition and other biotic interactions.

The changes in lifeform predicted by these models will feedback to influence lifeforms simulated within BGC. We will aggregate to biome level predictions of dominant ecological systems from the correlative models, providing semi-dynamic updates to BGC so that ecological process outputs reflect modeled changes in vegetation composition. Predictions of relative biome suitability will be used to weight BGC outputs to account for biome shifts and mixing under future climates. More detailed modeling of species and ecological systems of primary concern to our partners will be conducted. Priority species and systems will be identified by reviewing existing planning documents as well as through meetings with partners. We will use variance partitioning method to estimate the relative contributions of different sources of uncertainty in correlative models. Correspondence in the predictions from process based modeling of vegetation lifeform using LPJ and correlative modeling of ecological systems, and dominant plant species will be used to quantify additional dimensions of uncertainty.

Since our proposal was submitted a number of efforts to model tree species and community response to climate change have been published Table 3. We will begin our work by synthesizing the methods and results of these previous efforts both as input into our vulnerability assessments and to guide our biophysical modeling efforts.

Table 3. Published studies on Biophysical modeling of tree species and communities under climate change.

Authors	Method	Domain	Species	Time	Grain	Models / scenarios
Iverson et al. 2008	Machine learning (randomForest, bagging trees, single decision tree) to model spp. abundances using FIA data and env data	Eastern U.S.	134 tree species	2100	20 km	HadleyCM3, GFDL CM2.1, PCM A1, B1, ave.
Potter et al. 2010	17 env factors reduced with PCA, correlated with FIA presence	North America	200 tree species	2050 2100	4 km	Hadley, PCM A1, B1
Coops and Waring 2011	Id climate limitations to Douglas fir growth for 1950-75 with process-based model (3-PG), use decision trees and FIA data to predict presence.	Western U.S.	15 tree species	2011 - 2040 2041 - 2070 2071 - 2100	1 km	CGCM3 downscaled using CLIMATE-WNA A2, B1
McKen-ney et al. 2011	BIOMAP generates statistical distributions for bioclimatic variables where species are. Locations that fall within some portion of the reference distribution are retained.	North America	130 tree species	2011-2040 2041-2070 2071-2100	10 km	CCCMA) v. CGCM2 v. GCM3.1 CSIRO v. CSIRO-Mk2.0 v. CSIRO-MK3.5 NCAR v. PCM v. CCSM3.0 A2

Vulnerability Assessment

The simulations above will provide objective information on components of *vulnerability* and *uncertainty* for the indicators that will be used in vulnerability assessments at the three levels of ecological organization. Vulnerability to climate and non-climate stressors will be evaluated by focusing on three components of vulnerability (Fig 7; Turner et al. 2003; Glick et al. 2011).

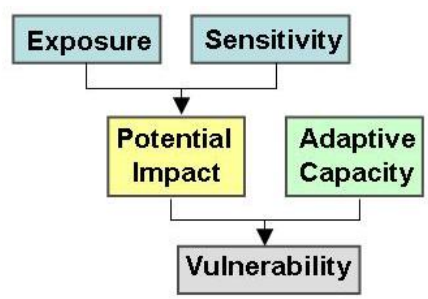

Fig. 7. Key components of vulnerability, illustrating the relationship among exposure, sensitivity, and adaptive capacity. From Glick et al. 2011.

Exposure is the degree of change in climate and land use, which are key drivers of ecological processes and biodiversity. *Sensitivity* of ecosystem processes will be evaluated as change in ecosystem processes as a function of change in exposure. *Adaptive capacity* is the ability of a system to adjust to climate and non-climate change. Exposure is essentially the result of extrinsic factors at all scales, and we will use common data sets for estimating exposure at species, ecological systems (essentially, a 'habitat' level), and biomes (Table 4). Level-specific data will be used to assess sensitivity and adaptive capacity. Our proposed approaches to assessing vulnerability at species and biome levels are relatively straightforward and more or less established in reports and literature. Our approach to

Table 4. Components of vulnerability and LCC-VP general approach and data for evaluating the components at three levels of ecological organization.

