Department of Interior North Central Climate Science Center Foundational Science Areas Implementation Plan 2012

NORTH CENTRAL CLIMATE SCIENCE CENTER

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1. Summary

This document provides the implementation plan for the three foundation science areas of the North Central Climate Science Center. These areas are 1) regionally informed and relevant climate information (abiotic), 2) the impacts of past, present, and future climate on living things (biotic), and 3) the adaptation and mitigation planning options available to managers (the human dimension). These three foundational science areas are explained and justified in the NC CSC five year science agenda[1]. This document expands upon that agenda with five sections. The first provides an overview of the three areas and the linkages between them. The next three sections provide the near-term (1-2 year) detailed implementation plans for the three foundational science areas. The final section describes the long-term plans (1-4 years) to establish science teams for the three areas.

2. Overview and connection between the three foundational science areas

The North Central Climate Science Center efforts have been framed as a Resource for Vulnerability, Adaptation, and Mitigation Planning (ReVAMP)[1]. **The vision for the NC CSC is a coordinated and integrated regional approach to the management of the nation's land, water, fish and wildlife, and cultural heritage resources that utilizes the best possible understanding of past, present, and future climate into the decision process.** However some of the technical components involved with implementing this vision (including downscaling and regionally informed climate projections, ecological response models, and assessing social ecological vulnerabilities and adaptation planning) are nontrivial. The NCCSC activities are organized to provide the best available climate science and inferences on impacts and adaptation strategies for natural resource management entities within the North Central Domain. The NC CSC will provide the understanding and information needed by decision makers and managers in the region so that a more complete understanding of potential impacts and adaptation strategies for a broad range of natural, cultural, energy, and other resource management activities will be available. This understanding and information exchange will be provided through a platform for interpreting an array of climate information on changes, impacts, and responses. The aim of these activities is to develop integrated information relevant to our natural resource managers and to ensure that these managers have access to products AND can use them. The NC CSC is directing its five-year science agenda toward science delivery through a **Re**source for **V**ulnerability **A**ssessment, **A**daptation and **M**itigation **P**lanning (ReVAMP). Co-development of research products with these managers working in partnership with research groups is a key component of our efforts.

The North Central University Consortium (NCUC) has formulated a team of researchers to carry out an integrated set of research activities to enable the Climate Science Center to provide climate relevant information to guide decision-making in the region. That is, the NCUC is providing the scientific foundation to be used within the ReVAMP.

Fundamental Science for the ReVAMP

The ReVAMP concept will serve as a centralizing theme to coordinate research done through the NC CSC and will also provide the mechanism by which the NC CSC can help serve stakeholder needs. The NCUC efforts are organized around three foundation research themes, which are meant to form an integrated approach to inform resource managers and researcher in our region:

- Understanding and quantifying drivers of regional climate changes,
- Assessing impacts of climate change on the natural resources of the region and the resulting vulnerability of socialecological system components, and
- Characterizing vulnerabilities, adaptive capacity, and management response options of communities and natural resource

[1] http://pubs.usgs.gov/of/2012/1265/

Collaborating between the decision makers, the climate modeling community and researchers within NCUC will work to connect the relevant climatological, ecological, energy, cultural, or management disciplines. Specifically, the NCUC research includes:

- Region-specific approaches for developing targeted climatological information that respects the full range of temporal and spatial scales of climate processes in order to understand vulnerability of conservation targets to changing climate and opportunities for renewable energy given future climate.
- Capacities to provide enhanced climate information at relevant spatial and temporal scales, both for historical climate and projections of future climate
- Ecological response modeling with enhanced climate information that respects non-stationarity
- Vulnerability and adaptation response studies of the social-ecological system

Research activities have emerged through discussions with university consortium members, LCC leaders, and other federal and tribal partners associated with the Stakeholder Advisory Committee for the NC CSC. The research plans were consolidated and further developed at two research planning workshops among NCUC institutions (May 2012, Bozeman and Oct. 2012, Fort Collins). These activities represent an initial development of a community analytical platform to evaluate impacts and response options that management entities may consider. The activities are described below in three research activities associated with extreme climate dynamics, impact analysis of ecosystem and habitat dynamics, and adaptive capacity and decision making approaches.

The research incorporates the concepts associated within the social-ecological system framework. This approach allows for better integration of research findings in a decision-making solution oriented manner due to the enhanced awareness of social dimensions of changes and impacts assessed across the regional domain. This framework allows for specific research to be carried out within certain disciplinary domains while providing a platform to link various findings within the system framework.

The NC CSC use directed funds in 2012 to support NCUC efforts to initiate these foundational science areas. The details of that work is given in the following three sections and associated appendices. The final section describes how these foundational research areas will persist through science teams and how synergistic research activities have been identified to further develop linkages between these elements to enhance the delivery and synthesis of information to the management process, including vulnerability assessments, adaptation, and mitigation.

