Understanding Land Use and Climate Change in the Appalachian Landscape

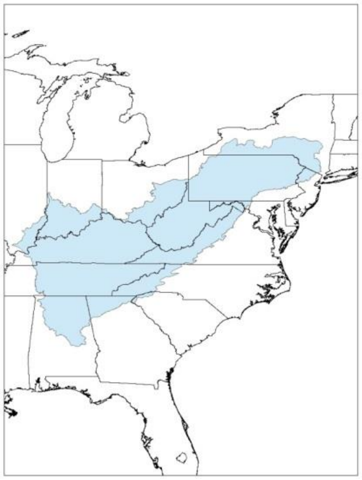
Phase I:

Alternatives for Climate Change Vulnerability Assessment

Report to the Appalachian Landscape Conservation Cooperative

Final Report

2014



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Phase I: Alternatives for Climate Change Vulnerability Assessment

A Report to the Appalachian Landscape Conservation Cooperative

I. Executive Summary

In 2012, the Appalachian LCC tasked NatureServe with a two-phase project that explores the understanding of climate change in the Appalachian landscape. The first phase focused on assembling a panel of experts to provide guidance on a) prioritizing species and habitats to assess for vulnerability to climate change; b) selecting approaches to conduct vulnerability assessments, and c) identifying appropriate climate data to use in the assessments. Using the recommendations of the Panel, Phase II conducts vulnerability analyses on selected species and habitats, and provides results within the context of other existing assessments. This report summarizes Phase I of this effort.

The Appalachian region is rich in biodiversity that is highly threatened by energy production, development and a host of other factors. Climate change will play out within this context, affecting habitats and species in different ways. How, then, should the Appalachian Landscape Conservation Cooperative (Appalachian LCC) acquire information about the vulnerability of Appalachian species and habitats to climate change to share with its partners? How should the LCC advise the greater LCC user community in conducting vulnerability assessments? This report summarizes the findings and recommendations of a seven-member Expert Panel that sought to answer this question, identified as a major research priority for the Appalachian LCC. The Panel addressed three aspects of the question: the selection of species and habitats to assess, approaches to vulnerability assessment, and the availability of downscaled climate data.

Species and habitat selection

The Panel identified six broad categories for selecting species for assessment: conservation significance, impact on the ecosystem, indicator species that can help detect climate change, management importance, relation to public health, and cultural value. Using criteria developed by the Panel, the highest priorities are species that are globally rare or Federally listed, and Appalachian endemics or near endemics. Highest priority

habitats are those that are unique, dominant, and/or important for high conservation value species.

Approaches to Vulnerability Assessment

Numerous reports and publications present alternative methods for assessing climate change vulnerability. The Panel grouped the literature into five broad categories of approaches, including qualitative narrative, index, synthesis /analysis of existing data, spatial modeling, and field and laboratory methods. Considerations about assessment objectives, data availability, time available, and human and economic resources will determine which method would best fit a given circumstance. Assessment methods currently described in the literature are summarized in Appendix 4.

Downscaled Climate Data

Numerous climate data products are available that cover the Appalachian region. Selection of appropriate data sets depends upon the specific vulnerability assessment methods to be used, scale of assessment, and time horizon selected. Uncertainty about climate projections is common to all data products and should be addressed in vulnerability assessments. For most places and time horizons, there is less uncertainty about temperature than there is about precipitation projections. Appendix 4 contains a table that allows comparison among spatial climate data products available for the Appalachian LCC region. Because the IPCC 5th Assessment Report had been released following late drafts of this paper and its inclusion was beyond the scope of this project, we relied on the IPCC Fourth Assessment data.

Recommendations to the LCC

The urgency of threats to biodiversity, the diversity and spatial distribution of unique habitats and species, and the varied constituents of the Appalachian LCC create a challenging context in which to provide specific recommendations for the development of climate change vulnerability assessments. The Expert Panel addresses the immediate need of the current project to assess a limited set of species and habitats in Phase II, and also the larger LCC community, who seek a broader range of options to conduct vulnerability assessments based on their specific goals and circumstances.
Bearing this in mind, the recommended approach for the LCC is as follows:

1. **The first step in all cases is to** determine the appropriate target of the assessment. In some cases, focusing assessment on a habitat can inform, and potentially reduce the need for, assessments of some species.

2. **Use coarse filter methods such as an index approach to assess the vulnerability of priority species and habitats:** those that are globally rare, Federally listed, endemic or limited to the Appalachian LCC region. The Climate Change Vulnerability Index has been used to assess over 600 species in the Appalachian LCC footprint. The advantages of this tool are that it works for all aquatic and terrestrial, plant and animal species occurring in the Appalachian region, and that many species have already been assessed using this method. For these reasons, the Panel recommends the CCVI for assessing species in Phase II of the current project. However, a broader array of coarse filter alternatives can be employed by individuals or groups within the LCC user community as appropriate to their needs. For habitats, an expert solicitation mechanism yielding descriptive narratives, such as that followed by the North Atlantic LCC, would be appropriate as a coarse filter due to the flexibility of the method for systems carrying amounts of ecological information available and the speed at which such analyses could be completed.
3. **Perform more in-depth assessments of the species and habitats flagged as highly vulnerable to climate change in the coarse filter analysis.** For species whose ranges appear to be climate-limited, we suggest the use of bioclimatic modeling to estimate how ranges may shift due to climate change. For habitats, use of expert elicitation to derive descriptive narratives of important habitats occurring where climates have changed most would be a pragmatic starting point. Used in conjunction with the Habitat Climate Change Vulnerability Index, these tools can provide a more comprehensive understanding of the underlying mechanisms, ecological processes, and vulnerable keystone species that may be influenced by climate change.