Component of Vulnerability	Species / Communities	Ecological System (ES)	Biomes
Exposure	Climate (TOPS) and land use (SERGoM) projections	Climate (TOPS) and land use (SERGoM) projections	Climate (TOPS) and land use (SERGoM) projections
Sensitivity	Bioclimate modeling; Dynamic vegetation modelling	Climate space modeling; TOPS projections	Biome BGC projections; controls of NPP; ecosystem model responsiveness
Adaptive Capacity	Species & habitat traits	Landscape facets; ecosystem modifications; connectivity; protection	Diversity at Ecological System level; conservation context

assessment at the ecological systems level synthesizes several promising avenues that are under active development. LCC-VP is unique among these efforts because of our ability to leverage the expertise of our PIs and their ongoing research programs on ecosystem modeling, connectivity, assessment of natural landscape, and projecting land use and land cover. We will integrate this information to systematically assess vulnerability of ecological systems within the GYLCC and ALCC (Table 5).

Table 5. At the level of ecological systems, variables and data sources that will be used to assess vulnerability to climate and non-climate stressors.

	Variable	Data for CC-VP analyses
Exposure		
	Temp & Precip change; Historical & projected	Historical change from PRISM; TOPS 1 km downscaled data for projections
Sensitivity		
	Ecological responses to climate changes	TOPS projections of water stress and changes in NPP
	Area of ecological system within current climate-defined niche that is projected to be lost or moved outside current range	NatureServe Ecological Systems
Adaptive Capacity		
	Distribution of landscape facets – redundancy and weighted proportion of facets lost due to climate shifts	Variables defining landscape facets: candidate variables include soil/lithography, aspect (radiation), seasonal water balance, elevation, climate variables (TBD)
	Extent of variation in landscape facets	Variables used to define facets (TBD)
	Extent of ecosystem modification	Human footprint
	Connectivity	Method depends on biome attributes. For Appalachian, Goetz et al. (2009); for Great Northern Theobald et al. (2011)
	Conservation context: Proportion protected	**PAD-US (USGS 2011)**

Evaluation of Management Options

The biological indicators within the NPS PACEs will be categorized based on priority ranking and management feasibility. The collaborators will place each indicator into one of three categories: 'Low Risk', 'Manageable', or 'Save at High Cost' (Table 6). This framework is sensible for management because it recognizes the limits of our ability to control natural systems in the face of large scale environmental change. For example, certain high-elevation species like the pika maybe lost under climate change irrespective of any reasonable management action short of very high cost and high risk options. Other species, such as the urban adaptable Nuttall's woodpecker may persist irrespective of environmental change. We will rely on our collaborators to ensure that proposed management options are relevant and linked to NPS policy and planning.

Table 6. Key response variables will be placed into one of these three management categories to guide selection for management

	Low Risk	Manageable	Save at High Cost
Management	None needed	Helpful	High cost/Risky
Exposure	Low	Moderate	High
Vulnerability	High	Moderate	High
Resiliency	High	Moderate	Low
Adaptability	High	Moderate	Low

For indicators deemed 'manageable', four basic types of management options are envisioned: (1) reduce existing stressors, (2) manage for ecosystem function, (3) protect refugia and improve habitat connectivity, and (4) implement proactive management and restoration (e.g., Fig. 8). These options can also be considered within the Vulnerability Assessment framework: actions should decrease exposure or sensitivity, or increase adaptive capacity.