3. Understanding and Quantifying Drivers of Regional Climate Changes

Understanding climate drivers is a central theme for all CSCs. Informing the north-central management community on the latest science related to climate drivers in the region and communicating the potential effects is a fundamental and critical element of the NC CSC ReVAMP. The climate in the north-central domain is driven by large-scale patterns in atmospheric circulation, the region's complex topography, and effects due to the nature of the local land cover. The multiscale nature of these climate drivers creates patterns of mean climate, climate variability, and climate change that are characterized by dramatic gradients in seasonal and annual temperature, effective moisture, and wind. The resulting climatic variability determines the diversity and distribution of habitats that support species and ecosystems and impacts the potential renewable energy resources for the area. It is necessary, therefore, to use region-specific approaches for developing targeted climatological information that respects the full range of temporal and spatial scales of climate processes in order to understand vulnerability of conservation targets to changing climate and opportunities for renewable energy given future climate.

Related Deliverables

This research focus will provide climate information across the region that will be tailored to resource management decision-makers' needs, as well as to inform researchers on the driver of impacts across an array of natural and cultural resource areas, from species, landscapes, biotic and biophysical resources,

and ecosystems. This information will be analyzed over historical periods as well as include projections of different scenarios of climate dynamics into the future.
Specific deliverables include the following:

- Publications and expert opinion focused on geographic areas and ecosystems/habitats of concern to the Stakeholder Advisory Committee and other clients on our current understanding of climate and climate variability in the region,
- World-class research on regional climate models in the NC CSC domain, with an understanding of how that research fits client-based and management decision activities
- Contributions to the future National Climate Assessment, and
- Climate information and products that are accessible and useable within the ReVAMP as input to the vulnerability assessment management options components of the framework.

4. Impacts and Vulnerability: Connecting Climate Drivers to Management Targets

Whereas climate drivers are a fundamental research component for the CSCs, for most management issues climate is often not the primary concern. For example, land managers are more concerned about animal populations or ecosystem services than they are about changes or trends in annual average temperature or precipitation. Yet climate drivers are linked to the conservation targets of concern. This research element is directed toward understanding and quantifying that linkage through ecological response models. Ecological response models, as enumerated in Glick and others (2011) help bridge between climate information and management goals.
This research area will look to leverage ongoing and active research and expertise in ecological response models where translational climate analysis can advance that work. The connection to management actions links this research area to the adaptation and decision-making research areas listed below. The NC CSC is looking to build ecological response modeling that can both (a) be improved with enhanced climate information that respects nonstationarity and (b) serve management issues that have been prioritized by the stakeholders. The ReVAMP infrastructure will facilitate the connections and interactions. The NC CSC will facilitate translational information and science/management exchange represented by these arrows. The related research in this focus area must be open to and agile enough to iterate with both the climate-drivers research component and relevant resource management goals and objectives.

Related Deliverables
The impacts research area will incorporate vulnerability to different exposure and sensitivity of system components to climate effects and drivers to address the nature of the vulnerability. It will build on current observations available in the region and utilize an ensemble of models to enhance the understanding of vulnerability to natural and cultural resources in the region. The vulnerability framework provides an analytical process to identify exposures and sensitivities of a system together, as well as separate parts of the system. Analysis of vulnerability will incorporate regional and temporal aspects to inform managers and researchers about interactions between factors and temporal dimensions of these interactions.
Specific deliverables include the following:

- The ecological-response-modeling component of the ReVAMP, which will link state-of-the-science understanding of climate with resource management decision support tools,
- Habitat integrity factors that influence the productivity and extent of these habitats across various changing environmental conditions,
- Species-level sensitivity of physiological or population limits that would affect the success of the species, and
- Ecosystem service changes that would alter management considerations of these resources.

5. Characterizing Adaptive Capacity of Stakeholder Communities and Informing Management Options

Connecting to decision makers is one of the main operating principles for the center and integral to its mission. This connection is not always obvious or automatic; it requires not only a strong research program but also a healthy infrastructure for transition, a strong interface with the user community, and continuous evaluation of the process (National Academy, 2000). This research area will ensure the NC CSC has these key components in place.

Adaptive capacity issues come into play in both the 2nd and 3rd steps of the Glick and others (2011) framework (fig. 5). Understanding and evaluation of the adaptive capacity of the social-ecological systems in the north-central region should be an integral component in the development of management strategies to deal with climate change. The vulnerability of natural resources and the adaptive capacity of the social-ecological system vary across the region due to local, State, Tribal, and regional accessibility to social-ecological capital resource assets. The science done through the NC CSC should work toward understanding the availability and use of capital resource assets in the region and how they are, or can be, used for implementing adaptive management practices. This understanding is critical in the development of useful and feasible management strategies.