II. Introduction

Problem addressed

In 2009 the Interior Department established the Appalachian Landscape Conservation Cooperative (Appalachian LCC) to achieve sustainable landscape-level conservation through science and management partnerships. To better appreciate the science and management needs of partners, the LCC convened a Conservation Priorities Workshop in 2011 attended by a group of over 150 researchers and managers. Understanding how land use and climate change will affect valued ecological resources was identified as a top science need at this meeting. In 2012, the Appalachian LCC tasked NatureServe with addressing this need by supporting multi-scale (species and habitat) climate change vulnerability assessments, especially range-restricted and endemic ones to determine their vulnerable to climate change. This report summarizes the first phase of this effort.

Challenges Presented by the Appalachian Landscape

When assessing climate change vulnerability, it is important to understand the context in which the assessment is being conducted. The Appalachian region in particular is characterized by high species richness. The ancient Appalachian Mountain ridge supports habitats ranging from lowland wetland forests to windswept high montane vegetation. The habitat complexity, dispersal barriers, and favorable climates explain why the area is a major biodiversity hotspot in the eastern United States (Stein et al. 2000; Noss 2000), supporting globally important centers for freshwater mussel and salamander diversity, as well as a number of other rare and endemic plant and animal species. The Appalachian LCC region is also facing threats that are particularly challenging, including those activities associated with energy production: mountaintop removal for coal extraction and the accompanying disposal of rubble into vulnerable stream habitats (Environmental Protection Agency 2003), wind turbine placement at high elevations (Kunz et al. 2007, Mabee et al. Rydell et al. 2010), and an alarming amount of hydro-fracturing to extract natural gas deposits (Gillen and Kiviat 2012; Entrekin et al. 2011). This combination of high biodiversity, species rarity, and very damaging threats to the landscape present a conservation challenge of some urgency. Climate change adds yet another layer of complexity to the picture. It is critically important, therefore, to understand how climate change will impact the biodiversity of the LCC.

Objectives

The specific objectives of this report are to provide guidance to the Appalachian LCC and its partners on:

1. Selecting approaches to prioritizing species and habitats to assess for vulnerability to climate change
2. Selecting approaches to carrying out vulnerability assessments
3. Identifying appropriate climate data to use in the assessments

This report first describes the intended audience, the methods used to arrive at the conclusions, and previous efforts at assessing the vulnerability of Appalachian species and their habitats to climate change. The report then explores each of the three objectives in detail, including tables (attached as Excel workbook appendices) comparing methods and climate data products. We conclude by summarizing overarching recommendations to the LCC.

Intended user groups

Two primary user groups are the intended audience for this report. The first is the Appalachian LCC, for whom we will conduct vulnerability assessments of species and habitats during the second phase of this project. The other user group is the larger conservation community and partners of the Appalachian LCC who are in need of guidance in conducting vulnerability assessments for a variety of purposes. This group includes the staff of wildlife agencies, wildlife refuges, land management agencies, conservation organizations, conservation practitioners, and other natural resource managers. They will likely focus their assessments on a range of species and ecosystems, they will use the results in different ways, and will have varying levels of resources to devote to vulnerability assessments. This report provides both sets of users with guidance on how to select vulnerability assessment methods, determine the appropriate climate data to include in analyses, and suggestions on how to prioritize species and habitats for assessments.

Methods used to derive recommendations in this report

In consultation with Appalachian LCC staff, we recruited seven experts from the climate change community that represented a range of expertise on vulnerability assessment methods and climate data. This Expert Panel comprised the following members:

- Kyle Barrett, Clemson University
- John O'Leary, Massachusetts Department of Fish and Wildlife
- Hector Galbraith, National Wildlife Federation
- Patricia Butler, Michigan Technological University, Northern Institute of Applied Climate Science
- Robert Cooper, University of Georgia
- Kim Hall, The Nature Conservancy, Great Lakes
- Healy Hamilton, Marine Conservation Institute

The charge of the Panel was to assess existing methods of conducting vulnerability assessments, identify and compare available climate data, and make recommendations in selecting priority species groups and habitats to assess. All of the Panel members, together with NatureServe scientists, contributed to the drafting of this report.

The Panel met with NatureServe staff by conference call three times prior to attending a meeting held at NatureServe's Home Office in Arlington, Virginia, on 14-15 January, 2013, and then twice subsequently by conference call. During the calls, the following three workgroups were established to address the range of climate topic areas identified by the Appalachian LCC:

1. Assessment and comparison of assessment methods (O'Leary and Barrett)
2. Downscaled climate models (Hamilton and Butler)
3. Criteria for selection of species and habitats to be assessed for vulnerability (Galbraith, Hall, and Cooper)

To aid the Panel, NatureServe compiled published, gray, and website literature initially made accessible to the Panel on a Google Drive web site. As the project progressed, these materials migrated to a Panel workspace created on the Appalachian LCC web site (applcc.org). In addition, NatureServe compiled a spreadsheet of existing vulnerability assessments recently completed on species and habitats occurring within the Appalachian LCC region. The final version is provided in Appendix 1 as an attachment to this report.