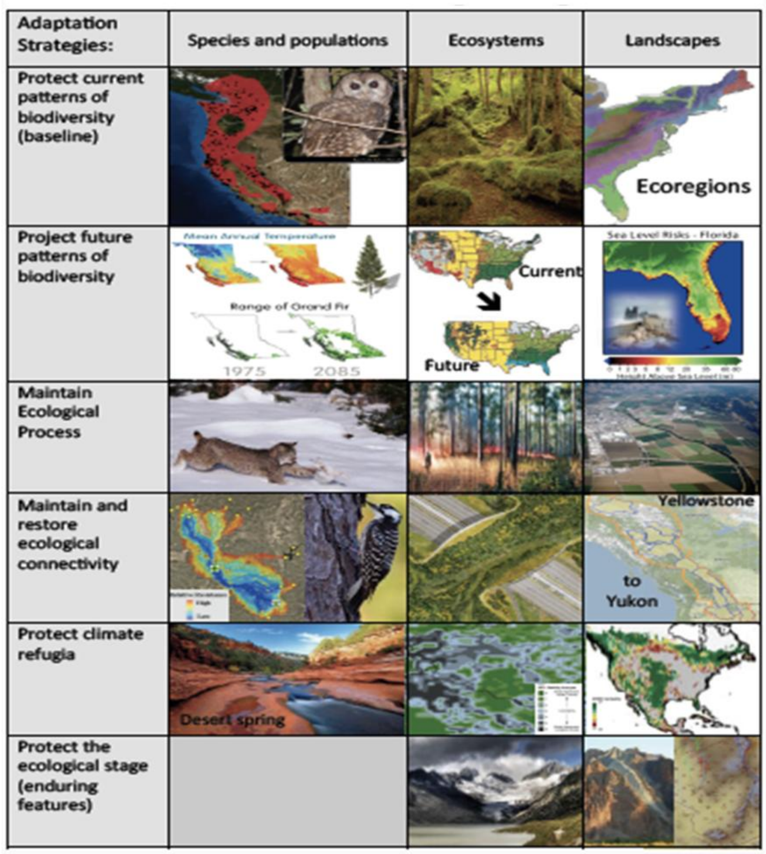

Fig. 8. Examples of the types of management options to be considered for three spatial scales. From the Yale Framework.

Choice of appropriate management option will depend on the nature of the vulnerability. For example, indicators that have suffered historic declines due to anthropogenic influences may require proactive management and restoration, while others that remain stable and viable may benefit from the protection of refugia and improvements to connectivity. This categorization of biological indicators and development of management options will be done with collaborators.

Illustration of a Multi-scale Management Approach

We will illustrate multi-scale management plans for the NPS PACEs and a handful of biological indicators that are targeted by each LCC. These plans will be guided by the National Fish, Wildlife, and Plant Adaptation Strategy (Fig 9). The approach here is to create a spatial vision for achieving the management options. Central to this vision is the creation of maps that clearly identify opportunities for preservation (locations where the indicator is expected to persist in the future), restoration (areas where the indictor occurred historically prior to anthropogenic influences and could recolonize with proactive management), and generation (areas where the indicator has never occurred in recent times but could in the future given climate and land use forecasts). Additionally, the maps will deliver two other types of information that are equally relevant to enacting management: loss (areas where the indicator is not expected to persist in the face of environmental change) and uncertainty (areas where we have low concordance or confidence in our predictions).

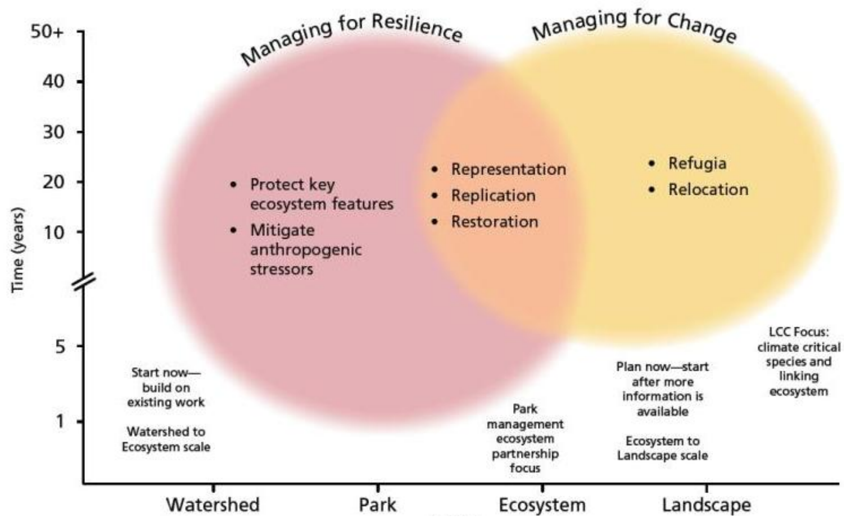

Fig. 9. Adaptation strategies linked in space and time.

Decision Support

Our decision support products will be scaled to the four spatial scales relevant to the LCCs (Table 7). These products are of several categories.

- Data sets and the methods used to produce them in the form of NPS Standard Operating Procedures. Data sets will differ in extent and grain and thus will be applicable differentially to the 4 spatial scales of interest in the LCCs.
- New metrics for conservation. The LCCs are interested in metrics that can be used to quantify and monitor change in ecological condition of their lands.
- Synthesis reports. A vast volume of data and primary studies are now becoming available to land managers. The GNLCC currently has access to 4 different climate downscaling efforts, for example. Our project will synthesize key data and research to help managers understand major trends and biological responses.
- Climate adaptation strategies. Provide concepts and tools for developing, evaluating, and implementing management strategies within individual management units.
- Demonstration of overall approach. Few examples exist of executing all four steps in the Glick et al. 2011 framework. This project will demonstrate implementation of the full

framework, which should serve as a model for the LCCs as they become more fully operational. This will be aided by training sessions on components of the implementation.