To identify conservation targets and implement management options, it is imperative to understand the social-economic context and drivers. The NC CSC is very committed to identifying end users' needs and understanding and facilitating the incorporation of climate science into management decisions through quantitative decision support tools. As such, research will be directed in this area and the NC CSC will look to coordinate with the USGS Science and Decision Center[2] as well as the staff and resources available through the NCTC structured decision-science curriculum[3]. Key components of this research area will include quantitative scenario planning (Kass and others, 2011) and management-decision-based simulation studies (for example, Frid and Wilmshurst, 2009).

Related Deliverables

This focus area will provide a critical analysis of how the different management entities represented on the Stakeholder Advisory Committee (SAC) and across the region have an ability to implement adaptation and mitigation strategies. This analysis will evaluate the options available to these entities to both address the impacts on the system and identify potential vulnerabilities. This information will provide a framework to build capacity to cope or respond to different stressors. The analysis of capital assets will be made within the decision-making context of these entities and with the help of quantitative decision support tools.

Specific deliverables include the following:

- Detailed information on management options and institutional resources and how these are utilized under various decision-making situations,
- Integration of the information derived from the other research activities above, shared with stakeholders across the region to enhance adaptive capacity, and
- Quantitative decision-support tools for the ReVAMP.

6. Synergies and continuing the foundation science teams

The NC CSC five year science agenda is founded on the three focus areas described above. In this section we describe the infrastructure that will be used to maintain continued work in these areas and have that work integrated into the other work at the center and in the region.

[2] http://www.usgs.gov/sdc/

[3] http://training.fws.gov/EC/Resources/Decision_Analysis/SDM.htm

Financial support of the Foundation teams

The approach will be to establish science teams around the three areas. Beyond the initial work funded in 2012 (detailed in the appendices), the NC CSC will provide resources to each team. Assuming consistent funding for the center in future years, the support per team is anticipated to be on the order $150,000 per team per year for 2013-2016. Each team will have a leader who will be responsible for organizing the work within that area as well as connecting the work within that area to both the other foundational science areas and into the ReVAMP science delivery mechanism. An example for using the team resources could support from 2 to 4 months time for the team leader, a post-doctoral researcher, and one or two team workshops per year. However, it will be up to the team lead, working in collaboration with the NC CSC, to utilize the budget to maximize the impact of each team.

Selection of team leads and governance

Long-term planning efforts on how the NCUC will be able to continue support of research efforts in the region will be carried out by the lead of these research elements. As such the NCUC will help in the selection of the team leads. The inaugural leads, starting in in 2012, are Dr. Chris Anderson for climate (U of Iowa), Dr. Andrew Hansen for impacts (Montana St U), and Dr. Dennis Ojima for vulnerability and adaptation responses (Colorado St U). These leads volunteered to take on this role as it was being defined at the May 2012 science-planning workshop.[4] Their initial interest and work have provided a tremendous asset to the NC CSC as it has established its five-year plan. In 2013, the NC CSC will work with the existing team leads, it NCUC, and Stakeholder Advisory Committee (SAC) to determine the leads for the next two years. The strategy will be to select team leads from within the NCUC community, looking for leads to commit to a two-year term. The selections will be made by NC CSC management, but with discussion and concurrence from the SAC and NCUC. In 2015, NC CSC will revisit the selection of team leads; with current team leads being eligible for consideration to continue if they are so inclined. Once selected, the team leads will be given funding as described above and provide support as described below.

Consultation to assist with directed work

In addition to the specific funding dedicated to each team lead, the team leads will be used as consultants to the NC CSC for recommendations and insight on how to spend directed funds available through the center. In 2013 and 2014 the NC CSC will spend approximately ½ of its research funds on solicited/competed work and maintain roughly ½ for directed funding. As competed funds are awarded, the foundation science team leads will be consulted with to evaluate those projects against the capacity of the center and help guide the use of directed funds to a) augment the work of the solicited projects and b) fill any critical climate-science research gaps.

Assistance with coordination

The foundational science teams will help ensure coordination with other national and regional initiatives. Priority regional coordination opportunities include working with the NOAA's Western Water Assessment and Landscape Conservation Cooperatives. Priority national level coordination opportunities include working with NOAA's National Climate Projection and Prediction program, the National Climate Assessment (NCA; disseminating information from the 2012 NCA and helping prepare information for the 2017 NCA), and the National Center for Atmospheric Research (NCAR).

Support for the mission of the NC CSC

Finally, it is the ultimate objective of the three foundational science teams to support the mission of the NC CSC to deliver the best possible climate-related science to regional resource managers. Currently, the lead investigators for each of the 3 elements (i.e., climate, impacts, and vulnerability and adaption response) have routinely communicated on research efforts and prioritization of research activities to

[4] *http://www.doi.gov/csc/northcentral/upload/NC-CSC-science-planning-workshop-report-May-2012.pdf.*

enhance the linkage of research products for enhance understanding and for use in natural resource management decision making. With the resources and objectives outlined here, the NC CSC hopes it will be possible to enhance the coordination among these elements. The team will serve to better coordinate between and to develop a more integrated framework to link these elements in a climate-ecololgical-social system framework.