Existing efforts to assess climate change vulnerability of species and habitats in the Appalachian LCC region

Many efforts have contributed to our current understanding of the vulnerability of Appalachian species and habitats to climate change. Here we review the studies of which we are aware. Until recently there has been no compilation of climate change initiatives in the region, so some efforts may have escaped our notice. As of this writing, we have identified over 700 species vulnerability assessments using NatureServe's Climate Change Vulnerability Index that have been conducted within five states in the Appalachian LCC[1] [New York (Schlesinger et al. 2011), Pennsylvania (Furedi et al 2011), West Virginia (Byers and Norris 2011), Illinois (Walk et al. 2011), and Virginia (unpublished data)]. Two regional studies include assessments in the Southern Appalachians (Carroll 2011), and in the Cumberland-Piedmont Network of the National Park Service (Bruno et al. 2012). These include 84 plants, 46 mammals, 74 birds, 113 fish, 13 turtles, 47 amphibians, 65 mussels, 11 gastropods, 21 reptiles, 25 lepidoptera, 22 odonates, as well as 103 species of other invertebrates. Of these, 14% had been assessed in more than one state or assessment area. We also identified a climate and species modeling study (Kane et al.) that assessed the vulnerability of 20 species, including 14 trees, 1 bird, 2 fishes, 2 amphibians, 1 reptile, and 1 mollusc. In addition, the predicted Importance Values of 94 tree species in the Central Appalachian portion of the LCC region conducted by Butler et al. (in review) is also included. Appendix 1 lists the species and habitats and the state or region of assessment completed.

The LCC is a large geographic area encompassing a great deal of topographic and climatic diversity. Vulnerability assessments are not generally conducted on areas encompassing such a large area, because species are apt to be affected differentially across the climatic gradient. To address this variation, we divided the Appalachian LCC into three separate ecologically coherent subregions (Figure 1). In the Central Appalachian subregion, species assessments had been completed in Pennsylvania (Furedi et al. 2011), West Virginia (Byers and Norris 2011), Virginia (Virginia Division of Natural Heritage 2010; Kane et al. 2013) and New York (Schlesinger et al. 2011). Over 75% of the land mass of both Pennsylvania and West Virginia lie within the Central Appalachian Subregion. We assumed that results of species assessed in either of these two states could be reasonably extrapolated to the whole of the subregion, so the results of species assessed in either state were considered to be valid for the entire Central Appalachian subregion. New York and Virginia make up a smaller portion of the subregion, so a species not assessed by West Virginia or Pennsylvania was considered valid in that subregion if it was assessed by both Virginia and New York, a situation that occurred only once. We extrapolated results for the other two subregions in a similar manner, to be described more fully in Phase II. We will also use the same assessment subregions in Phase II for species that range across all or much of the Appalachian LCC region.

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[1] States included in the Appalachian LCC either in part or in whole include: Alabama, Georgia, Illinois, Indiana, Kentucky, Maryland, New York, New Jersey, North Carolina, Ohio, Pennsylvania, Virginia, West Virginia, South Carolina, Tennessee