These decision support products will be served within the GNLCC Landscape Conservation Management and Analysis Portal (LC MAP). LC-MAP (http://greatnorthernlcc.org/lcmap) provides a collaborative virtual workspace allowing partners of the Great Northern LCC to securely share, access, and analyze common datasets and information to further coordinated research, management, and resource conservation.

Table 7. The spatial scales at which decision support products from the project will be most relevant. Key collaborators at each spatial scale are: LCC – Tom Olliff (GNLCC co-coordinator), Jean Brennan, (APLCC coordinator); Ecoforum – Virginia Kelly (Greater Yellowstone Coordinating Committee), Jim Comiskey (NPS I&M Mid-Atlantic Network); PACE – Jay Fredrick, Chair of the GYCC Whitebark Pine Subcommittee; Mgt Unit – Roy Renken, Yellowstone National Park, Jim Schaberl, Shenandoah National Park.

Decision Support Product	Spatial Scale			
	LCC	Ecoforum	PACE	Mgt. Unit
Data layers (e.g., downscaled climate, SERGoM projections, TOPS and biodiversity outputs)	X	X	X	X
Development of metrics for conservation targets. (e.g. permeability; bird diversity as indicator of diversity)	X	X		
Syntheses reports (e.g., on climate and land use change)	X	X		
Test theory of vulnerability assessment at scales relevant to management.			X	X
Development of climate adaptation options			X	X
Implementation of climate adaptation strategies				X
Demonstration of full four-step vulnerability assessment.	X			
Training on vulnerability assessment and management	X	X	X	X

Products and Outcomes

Objective 1. Ecological Hindcasting and Forecasting.

Input data for SERGoM include: a) 2010 Census Bureau data on the number of housing units and population by census block; b) undevelopable lands data on land ownership based on an updated version of the Conservation Biology Institute's PAD v2 database; c) road (TIGER 2010), land cover from USGS NLCD 2006, and groundwater well density data; d) county population projections drive the growth forecasts; e) commercial/industrial land use data mapped from NLCD 2006 and Census Bureau Location Employment Database. Forecasting will be done for IPCC SRES scenarios. Inputs for TOPS modeling include: NOAA NCDC meteorological data; MODIS land cover, snow cover, NDVI, and LAI/FPAR products; STATSGO soils data and

US NED elevation data.   Forecasts will be based on WCRP CMIP3 downscaled IPCC Fourth Assessment Report (AR4) climate scenarios and SERGoM land use changes scenarios.

The products from hindcasting and forecasting are consistent with the suite of physical, chemical, and biological indicators that the NPS I&M has identified to characterize "vital signs" to evaluate status and trends in park condition (Fancy et al. 2009). These products are listed in Table 8. The results of the assessment will be summarized in reports and publications.

Table 8. Indicators that will be developed by this project.

Category	Indicator	Resolution	Source and reference	Delivery
Climate and Weather	Climate gridded daily	1 km; 2001-2010	TOPS, Nemani et al. 2008; Jolly et al. 2005	SOP; ArcGIS Server
	Long term Climate scenarios (monthly) (average by land cover type)	12 km; 2000-2100	WRCP CMIP3; Maurer et al., 2007	Data available via FTP
Land Cover and Use	Population density	1 km; decadal; 1900-2010	US Census	SOP
	Land use class	30 m; decadal;1940-2010	SERGoM; Theobald 2005	SOP; contract
	Housing density	30 m; decadal;1940-2010	SERGoM; Theobald 2001 2003 2005	SOP; contract
	Impervious cover	30 m; decadal; 1984-2100	SLEUTH; Goetz 2010b.	SOP; contract
Ecosystem Process	Watershed outflow	1 km; decadal; 2000-2010 1 km; decadal; 2010-2100	TOPS SOP Nemani et al. 2008	SOP; ArcGIS Server
	Snow cover	1 km; decadal; 2000-2010 1 km; decadal; 2010-2100	TOPS SOP Nemani et al. 2008	SOP; ArcGIS Server
	Soil moisture / vegetation water stress	1 km; decadal; 2000-2010 1 km; decadal; 2010-2100	TOPS SOP Nemani et al. 2008	SOP; ArcGIS Server
	Primary productivity GPP/NPP	1 km; decadal; 2000-2010 1 km; decadal; 2010-2100	TOPS SOP Nemani et al. 2008	SOP; ArcGIS Server
	Vegetation Dynamics Lifeform	1 km; decadal; 2000-2010 1 km; decadal; 2010-2100	TOPS SOP Nemani et al. 2008	SOP; ArcGIS Server
Biodiversity	Land facets and connectivity	270 m; decadal;1940-2010	SERGoM; Theobald et al. 2012	SOP
	Ecosystem type and connectivity	1 km; decadal;1940-2100	Statistical modeling	SOP
	Dominant tree species and connectivity	1 km; decadal;1940-2100	Statistical modeling	SOP

Objective 2. Vulnerability Assessment.