Cross-project meetings (face-to-face and via internet) among the foundational research groups, other funded investigations, coordinated efforts, and management entities working with the NC CSC will be held to co-develop research products and translational material relevant, useful, and useable for natural resource management decisions. The foundation science teams will play a major role in the development of this integrated synthesis of research products aimed to meet natural resource management needs. An important product of this cross research element activity will be a development of synthesis papers outlining the implications of climate change effects on natural resources in the region and the potential response options that may be feasible.

7. Appendix A: Detailed Implementation of the climate science team

Collaborators (alphabetical by last name):
Christopher J. Anderson (leader, ISU), Sheri Fritz (UNeb), Bart Geertz (UWyo), Steve Gray (USGS), Bob Gresswell (USGS), Steve Hostetler (USGS), Steve Jackson (UWy), Greg McCabe (USGS), Dave McWethy (MSU), Robert Oglesby (UNeb), Greg Pederson (USGS), Steve Running (UM), Jasmine Saros (UMaine), Bryan Shuman (UWyo), John Stamm (USGS), Bob Thompson (USGS), Cathy Whitlock (MSU), and expanded as needed.

Background:
This research element supports vulnerability assessment for climate adaptation (Glick et al. 2011) by focusing on the provision of best available climate information for the region in order to inform analysis of ecosystem exposure to change. Specifically, Glick et al. (2011) encourage the following considerations for using climate information in assessing exposure and sensitivity components of vulnerability analysis:

- Vulnerability assessment can be conducted either based on historic observed changes in climate, future modeled projections, or a combination of both.
- Consider only well-established models, whose strength and weaknesses are already extensively described and evaluated in the peer-reviewed scientific literature.
- The models chosen should encompass the greater range of uncertainty in climate sensitivity simulated by global climate models.
- Note that within any climate model, uncertainties will vary for different simulated phenomena.
- When assessment is based on quantitative and qualitative analyses and a synthesis of the scientific literature by experts, then uncertainty is found in the lack of available information specific to the question of interest in the quantitative studies.
- The key to combining multiple sources of uncertainty is to identify interactions between the different components … This can be done qualitatively through conceptual models, diagrams, and narratives, or more quantitatively through scientific models and computational algorithms.

Climate in the North Central United States (NCUS) is driven by a combination that includes large-scale patterns in atmospheric circulation, the region's complex topography extending from the High Rockies to the Great Plains, and geographic variations in water and surface-energy balance. The multi-scale nature of these climate drivers creates dramatic spatial gradients in seasonal and annual effective moisture, as well as temporal shifts in the climate mean, climate variability and weather. Hydroclimatic variability within the NCUS determines the sustainability of ecosystems in the region as well as the ecosystem goods and services they provide. We propose, therefore, to use a diverse set of region-specific approaches for developing a hydroclimatology that is faithful to the full range of temporal and spatial scales of climate processes in order to evaluate efficacy of climate model simulations, provide interpretation of climate change mechanisms, and advance understanding of co-variability between climate, ecosystems, and species of interest to stakeholders.

The proposed activities are intended to clarify and quantify the trajectory of change in past, present, and future water balances within the NCUS and to contribute to the data and knowledge base envisioned for REVAMP by addressing the list of key climate information characteristics provided above. In year 1, the team of university and USGS scientists will undertake research in three areas:

(1) We will develop a data-model framework to examine past and present climate changes and the ability of climate models to simulate historical changes (to provide confidence in their future projections), satisfying the need for a common knowledge base of historic and modeled future changes that includes multiple future scenarios for uncertainty analysis by consortium collaborators and stakeholders.

(2) We will provide a region-wide evaluation of water balance change, providing an ecosystem and habitat relevant interpretive lens for deepening knowledge on historic changes and capacity of climate models to simulate variability and enabling dialogue between scientists and stakeholders.

(3) We will provide climate information to ecosystem scientists in the USGS and consortium universities and stakeholders for targeted ecosystem vulnerability studies.

Data-model framework

Regional climate research in the NCUS, spanning the Holocene to future, is underway by scientists in the USGS and at consortium universities. Paleo and historical studies based on pollen, diatoms, tree-rings, geochemistry, lithology, charcoal, streamflow, and historical records are used to reconstruct past conditions. Climate modeling efforts focus on dynamically downscaled simulations of ecosystem-important climate parameters, and evaluation of the scales at which climate model processes are realistic within the NCUS. Building on and investing in this collaboration will advance the NC CSC science plan by ensuring the best available climate knowledge is used in ecosystem vulnerability studies and referenced by stakeholders.