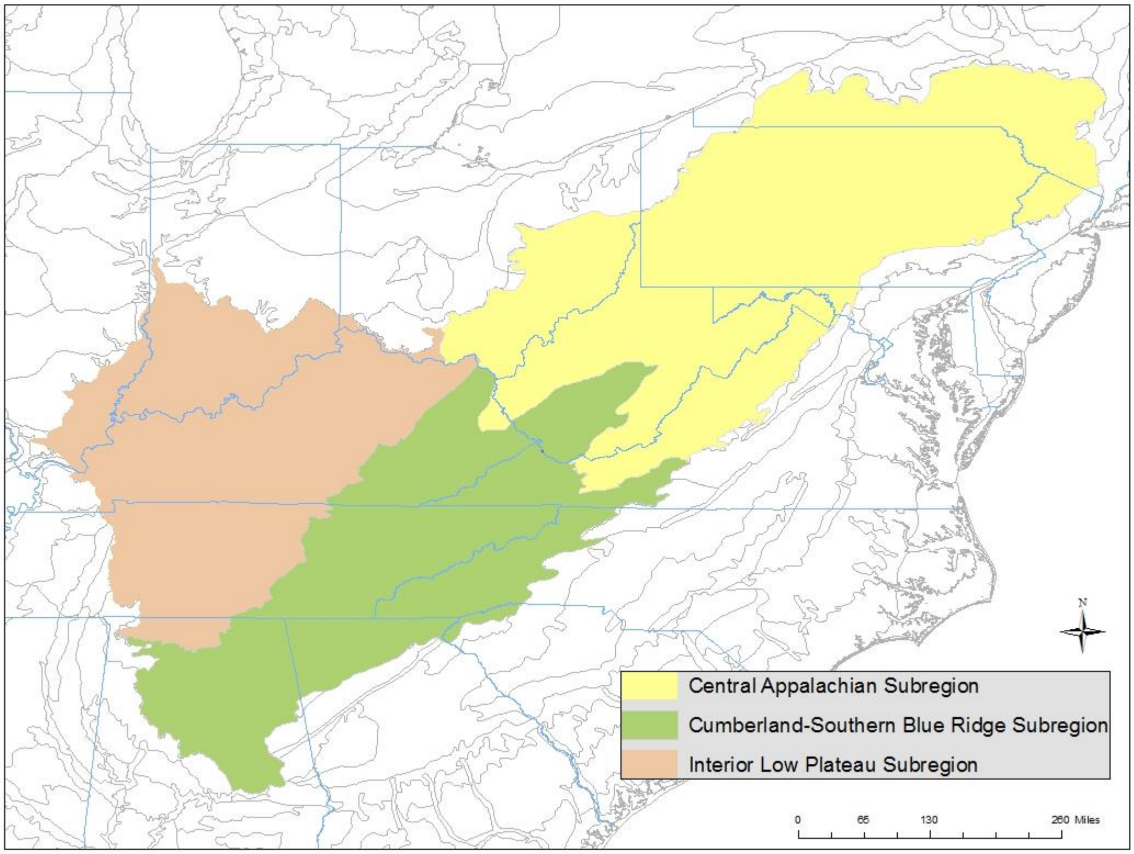

Figure 1 Appalachian LCC Subregions of Assessment

Habitat vulnerability assessments completed in the adjoining southern portion of the North Atlantic LCC extending into the Appalachian LCC include cold water fish habitat (Manomet Center for Conservation Sciences and the National Wildlife Federation 2012a), and five terrestrial habitats: Central and Southern Appalachian Spruce-Fir Forest, Laurentian-Acadian Northern Hardwood Forest, Northern Hardwood Forest, Northeastern Interior Dry-Mesic Oak Forest, and Central Mixed Oak-Pine Forest, (Manomet Center for Conservation Sciences and the National Wildlife Federation 2012b). In addition, a 26 million-acre forest ecosystem vulnerability assessment is nearing completion in portions of Ohio, West Virginia, and Maryland by the Northern Institute of Applied Climate Science (Butler et al., *in review*). In the Cumberland – Southern Blue Ridge subregion, 13 vulnerability assessments were drafted for habitats in the Appalachians of North Carolina by the North Carolina Department of Environment and Natural Resources (NCDENR 2010). We did not attempt to extrapolate the results of the North Carolina assessments to the entire subregion, however, as North Carolina makes up a relatively small land mass of the Appalachian LCC region.

III. Selection of Species and Habitats to Assess

The complexity of biodiversity precludes assessment of all individual species or ecosystems at a landscape scale, yet there remains a great need to conduct meaningful, timely, and cost-effective assessments. The information need is, of course, dictated by the questions to be addressed and, in cases where information on a particular set of species or taxa is required or mandated, the selection of species or habitats to be assessed is usually straight-forward. Decisions about species selections may be driven by a particular management mandate, but even so, achieving that mandate may depend on other species (pests, invasives) that have profound effects on the species assessed. Often, guidance is needed by those who must make decisions about large numbers of species and habitats to assess in a limited time and with limited resources. The results of assessments indicating vulnerability in a set of species or a habitat may reasonably suggest potential vulnerabilities in related taxa or guilds, although one cannot safely assume that species judged to be relatively stable to climate change indicate similar stability in other similar species.

How does one decide what to assess? The following criteria have been identified to assist in this selection process. The species or habitat eventually chosen will depend on the specific goal(s) to be accomplished, the target audience, and the scope and scale of management responsibilities. Different people will prioritize in different ways. Our intention is to encourage broad thinking about the reasons for doing the assessment, to consider the types of changes that may have the most negative impact on biodiversity, and to influence how resources are made available for management. Other factors to be considered in species and habitat selection, but not suitable for prioritizing with the factors listed here, are the state of the knowledge and the ease of sampling.

Species

Table 1 summarizes potential categories to consider in selecting species for assessment.

High conservation significance

Species of high conservation significance include those already categorized by states or by the federal government as being of greatest conservation concern. For example, species listed as Endangered or Threatened under the Endangered Species Act, or listed by states in the region as being of high conservation concern are included under this category, as well as:

- Species with high conservation status ranks, e.g. species ranked G1-G3, or species endemic to the Appalachian LCC region. Their loss from the region also equates to their loss as a whole.
- Other species for which the Appalachian LCC region has a high level of responsibility (i.e., that may be threatened and with a significant portion of their range in the LCC region). We suggest that "high responsibility" are those species for whom 75% of their range falls within the Appalachian LCC boundaries.
- "Leading edge" species with >50% range in LCC, including those with potential to expand into the region
- Species on established lists, such as high priority species in state wildlife action plans, not included in one of the categories above.