Inputs include the hindcasting and forecasting outputs from Objective 1 (Table 8, Table 5). Outputs will be the ranked vulnerability of conservation targets at three levels of ecological organization, identification of the causes of vulnerability, and estimates of uncertainty. These results of the assessments will inform the evaluation of prioritized importance for research and /management options that address sources or causes of each indicator based on vulnerability and uncertainty as determined by the expert panels presented in the form of summary reports.

Objective 3.   Evaluation of Management Options.

The priority ranking from Objective 2 will be the input to the evaluation management feasibility and the design of management options. Outputs will be summarized in reports and publications.

Objective 4. Implementation of Management.

The results from Objective 3 will be used to guide development and hopefully, the implementation of specific management plans in response to climate and lands use change.

Roles and Responsibilities

P.I. Hansen - direct the project; focus on the ecological system and plant species modeling and the vulnerability assessment; supervise Research Associate L. Phillips (vegetation modeling and communications), a Ph.D. student (vulnerability assessment), and Administrative Assistant Sondra Torma (budgeting and travel); and participate in each of the project elements.

Co-I. Goetz - focus on modeling land use, hydrology, and vegetation change in the east; liaison with the eastern NPS I&M networks and ALCC; supervising and working closely with Research Associate Patrick Jantz (vegetation modeling).

Co-I. Melton – selection of IPCC scenarios; TOPS modeling and decision support and data distribution; application of the model results to support vulnerability assessments and management planning.

Co-I. Monahan - development of management options applications in the NPS PACEs; serve as the overall liaison with the NPS I&M program; participate in biodiversity modeling in Rocky Mountain National Park.

Co-I. Nemani - supervise TOPS modeling and participate in project analysis and synthesis.

Co-I. Olliff - co-lead with Dr. Monahan the development of management options applications; and serve as the primary liaison the western NPS I&M networks and GNLCC.

Co-I. Theobald - forecasting of land use change; lead modeling of connectivity of biological elements; contribute to hydrological modeling along with Goetz and Melton; supervise Research Associate Sarah Reed (connectivity modeling).

Collaborators Britten, Comiskey, Langdon, Marshall, Schnerbl - primary representatives of their networks and parks and participate fully in project planning, implementation, training, and outreach.

Unnamed Participants in Expert Panels – rate vulnerability, uncertainty, and priority for management of ecological response variables.

Unnamed Public Lands Managers – evaluate, design, and implement management approaches.

Project Diagram

The major components of the project and the flow between them are shown in Fig. 5.

Major Activity Schedule

Our work with the two LCCs will be phased. We will focus on the GNLCC in Years 1-3 (Table 9) and the APLCC in Years 2-4 (Table 10). This schedule recognizes the more rapid start-up of the GNLCC. It also is aimed at fitting well with our collaborating agencies cultures of more focused and shorter term projects.

Table 9. Schedule for APLCC.

Schedule	Year 1											Year 2											Year 3										
Task	S	N	D	J	F	M	A	M	J	J	A	S	N	D	J	F	M	A	M	J	J	A	S	N	D	J	F	M	A	M	J	J	A
Study Design																																	
Refine dispersal zones, ecological systems types	■	■	■	■	■	■	■	■																									
Forecasting																																	
Select IPCC scenarios	■	■	■																														
Downscale climate	■	■	■	■	■																												
Compile SERGoM and TOPS input data	■	■	■	■	■	■																											
Hindcast and forecast land use change	■	■	■	■	■	■																											
Crosswalk SERGoM to TOPS					■	■																											
Diagnostic TOPs runs and validation							■	■	■																								
TOPS and LPJ forecasts							■	■	■	■																							
Compile biodiversity data							■	■	■	■																							
Develop biodiversity predictor data							■	■	■	■																							
Biodiversity model development											■	■	■																				
Biodiversity forecasts														■	■	■																	
Biodiversity validation															■	■	■																
Vulnerability Assessment																																	
Identify expert panels									■	■																							
Analyze trends in indicators														■	■	■	■	■															
Expert workshops												■										■											■
Summarize results													■										■										■
Management options																																	
Identify mgt partners												■																					
Develop options																						■	■	■									
Evaluate options																						■	■	■									
Management approach																																	
Design approach																									■	■	■	■	■	■	■		
Decision Support																																	
SOPs									■	■	■									■	■	■									■	■	■
Training																															■	■	■
Serve data/products								■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Outreach																																	
Monthly Team Calls	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Biannual team meetings	■					■						■					■						■					■					■
Reporting, publishing, outreach	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