We propose to develop a regional data base of paleoclimate information, recent observations, and modeling efforts for evaluation of NCUS hydrological processes from the past (Holocene) through the future (2100 AD). Paleoclimate information for the region will be obtained from existing data repositories (e.g., Neotoma Paleobiology database, NOAA World Data Center for Paleoclimatology, and Global Palaeofire Database) and unpublished sources Climate models are the sole tools for quantifying past and future oceanic and atmospheric circulation under different boundary conditions (e.g., in trace gases, insolation, albedo, vegetation) than those at present. Iterative comparisons of data and models provide both a better understanding of climate change and an opportunity to improve models. The data-model framework will enable coordination among climate scientists that is currently not possible. For instance, it will be used to evaluate the ability of climate models to replicate recent historical trends and climate extremes as well as their ability to simulate climate extremes that exceed recent conditions, thereby increasing our confidence in projections of future conditions that may exceed recent changes.

Research activity and focus:

(a) We will develop a vetted database of historical and paleoenvironmental records for targeted areas in the region. The database will bring together proxy data (pollen, charcoal, macrofossil, diatoms, geochemical data, tree-ring records) and derivative products (reconstructions of snowpack, lake turnover, area burned, insect outbreaks, lake level, glacier fluctuations, stream flow, PDSI reconstructions).

(b) We will develop a historical daily climatology from 1950 – present with new advances incorporated into the WxTopo. The gridded dataset will be based on the surface observation network and, importantly, it will improve vertical interpolation by being the first to use MODIS land surface temperature to improve representation of terrain and atmospheric reanalysis to improve representation of lapse rate. WxTopo will produce daily output, though trend estimation of the daily data is not recommended, and it will produce several derived variables not available in other interpolated data sets such as PrISM, TOPS, and Daymet, such as daily VPD and incident radiation. Finally, WxTopo will be developed as open source code facilitating iteration on WxTopo development with end users.

(c) We propose to produce high-resolution simulations of recent climate with the Weather Research and Forecast (WRF) model driven by North American Regional Reanalysis (NARR) data. WRF simulations will have a nested domain configuration. A 12-km grid covering the continental United States will be used to simulate processes in the Great Plains. It is important that the 12 km domain extend well to the south, so as to properly capture monsoon processes and low-level moisture transport from the Gulf of Mexico within the NCUS. A nested domain with 4-km grid will be used to simulate the inter-mountain west, covering the high elevations of the Rockies. The WRF simulations will be evaluated for agreement with the gridded 1-km observations and for propagation of precipitation systems from the lee of the Rockies into the Plains, a characteristic of warm season rainfall in the Plains that is absent in global climate model simulations.

Water balance change

Together, climate and ecosystem scientists will work to identify dependence between climate and broad aggregates of biodiversity, defined by NatureServe as "Ecological System Types" (ESTs; shttp://www.natureserve.org/publications/usEcologicalsystems.jsp). The aggregate nature of ESTs means they may capture 80-90% of species within a planning area, including individual species (e.g., wolverine) and vegetation types (e.g., subalpine forest) listed as conservation targets by partnering Landscape Conservation Cooperatives. ESTs will be evaluated by ecosystem scientists in the university consortia for their ability to predict species distributions. Given the obvious dependence of vegetation type on water, we hypothesize that ESTs across the NCUS will co-vary with hydrological conditions. The recent past hydrology of the region contains a geographic pattern of change evident as drying in the western sector and increasing precipitation and stream flow in the eastern sector. This recent change provides an immediate opportunity to examine co-variability of ESTs and hydrology. We propose to use a one-dimensional water balance model [precipitation – potential evaporation] to quantify temporal and spatial scales of hydrological change during the recent historical past through the future.

a) We will apply the one-dimensional water balance model to WRF output to evaluate its capability for simulating recent change (using simulations driven by NARR) and to produce an ecosystem-relevant projection of future changes.
b) We will develop a multi-proxy paleoclimatic database for a better understanding of the regional climate history .
c) We will examine the ecological consequences of extreme climate events in the Holocene, including past megadrought, as a point of comparison with projected future climate change. . Similarly, we will work with ecosystem scientists to identify recent extreme ecological events (that may or may not be extreme climate events) and seek analogues in the past through data query and model comparisons.

Linkages between Climate and Ecosystem Scientists in the University Consortia

The following research and activities will foster close collaboration between climate and ecosystem system scientists:

a) We will remain in close dialogue with ecosystem scientists (participating in Research Activity 2 and others) as they define candidate ESTs for analysis and as the modeling approaches used to simulate them are determined. In the first year, the dialogue will be maintained by quarterly teleconferences, additional project-specific teleconferences as needed, and at least one jointly held workshop.
b) We will provide expert information on climate change in support of the delivery of observational and model data for use in identifying co-variability between climate and ESTs. This will entail much more than passing along data. Our dialogue will produce guidance on temporal and spatial scales that are appropriate for the use of climate data, and this initial collaboration will begin the first steps in building region-wide recommended uses of climate data. The collaboration will identify how to transform climate model output so that it is suitable as input data for ecological-hydrological process models.
c) We will build a proof-of-concept hydrologic/ecosystem model within one of the selected ESTs. We will use the RHESSyS model, a watershed model that will be placed in a targeted watershed, and provide validation from the past hydrologic/ecosystem. This will enable mechanistic interpretation of covariability between climate and the selected EST. It will engage climate and ecosystem scientists in the process of understanding relevant scales and transformation of climate model data, identification of historical and paleo climate conditions relevant to ecosystem extremes, and interpretation of how changes in water balance are manifested in ecosystems.