Species with high impact on an ecological system or habitat

This group includes foundation or keystone species whose loss would greatly impact a habitat and/or ecological system. Many keystone or foundation species are primarily plants, but also include some animals that substantially alter or even create new habitats. For example, beaver can profoundly alter the hydrology of habitat, changing upland forests to open marshes. White-tailed deer browse can remove substantial cover of understory vegetation, and their preferences for some species over others can change species composition considerably. Where keystone or foundation species are also dominant in a habitat, conducting the species assessment can provide a useful check on, or even replace the need for, a habitat assessment. Taxa within this category include:

- Food sources: e.g., masting tree species that provide abundant seeds in a regular or episodic manner.
- Ecosystem engineers such as beavers, or trees that ameliorate microclimates for understory plants and soil fauna.
- Species that strongly influence the structure or species composition of a habitat, such as white tailed deer, or leaf-eating insects.
- Biomass-based dominant, such as *Sphagnum* species in a bog system, or spruce and fir in high altitude forest.

Table 1 Selection Categories for Climate Change Vulnerability Assessment of Species

CATEGORY	ASSESSMENT FOCUS	EXAMPLES	JUSTIFICATION
High conservation significance	Endemic or of high regional responsibility	Amphibians, reptiles, plants	Loss in region means loss globally
	Remaining Rare/SGCN[2]/T&E[3]	State-listed birds	Loss would cause major national/regional conservation impact
Importance to ecological system	Foundational/Keystone species	Red spruce, salmonids, top predators	Loss would cause disproportionate impact on important habitats
	Important food sources	Oaks, aquatic plants, wetland grasses, fleshy-fruited shrubs	Loss would impact wildlife populations
	Ecosystem engineers	Beaver, white-tailed deer	Loss would cause disproportionate impact on important habitats
Climate change indicators	Species already exhibiting range changes	Red spruce	Serves to heighten public awareness, and to focus immediate attention
	Important Processes (Fire, Hydrologic cycle)	Pitch pine, vernal pool spp.	Disruption of valued habitats
Management importance	Game species	White-tailed deer, game birds	Losses would heighten public awareness
	Pests/Invasives	Wooly adelgid, invasive plants	Increases could lead to significant losses in value of native species and habitats
Public health	Human/livestock Health	Mosquitoes, ticks, other disease vectors	Could lead to significant human and livestock health problems
Cultural Value	Iconic species	Moose, bear, trout	Loss of cultural value for Native Americans and others

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[2] Species of Greatest Conservation Need

[3] Threatened or Endangered status by Federal Endangered Species Act

Indicator species for detecting and tracking the process of climate change

In many cases, changes in species' distributions and population sizes provide us with the best evidence that the effects of a changing climate are already happening in particular areas. Early evidence of change can stimulate support for immediate management action. Potential indicator species are typically abundant enough or easy enough to survey and thus effectively monitored. Taxa in this category include:

- Species for which we have good *a priori* evidence of their vulnerability to climate change: examples may include species with clear sensitivities –narrow or low temperature thresholds, or high drought sensitivity. An additional benefit is that assessment of these species helps us to communicate the impacts of climate change to the general public.
- Species that are indicators of a specific ecological process (e.g., frequent fire, or a particular hydrologic regime) that is influenced by climate change: changes in those species' distributions or abundance may signify a substantial change in the factors that shape a particular system, and may suggest vulnerability of other species that depend on that system.

Management importance

- Game species of fish and wildlife: these are of high importance because of their value to the public, and as a source of revenue (through sale of licenses and other taxes and fees) for management entities. Many management activities, such as habitat acquisition and enhancement for game species also benefit nongame species (and vice versa). Also, a higher proportion of the public knows at least something about one or more common game species. Identifying how climate influences these species provides a good opportunity to educate and build support for updating our management approaches more generally.
- Harmful invasive species – either native to the region south of the LCC, or non-native to North America, have the potential to drastically affect the function and species composition of a system. Some invasive species are similar to keystone species whose presence and activities play significant roles in maintaining a system. Examples include non-native earthworms, kudzu, zebra mussel, gypsy moth, emerald ash borer, and hemlock wooly adelgid. It is a generally positive action to increase connectivity among habitat patches to benefit vulnerable species, but this action can also have a negative effect by providing dispersal corridors advantageous to invasive species.

- Pest species populations and functions affected by climate change: some important pest species that are currently adversely affecting native habitats in the Appalachians are at least partly limited by climate. For example, hemlock wooly adelgid and gypsy moth are limited by low winter temperatures at their northern range limits, and by warm temperatures to the south. It is important that we understand how a changing climate may benefit or harm these pests and impact the habitats where they occur.
- Species that act as key vectors of diseases as well as pathogens can impact wildlife, fisheries, forestry, agriculture and livestock production, or water quality: examples include mosquitoes, whirling disease, chytrid fungus, and potential transfer of diseases between wildlife and livestock.

Relevance to public health: Species that act as key vectors of diseases or pathogens that affect people

Understanding how pathogens or diseases might change as a result of climate change has important implications for management of species and systems (including control actions, which may or may not have impacts on other biodiversity). Information on mosquitoes, ticks, and other species that act as disease vectors, as well as toxic algae, Giardia and others is likely to be of great interest to decision-makers and to the public.