Table 10. Schedule for APLCC.

Schedule	Year 2											Year 3											Year 4										
Task	S	N	D	J	F	M	A	M	J	J	A	S	N	D	J	F	M	A	M	J	J	A	S	N	D	J	F	M	A	M	J	J	A
Study Design																																	
Refine dispersal zones, ecological systems types	■	■	■	■	■	■	■	■																									
Forecasting																																	
Compile biodiversity data							■	■	■	■																							
Develop biodiversity predictor data							■	■	■	■																							
Biodiversity model development											■	■	■																				
Biodiversity forecasts														■	■	■																	
Biodiversity validation															■	■	■																
Vulnerability Assessment																																	
Identify expert panels									■	■																							
Analyze trends in indicators														■	■	■	■	■															
Expert workshops												■										■											■
Summarize results													■										■										■
Management options																																	
Identify mgt partners												■																					
Develop options																						■	■	■									
Evaluate options																						■	■	■									
Management approach																																	
Design approach																									■	■	■	■	■	■	■		
Decision Support																																	
SOPs									■	■	■									■	■	■									■	■	■
Training																															■	■	■
Serve data/products								■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Outreach																																	
Monthly Team Calls	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Biannual team meetings	■					■						■					■						■					■					■
Reporting, publishing, outreach	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

Risk, Challenges, and Sustainability

The final report of our previous applications project (Hansen et al. 2011) summarized "Lessons Learned" from the project. We distilled these lessons down to key strategies to minimize challenges and risks. These are summarized below.

Risk 1. A genuine science and management partnership is not created nor sustained.
Strategy: Identify key collaborators early, engage them fully in the project, agree on expectations.

- We identified LCC and NPS I&M partners during proposal preparation and solicited input on study design and approach.
- After the proposal was funded we solicited input from the collaborators on the specific collaborative issues that the project can best address. Criteria for ideal activities were identified as:
  - clear and explicit importance to a park, region, consortia, or other specific group
  - clearly identified group of very interested and engaged stakeholders
  - an identifiable lead – a person we can contact and with whom we could expect sustained involvement
  - a group or process that can use our data/analyses/expertise but otherwise has no access to or limited capacity to use this sort of data and/or technology. I.e., our group would add real value.
  - a specific purpose and/or outcome and a plan to achieve it within 3 years. This outcome could be a planning document (GMP, RSS, EIS, restoration plan, species or habitat mgt plan, etc.), decision, or management action
  - involves multiple land managers and jurisdictions. I.e., a watershed group, or consortia involving NPS, USFS, etc. We're most likely to add value at the landscape scale.
- We identified characteristics of ideal management partners for the project and are now in the process of identifying those partners:
  - Shared Timing: Groups that are in the early stages of projects ultimately aimed at making either on the ground management decisions or drafting management plans (in relation to CC vulnerability) over the next 1-3 years.
  - Complementary Needs: Groups that are "weak" in terms of bringing data and analyses to their projects, but have expressed interest in having that support (perhaps un- or under-funded on the science and research front).
  - Proven Capacity: Groups (or particular people) with proven track records of completing management and/or planning projects (so we can be more confident about having our work really be put to use in a meaningful way).

Risk 2. The enhancements to decision support produced by the project are not adapted by the collaborators.
Strategy: Carefully identify our outreach and decision support goals and products and user groups and design the project to meet them.

- This is a large, complex project with many potential partners. We are carefully identifying our decision support targets at the LCC level, the regional landscape planning area level and the individual national park level.

Risk 3. The state of the science on vulnerability assessment under climate change is changing rapidly, possibly leading to redundant efforts with other research teams.
Strategy: Assess the current state of the science and modify the project to maximize the quality of our vulnerability assessment.

- We have met with other groups funded by this NASA program and have agreed to share science resources where appropriate. We are reviewing the most recent literature on vegetation modeling under climate change and evaluating how to incorporate and add value to other highly complementary efforts.