Deliverables and Outcomes:

At the end of Year 1, the climate drivers team will provide the following deliverables:

- We will complete a database of historical and paleodata on extreme climate events throughout the NCUS. This will position the team to undertake analysis of climate conditions associated with extreme ecological events.
- Working with university consortium ecosystems scientists and decision scientists (Research area 2 and 3), we will select a watershed basin for development of RHESSyS proof of concept hydrologic/ecosystem modeling that will work through the steps of coupling to datasets generated by the climate drivers research team.
- Hourly output from WRF simulations forced by NARR will be generated.
- We will provide evaluation of water balance change for 1950-2100.
- Working with stakeholders, ecological system team, and decision science team, we will build a proof-of-concept hydrologic/ecosystem model within one of the selected ESTs.
- We will initiate a climate model working group and invite scientists at universities both inside and outside of the university consortium and at USGS science centers to participate.
- Among the first activities of the climate model working group will be a peer reviewed paper of existing climate projections for the NCUS.
- We will initiate cross working group activities with the ecological system and decision science teams.

There are several stepping stone outcomes of the proposed deliverables. First, a peer-reviewed synthesis report for climate projections in the NCUS will provide clarification on projected changes that scientists and stakeholders in the region can then reference. It will serve as a common reference point for outreach materials. As well, it will serve as the standard of comparison for the high-resolution dynamical downscaling with WRF. Second, databases of gridded observations and simulations of recent historical climate with WRF will provide data sets with which to experiment on alternative ways to use climate data with ecosystem models and expert ecosystem judgement. Third, the water balance data set will integrate changes in precipitation, humidity, and temperature in an ecosystem-relevant manner. It will provide the climate science framework from which interpretation with ecosystem models and expert judgment will be made. Fourth, the database of paleo and historical extremes will provide insight into the interdependence of extremes across the region. It will enable more insightful analysis of climate model data. Finally, the high-resolution WRF simulations will be the first of their kind and have the potential to change scientific perspectives on the potential for future global climate change to alter this region's precipitation regimes.

Data Management:

The output from the WRF simulations will be saved on an hourly basis. A basic subset of the hourly climate model data likely to be used most often (e.g., surface temperatures and precipitation) will be stored at NC-CSC and available via website. The full climatology will be stored at Wyoming Supercomputer center and available on demand. (Recognizing that that full dataset is likely to be several petabytes.) The daily 1-km water balance dataset from 1950 – 2100 will be delivered to other team members for further ecosystem impact and vulnerability

8. Appendix B: Detailed Implementation of the impacts science team

Collaborators

Montana State University: Andy Hansen, Nate Piekielek, Tony Chang
Iowa State University: Diane Debinski, Kristin Kane
University of Wyoming: Bill Lauenroth, John Bradford, Daniel Schlaepfer
Colorado State University: Barry Noon, Helen Sofaer, Susan Skagen, Valerie Steen
NC CSC: Marian Talbert, Colin Talbert

Background

Vulnerability refers to the extent to which a species, habitat, or ecosystem is susceptible to harm from climate change impacts (Schneider et al. 2007). Components of vulnerability include exposure to change, sensitivity to change, and capacity to adapt to change (IPCC 2007b). Determining which resources are most vulnerable enables managers to better set priorities for conservation action (Glick et al. 2011 Step 3). Understanding why they are vulnerable provides a basis for developing appropriate conservation responses (Glick et al. 2011 Step 4). Accordingly, we are forecasting change in biodiversity response variables under scenarios of climate and land use change.

The Landscape Conservation Cooperatives (LCCs) in the North Central CSC domain have identified both individual species and vegetation types among their conservation targets. We have chosen a subset of these targets for our initial vulnerability assessments. As a common organizing framework, we have are following the vulnerability assessment strategy from Glick et al. (2011) (Fig. 1), which includes three components of vulnerability: exposure, sensitivity, and adaptive capacity (Fig 2). Exposure is the degree of change in climate and land use, both drivers of change. The Climate Group (see above) will aim to provide "state-of-the-science" for expected changes in climate as well as the uncertainty of those projections and potential ensembles of climate projections to consider. The Impacts Group will evaluate sensitivity as the likelihood of a vegetation type and plant and animal species to change as a function of exposure. Potential impacts will be quantified as projected change, integrating both exposure and sensitivity. The potential impact and adaptive capacity of the vegetation type or species to accommodate changed environmental conditions will be combined to estimate vulnerability. For each level in the assessment framework, we aim to document the level of uncertainty in projected response. The results of our vulnerability assessment will provide input to Research Activity 3 on Adaptation Planning.