Species of cultural value

Native American tribes value native species such as wild rice, sturgeon, walleye, white-tailed deer and other game species for cultural reasons. Iconic species such as black bear and migratory songbirds, as well as systems such as ancient forests and headwater streams, have broad public appeal. Assessments of vulnerability of these species and habitats can heighten public awareness and generate support for conservation and management.

Habitats

For habitats, we suggest three important selection categories, also summarized in Table 2:

- Unique habitats: e.g., karst habitats, high-elevation balds, cove forests.
- Habitats such as free-flowing streams with high connectivity that are particularly important for species of high conservation value.
- Dominant habitats: a focus on those habitats that cover the largest proportions of the land area can benefit much of the LCC region by understanding effects on a relatively few habitat types. For example, climate change vulnerability assessment of 16 habitats in the North Atlantic LCC applied to approximately 70% of the region's land area (Manomet Center for Conservation Sciences and National Wildlife Federation 2012 (a and b).

Table 2 Selection Categories for Climate Change Vulnerability Assessment of Habitats

CATEGORY	ASSESSMENT FOCUS	EXAMPLES	JUSTIFICATION
Habitats	Endemic / unique habitats	High-elevaiton balds, karst formations, caves	Loss in region means loss globally
	High connectivity	Undammed rivers and streams	Provides dispersal corridors for species moving with climate change
	Dominant habitats	Mesophytic forests	Appalachian forests are among the most diverse in the nation

Ultimately, sustainable populations of species depend on intact habitats. Other factors to consider in the selection of habitats include important species interactions and ecological processes, including:

- Hydrologic regime: The southern Appalachians region is a national hotspot of aquatic biodiversity; the highest concentration of at-risk fish and mussel species in the country occurs in the Appalachian LCC region (Master et al. 1998). Understanding how management actions interact with aquatic vulnerabilities to climate change will improve the effectiveness of actions taken to maintain or improve periodicity, quantity, quality, and connectivity of hydrologic systems.
- Disturbance: Fire regimes and the species they maintain are important to monitor; other important disturbance factors include windthrow and ice damage,

particularly at higher elevations. Erosion and sedimentation may be exacerbated by extreme flooding events and high-intensity fire on slopes.

- Insectivory: Because climate change has the potential to alter phenological patterns for trees, other trophic levels are likely to be affected as well. For example, the tritrophic relationship of deciduous trees, herbivorous insects, and insectivorous birds (especially migratory species) could be disrupted with climate change.
- Pollination: climate change effects on plant species could also affect the insects that pollinate them, and vice versa.
- Migration/species movement: Migratory birds depart their wintering grounds based primarily on photoperiod, rather than on temperature. Thus, the potential exists for a mismatch between nesting chronology and the abundance of their insect food source.

IV. Climate Change Vulnerability Assessment Methods

Introduction

A number of approaches to assessing the climate change vulnerability of biodiversity elements have been developed to aid resource managers (Rowland et al. 2011). Most theoretical frameworks describing climate change vulnerability divide the concept into three components: exposure, sensitivity, and adaptive capacity (Williams et al. 2008), and therefore vulnerability assessment methodologies tend to require input data on these same components.

Exposure

Most assessments use information on projected changes in temperature and precipitation from a baseline measure. Additional weather variables (e.g., cloud cover, evapotranspiration, weather extremes, wind, and fog) can also provide information important in regulation, abundance, and distribution of a species or habitat, but are more challenging to acquire and process. Many derived variables, such as changes in the probability of precipitation occurring as snow or rain, can be calculated from projected changes in temperature and precipitation variables. Availability of exposure data for this region is covered more fully in the Spatial Climate Data section, below.

Sensitivity

Information on the sensitivity of the species or habitats to be assessed is gathered from many sources depending on the assessment methodology, and includes what is known about life history and tolerance to projected changes in climate. Information about the species' or habitat's sensitivity to existing climate conditions (e.g., drought tolerance, cold adaptation) provides a baseline from which to measure responses to projected changes in climate. Much of the difference among assessment methodologies lies in the type of sensitivity data required and how it is analyzed.

Adaptive Capacity

Species have two intrinsic means of exhibiting adaptive capacity, or the ability to cope with climate change. Their ability to alter their development, physiology, behavior, reproduction, and other life history characteristics in response to changing environmental conditions is known as phenotypic plasticity. Second, their genetic diversity defines the limits by which they can evolve over time to adapt to changing climatic conditions. Defining a species' intrinsic adaptive capacity, and threshold limits of environmental change, can be difficult, but the capability of altering phenology, dispersing, or specializing in specific niches can be used as a proxy for adaptive capacity

(Miller-Rushing and Primack 2008). Foden et al. (2013) provide additional guidance on identifying individual traits that confer adaptive capacity. Some assessment schemes also include the concept of extrinsic adaptive capacity, variously defined as how the environment influences adaption such as through nearby climate refugia (Hall 2012) or readiness by which species respond to management interventions.

Many methodologies for assessing species or habitat vulnerability to projected changes in climate include anthropogenic, non-climate impacts and stressors (e.g., habitat fragmentation, fire suppression) that are already occurring. In these cases, vulnerability is a combination of all of the factors, climate and non-climate, weighing on the species. Other methods isolate vulnerability to climate change to highlight the role of climate in the conservation status of a species and habitats. Selecting an approach will depend on the intended uses of the vulnerability assessment results, and it is important to be cognizant of whether the study assesses impacts of climate change independently of other threats.