Risk 4. Delays in completion of TOPS or SERGoM runs may affect delivery of data to other collaborators, delaying the start of the subsequent modeling activities.
Strategy: Work on TOPS and SERGoM model runs were begun immediately upon project initiation and slack was allowed in the schedule to account for inevitable delays.

- Team will maintain close communication to track progress, and will provide information on expected data products, formats, etc to allow work on set-up of subsequent modeling to begin in the first year of the project.

Risk 5. The project plan includes examination of multiple climate and land use scenarios, and will generate on the order of 25-50 TB of data. Maintenance and storage of these data will be an additional expense, and may be beyond the ability of partner agencies to support in an era of declining budgets.
Strategy: Early in the project, the project team will work with agency partners to identify key datasets and data summaries which need to be added, archived, and distributed.

- The team will use the NASA Earth Exchange to convert data into formats that are convenient for NPS and other agencies to archive and distribute.

Risk 6. The project plan includes operation of multiple complex models which require specialized knowledge to operate. Transfer of modeling capabilities to agency partners is beyond the scope of the proposal, presenting a challenge for future updates of data products.
Strategy: While the project is focused on two geographic regions, all model runs will be completed for the contiguous U.S.

- The project team will work with NPS to develop tools to facilitate extraction of subsets for other regions, and all subsequent processing steps will be documented in SOPs.
- In addition, the project team intends to document the methods used to produce all modeled data products in the peer-reviewed literature.

Transition and Sustainability

We envision 5 levels of products to enhance agency decision support relative to climate change: data sets and methods; new metrics for conservation; synthesis reports; climate adaptation strategies; and demonstration of overall approach and training. Our goal is to positively influence the longer-term decision support capabilities of the partners by working with the partners to develop and demonstrate these products. With regards to the data products, we expect the collaborators to use our SOPS and continue to produce a subset of these products beyond the lifespan of this project. We learned, however, from our previous project, that some of the data products will need to be produced by the NASA TOPS program and this is contingent on TOPS procuring project funding.

The strategies we will use to support the transition to partners are:

- careful selection of partners and projects as outlined under Risks and Challenges above;
- engaging key partners in the project throughout its lifespan;
- conducting annual workshops of science and management experts to keep the project grounded in the needs of the partners;
- publishing the methods and outcomes of the project to leave a written legacy for partners to draw from in the future.

Communication

The research team communicates regularly through monthly conference calls and semiannual workshops. Additionally, we talk individually by phone as needed and meet at scientific meetings that we happen to co-attend. We communicate with our NPS and LCC partners through either webinars or memo semiannually and through one to one communications as needed. Effectiveness of our communication with partners is enhanced because our co-Is are from within the agencies of our key partnering group. Co-I Monahan (NPS-I&M) is serving as primary liaison with NPS I&M collaborators and Co-I Olliff (GNLCC) is primary liaison with the LCC partners.

Assessment Metrics

We aim to enhance decision support with our LCC and NPS I&M partners at four levels: LCC-wide; within Ecoforums; within ecosystem groups and ad-hoc networks; and within landscape management units.

LCC-wide. The LCCs have broad objectives that generally relate to increasing collaboration among federal land managers. One specific objective of the GNLCC is to compile/develop/serve data on key abiotic, biotic, and socioeconomic factors seamlessly across the many agency and private jurisdictions within their domains. This is being done with The Landscape Conservation Management and Analysis Portal (LC MAP), which provides a collaborative virtual workspace allowing partners of the GNLCC to securely share, access, and analyze common datasets and information to further coordinated research, management, and resource conservation. **The key assessment metric level for the project at the level of LCCs is the number and usefulness of indicators of ecosystem condition that we provide.** We anticipate producing the indicators listed in Table 8 across full LCCs. Some of these may be redundant with existing LCC data, some will be variants of indicators that the LCCs are obtaining from 1-3 other sources (e.g., downscaled climate), and others will be uniquely provided by our project (e.g., primary productivity).