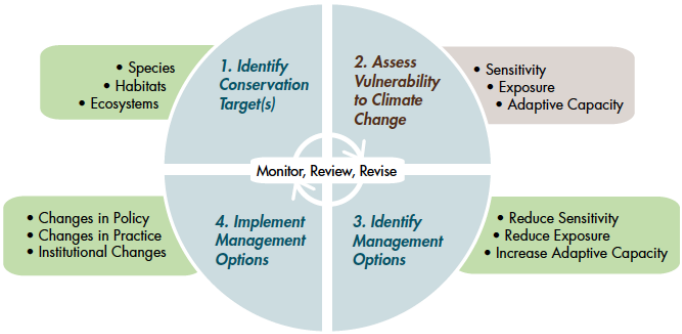


Figure 1 Framework for developing climate change adaptation strategies. From Glick, P., B.A. Stein, and N.A. Edelson (editors). 2011. Scanning the Conservation Horizon: A Guide to Climate Change Vulnerability Assessment. National Wildlife Federation, Washington, D.C..

Goal

Leverage the expertise of the university consortium to develop the capacity within the NCCSC to assess the vulnerability of elements of biodiversity to climate and land use change to inform the development and implementation of management options.

Objectives

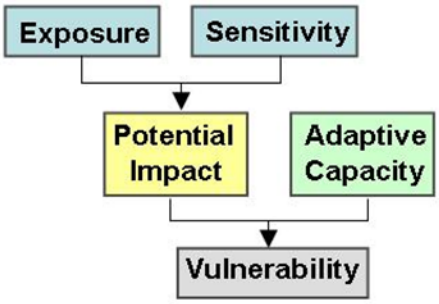


Fig 2. Key components of vulnerability, illustrating the relationship among exposure, sensitivity, and adaptive capacity. From Glick et al. 2011

1. Use the Glick et al. (2011) framework to organize our vulnerability assessment research.

2. Evaluate the utility of a suite of modeling approaches for vulnerability assessment of particular targets in specific locations within the NCCSC.

3. Apply "best" methods to evaluate potential ecological response to future climate and land use change as a basis for assessing vulnerability.

4. Explore the development of a community platform for biodiversity modeling and vulnerability assessment across the NCCSC university consortium through workshops, webinars, and conferences.

Test-bed Ecosystems and Partners

Test beds within the modeling framework include: Inter-montane sagebrush ecosystems, the Greater Yellowstone ecosystems, grassland steppe ecosystems, and prairie pothole ecosystems (Fig 3).

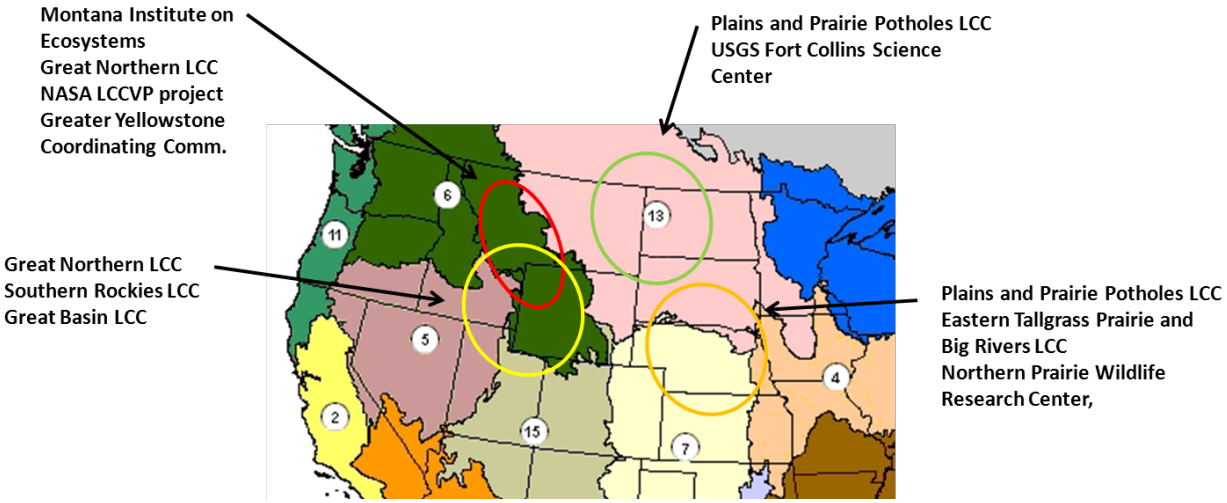
Northern Rockies Ecosystems: Dynamics of up to five key ecological system types (e.g., whitebark pine) under climate and land use scenarios across the GYE. (Hansen)

Sagebrush Ecosystems: Sagebrush and cheatgrass regeneration at leading and trailing edges of the climate change projected sagebrush ecosystem distribution. (Lauenroth)

Tallgrass Prairie and Montane Meadow Grasslands: climate change effects on Iowa tallgrass prairie and GYE montane meadow ecosystems. (Debinski).