All assessment methods have strengths and weaknesses, and it is our judgment that most published methods are neither wholely correct nor incorrect. Rather, it is important to understand how these methods are best applied, and under what circumstances they should be avoided or used in combination with other methods. We reviewed the literature on existing climate change vulnerability assessments and grouped them according to five categories of methods used:

1) **Qualitative narrative:** The quickest and least expensive approach is to develop a qualitative narrative regarding the species and habitat response to climate change. Such narratives can serve to address the three components of a CCVA (sensitivity, exposure, and adaptive capacity) by literature review, expert opinion, and a qualitative overlay of downscaled climate data. Aitken et al. (2008) took this approach when they surveyed tree response to climate change. Their survey was global in scope; however, they were able to compile critical information regarding which natural history traits may make some groups of trees more vulnerable than others under various climate change scenarios. Specifically, Aitken et al. (2008) examined existing species distribution models for trees, then evaluated those distribution model forecasts in light of phenotypic variation, fecundity, interspecific interaction, gene flow, and a number of other factors. They concluded that widespread species with high fecundity are likely to fare better under climate change than will species with small populations, fragmented ranges or low

fecundity. Such information, synthesized from a variety of pre-existing sources, offers specific and immediate context for long-term management.

2) **Index:** In cases where multiple species/habitats are being assessed, or if users desire an approach for which the parameters have already been developed, an index-based approach may be advisable. A typical CCVA index provides users with a series of questions that address the range of issues associated with climate change vulnerability and then output (1) key factors of vulnerability along with (2) a qualitative score of relative vulnerability which can be helpful when developing prioritization schemes. NatureServe has developed a Climate Change Vulnerability Index that has been widely employed by many state agencies for species-based assessments (http://www.natureserve.org/prodServices/climatechange/ccvi.jsp), and a habitat-based index was recently developed for the northeastern United States (Manomet Center for Conservation Sciences and National Wildlife Federation 2012). Another example of an index approach is that of Bagne et al. (2011), who developed a web-based System for Assessing Vulnerability of Species (SAVS) to Climate Change (http://www.fs.fed.us/rm/grassland-shrubland-desert/products/species-vulnerability/). A Climate Change Vulnerability Index for habitats (HCCVI) was also recently developed by NatureServe and piloted in the Mojave and Sonoran Deserts (Comer 2012).
3) **Synthesis/analysis of existing data:** In some cases, users will be interested in assessing species and habitats for which there are an abundance of historical data available. In these cases, particularly when historical weather and/or climate data are also available for the area of interest, the CCVA may take the form of a synthesis or analysis of existing data on species and habitat response to weather variability. These types of approaches make the implicit assumption that historical resiliency to variability in exposure is likely to predict future resiliency to similar changes. Enquist and Gori (2008), who assessed species and habitats of New Mexico, found this approach to be useful toward addressing end-user concerns about the uncertainty associated with future climate model projections. In cases where resources and/or technical expertise are readily available, such syntheses can take on the form of sophisticated physiological models that have been constructed from known distribution patterns and/or physiological relationships (Bernardo et al. 2007, Walls 2009)
4) **Spatial modeling:** For range-limited and / or rare species or habitats, and the distribution is believed to be influenced by climate, then an approach based on spatial modeling can be employed. This category includes a wide range of techniques that fall under the heading of niche model, bioclimatic model, climate envelope model, or species distribution model. The field of spatial modeling is

developing rapidly and there are many resources available to those wishing to employ these methods (Elith et al. 2006, Morin & Thuiller 2009). Some techniques can now be implemented quite easily, although it is usually best to avoid these tools unless there is sufficient expertise available to understand model assumptions and interpret model results. A modeling approach is best used in combination with other methods that account for adaptive capacity, interspecifc competition, and other life history characteristics.

5) **Field and laboratory approaches:** When embarking on a long-term CCVA, or when specific vulnerability mechanisms need to be identified and understood, field or lab-based experimentation or modeling may be appropriate. Such empirical studies have been employed as a way to understand both general patterns of vulnerability across taxa (Parmesan & Yohe 2003, Parmesan 2006) and specific responses of key species or processes to climate change (Garten et al. 2009, Lowe 2011).

Appendix 4 (accompanying this report) contains a summary of the methodological review, including the attributes of vulnerability assessments (such as how they handle uncertainty in climate change projections, operational costs, time frame considered) and how the various assessments address each of these attributes. This depiction allows easy comparisons and contrasts among the many techniques available. Appendix 3 provides examples of a decision support tool that can help the LCC community determine appropriate approaches to climate change vulnerability assessment given specific objectives and constraints.

V. Spatial Climate Data for Vulnerability Assessments

Climate change vulnerability assessments generally require spatially explicit information about possible future climate parameters. The most widely used sources of projected future climate data are Global Circulation Models (GCMs), which attempt to simulate physical processes controlling the flow of energy through the atmosphere, land, and ocean. Almost two dozen GCMs were vetted for the last assessment report of the Intergovernmental Panel on Climate Change (IPCC, 2007)[4], many of which were run under different scenarios of future greenhouse gas emissions (IPCC 2000). The result is a wide array of climate model outputs that can be selected and applied to natural resource management questions.