Ecoforums. The GNLCC has identified three regional forums that deal with adaptation to climate change within geographic subsets of the full LCC. These forums are an engagement of conservation practitioners and partnerships that share landscape conservation challenges in an ecogeographic context: Columbia Basin, Rocky Mountain, and Sage-Steppe. We will partner with the Rocky Mountain forum. In addition to the ecosystem condition indicators described above, we will conduct vulnerability analyses (our objective 2) with expert panels including regional forum members. **The key assessment metrics at the regional forum level will be the value of the results of the vulnerability assessments.**

Ecosystem Management Groups and Ad-Hoc Networks: Within the Great Northern Landscape, several ecosystem or coherent landscapes have developed groups that meet and cooperate on management across jurisdictional boundaries. Examples include the Greater Yellowstone Coordinating Committee; the Crown Managers' Partnership; the High Divide Management Group; the Wyoming Conservation Landscape Initiative; and the Arid Lands Initiative. GNLCC Partner Forums are generally led by a consortium of these groups (for example, both the GYCC and the CMP are on the Rocky Mountain Partner Forum Leadership Team. These groups bridge the gap between landscape assessments and partnerships and individual land management units. In addition, several ad-hoc groups are developing in response to conservation needs. For example, USGS, State, and federal land managers are working together to develop guidelines for monitoring sage-steppe systems based on disparate on-going monitoring programs. These two types of groups will be the entry level for the LCC-VP team engaging managers.

Landscape Management Units. Much of the actual management under climate change will continue to be done at the level of individual land management units (e.g., national parks) and the surrounding ecosystem. Examples include the Whitebark Pine Subcommittee of the Greater Yellowstone Coordinating Committee and the Crown Partnership which includes Glacier National Park. We are partnering with these groups to help devise, evaluate, and implement management options within such landscape management units (our objectives 3 and 4). **The primary assessment metrics will be the extent to which the evaluation and implement of management options were enhanced by the products from objectives 1-4 of the project.**

For each of the assessment metrics described above we plan to quantify the project's contributions by pre and post surveys of the partners. The pre survey is scheduled for Summer 2012.

Literature Cited

Coops, N. C., R. H. Waring, C. Beier, R. Roy-Jauvin, and T. L. Wang. 2011. Modeling the occurrence of 15 coniferous tree species throughout the Pacific Northwest of North America using a hybrid approach of a generic process-based growth model and decision tree analysis. Applied Vegetation Science 14:402-414.

Fancy, S. G., J. E. Gross, and S. L. Carter. 2009. Monitoring the condition of natural resources in US national parks. Environmental Monitoring and Assessment 151:161-174.

Glick, P., B. Stein, and N. Edelson. 2011. Scanning the Conservation Horizon: A guide to climate change vulnerability assessment. National Wildlife Federation, Washington, D.C.

Goetz, S. J., P. Jantz, and C. A. Jantz. 2009. Connectivity of core habitat in the northeastern United States: parks and protected areas in a landscape context. Remote Sensing of Environment 113:1421-1429.

Hansen, A.J., N. Piekielek, S. Goetz, J. Gross, F. Melton, R. Nemani, D. Theobald. 2011. Ecological Condition of US National Parks: Enhancing Decision Support Through

Monitoring, Analysis, and Forecasting. Final Report. Unpublished report, Montana State University, Bozeman, MT.
Iverson, L. R., A. M. Prasad, S. N. Matthews, and M. Peters. 2008. Estimating potential habitat for 134 eastern US tree species under six climate scenarios. Forest Ecology and Management 254:390-406.
McKenney, D. W., J.H. Pedlar, R.B . Rood, D. Price. 2011. Revisiting projected shifts in the climate envelopes of North American trees using updated general circulation models. Global Change Biology (2011) 17, 2720–2730.
Potter, K. M., W. W. Hargrove, and F. H. Koch. Predicting climate change extirpation risk for central and southern Appalachian forest tree species. Pages 179-189 Proceedings from the Conference on the Ecology and Management of High-Elevation Forests in the Central and Southern Appalachian Mountains.
Theobald, D. M., K. R. Crooks, and J. B. Norman. 2011. Assessing effects of land use on landscape connectivity: loss and fragmentation of western U.S. forests. Ecological Applications 21:2445-2458.
Theobald, D. M., S. E. Reed, K. Fields, and M. Soule. 2012. Connecting natural landscapes using a landscape permeability model to prioritize conservation activities in the US. Conservation Letters in press.
Turner, B. L., R. E. Kasperson, P. A. Matson, J. J. Mccarthy, R. W. Corell, L. Christensen, N. Eckley, J. X. Kasperson, A. Luers, M. L. Martello, C. Polsky, A. Pulsipher, and A. Schiller. 2003. A Framework for Vulnerability Analysis in Sustainability Science. Proceedings of the National Academy of Sciences of the United States of America 100:8074-8079.