Prairie Pothole Ecosystems: Climate-induced changes in prairie pothole ecosystems and consequences for waterbirds. (Noon)

Fig 3. Focal research areas and federal partners.



Science Questions

1. What is the utility of various tools and approaches for modeling vegetation type and species response to climate and land use change?

2. How do interactions among climate and land use uniquely influence vegetation type and species response?

3. How can nonlinearities in response best be modeled and identified?

4. Where are tipping points in climate and land use drivers that lead to a change of state in response variables?

5. How will the spatial distribution of suitable habitats for key vegetation types and species shift across the region under future climate and land use scenarios?

Outcomes

A common protocol and framework for modeling vegetation type and species response to climate and land use change.

- Developed through consortium-wide workshops and served from a NCCSC website.
- Collaboration with Software for Assisted Habitat Modeling (SAHM).
-

A synthesis paper evaluating alternative methods of modeling vegetation type and species response to climate and land use change.

Publication of Test-bed applications.

Training of graduate students and post doctoral researchers in methods of addressing biodiversity under climate and land use change.

Shared data and computing resources (e.g., UW Yellowstone Super Computer).

Provide results of vulnerability assessments to management cooperators for incorporation into climate adaptation strategy planning.

9. Appendix C: Detailed Implementation of the adaptation and mitigation science team

Our efforts during the Fall 2012 through Spring of 2014 are focused on:

1. Identifying successful approaches and frameworks for integrated *social*-ecological vulnerability, adaptive capacity, and adaptation assessment and implementation in order to support regional natural resource management decisions dealing with climate change impacts
2. Analyzing decision making contexts and processes of existing, ongoing research efforts of the NC-CSC and related LCC issues
3. Assessing current social-ecological vulnerabilities and risks from climate change and variability impacts in the north central region

Research activity and focus

Formation of the Adaptation and Decision Making Working Group is on its way. The first conference call of the interested researchers was conducted January 11, 2013. The call participants agreed that there is a need for a working group to be formed of experts in the field of social-ecological systems vulnerability and adaptation approaches to address issues in our North Central region. Goals of this working group will be to build the research capacity in the region and work to evolve a framework or set of frameworks for integrated research and management approaches. This will help to better integrate the social-ecological-climate vulnerability and adaptation assessment activities to deal with climate variability and change in the region.

Goals and Objectives

1. Identifying useful frameworks for analysis of social-eco-climate system vulnerability and adaptation
2. Identifying and engaging experts and key decision makers in the region for vulnerability and adaptation assessment and planning

Elements of the Common Framework

The framework which we will build from includes the following concepts:

1) Incorporating a social-ecological systems (SES) research perspective and utilizing the SES elements to frame the basis of solution and response strategies
2) Defining decision-making processes and adaptive capacities in the north central region within the context of livelihood assets, such as natural, human, social, financial, infrastructure, and technological capitals
3) Utilizing an integrated social and biophysical sciences vulnerability assessment approach, (which can include elements of risk assessment) to evaluate the sensitivity, exposure, and adaptive capacity of the social-ecological systems of interest
4) Incorporation of decision-making approaches used by management entities engaged in the research studies

Next steps

1. We will expand the list of participants of the working group with experts in the region
2. Further develop a shared understanding of social-ecological characteristics of our region and of natural resource management issues being affected by climate change
3. Conduct webinars once or twice a month to share information on approaches, tools, and findings related to social-ecological vulnerability and adaptation studies in our region.
4. Hold a North Central CSC workshop (March 31-April 1) to share and present research approaches to studying social-ecological systems, vulnerability of system components, characterizing adaptive capacity, and planning processes for development and implementation of adaptation options for natural resource managers

5. Convene a working group session at the National Adaptation Forum in Denver April 2-4, 2013.
6. Host an open workshop on "Social-ecological approaches to vulnerability analysis, adaptive capacity characterization, and adaptation planning for natural resource management decision makers"

Expected Outcomes:

- Development of a research agenda for social-ecological vulnerability, adaptation, and mitigation activities in the North Central region
- Review paper or papers for peer-reviewed journal publication on Integrated VA for NRM/Conservation
- Proposal(s) to NSF, NOAA, others to fund large-scale research effort in the region
- Joint research projects

Timeline:

- 11 January 2013 first ADM WG conference call
- End of March/early April convene WG in Fort Collins for preparatory workshop to present at the National Adaptation Forum in Denver April 2-4 (working group session proposal submitted to NAF)
- First draft review paper: June 2013
- Initiate planning for fall open workshop June 2013
- Submit review paper: November 2013
- Development of joint research activities
- Hold open workshop: November 2013
- Workshop report: March 2014

Workgroup leader and participants

This effort will be lead by Dennis Ojima at Colorado State University and will include members of the NCUC and USGS Science Centers in the region. The working group will be supported by Dr. Shannon McNeeley, the post-doctoral fellow hired to work on adaptation research efforts.