Climate models are essential tools for exploring future climate parameters, based on our understanding of global environmental processes. Because they are trying to reproduce the basic physical processes of Earth's energy system, the spatial resolution of GCM grid cells is on the order of 2-3 degrees latitude/longitude. This scale is very coarse relative to both the scale at which components of the biosphere respond to climate, and the scale at which management and conservation decisions are implemented. Downscaling seeks to bridge these scales by interpolating GCM outputs to generate finer resolution climate data, usually accomplished by mapping coarse-scale model output to a finer resolution set of baseline observations. Downscaled climate data allows a natural resource manager to understand projected regional impacts that often are not represented in a global model (Swanston et al. 2011). Downscaling can be performed using various methods, each of which has advantages and disadvantages, a unique set of assumptions and caveats, and sources of uncertainty. This section describes the parameter categories of several downscaled climate datasets in an attempt to familiarize the user with the important decisions to make when selecting a data set. More detailed information on climate change science and application can be found in recent literature (Daniels et al. 2012, IPCC 2007).

The most widely available downscaled climate variables used in assessing species and habitat vulnerability are monthly mean, maximum, and minimum temperature, and monthly total precipitation. Derived hydrologic and bioclimatic variables, such as stream flow, snowfall, humidity, evapotranspiration, and soil moisture may be even more valuable in describing the relationship between species and climate, but are often only available for the current time period. Increasingly, downscaled datasets are becoming

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[4] As of this writing, the IPCC 5th Assessment Report had been recently released, its discussion here is beyond the scope of our project. See http://www.climatechange2013.org/report/ for additonal information

available that offer a range of bioclimatic variable projections derived from suites of GCMs (Wang et al 2012, Abatzaglou et al 2012).

Downscaled climate data can be either directly analyzed, or included as inputs into ecological models that assess climate change impacts to specific species or ecological processes, such as growth and reproduction, distribution, habitat connectivity, and fire behavior. A range of modeling approaches are available, such as exploring shifts in the distributions of species or vegetation assemblages, changes in phenology (the timing of biological events, such as leaf out dates), and other interactions of species, climate, and habitat. These models come with assumptions and caveats that increase with added layers of complexity. Interpreting the results of impact models can be strengthened by expert judgement, consideration of unique local conditions, monitoring, and other lines of evidence that point to similar conclusions in the absence of contradictory evidence.

Uncertainty in Future Climate Projections

The many sources of uncertainty in assessments of climate change impacts to biodiversity can be a major obstacle to management action. As with any modeling effort, however, uncertainties are an inherent part of the process. Action paralysis can be overcome by parsing uncertainty at different levels of the modeling process, and using robust approaches that explore as many alternative scenarios as time, resources, and data can support.

In climate projections, there are three main sources of uncertainty (Hawkins and Sutton 2009). The climate system itself is highly variable in time and space, and natural fluctuations occur in the absence of anthropogenic climate forcings. These fluctuations are important because they can obscure or compound longer-term trends that are associated with human-induced climate change. The second main source of uncertainty is from the climate models themselves. Climate models have been calibrated based on relationships between models and actual observed values during the second half of the 20th century, but it is unknown how accurately those relationships hold true under future change, and there is no calculated margin of error that can be associated with the future models. The third source of uncertainty is based on the unknown rate and magnitude of future greenhouse gas emissions. The IPCC has attempted to explore a range of well defined, plausible scenarios that allow users of climate model outputs to systematically explore the effect of future emissions over time.

Uncertainty is expected in climate models; they are representations of complex global processes, but they are still valuable sources of information about future environmental conditions. Two approaches are usually available for evaluating uncertainty from climate models. Users can evaluate outputs from an ensemble of climate models, where a suite of models run under similar parameters (e.g. the same emissions scenario) are averaged together, and the deviations across models are quantified to allow assessment of the degree of model agreement for a given parameter. The climate modeling community has embraced the ensemble modeling approach as a means to evaluate the influence of alternative global climate models on the outcome of impacts assessment. Alternatively, and somewhat more simplistically, users can choose to bracket future conditions. By using one model that predicts a high climate response to environmental forcings, and another that has a lower response, the range of values for future conditions can be projected, with the recognition that reality will likely fall somewhere in between. Climate data used for ecological impacts assessments should be used not to identify what the future *will* hold, but rather what the future *could* hold.

Downscaled climate data are an important input in many vulnerability assessment methods. There are many possible combinations of existing downscaled climate models, emissions scenarios, timeframes, and second-order variables currently available. To the average reader, understanding what parameters are important and how to choose them is an overwhelming task in itself. This section summarizes the common parameters of downscaled climate datasets, weighs the pros and cons of choosing specific parameter values, and provides a context for making decisions. Appendix 4, accompanying this report, contains a spreadsheet of downscaled climate datasets currently available for the Appalachian LCC region, as well as their general parameters.

Guidance on interpreting Appendix 4, Downscaled climate data available for the Appalachian region

The following sections refer to headings of the same name in Appendix 4

Spatial extent

Spatial extent may be defined by ecological or political boundaries, or a mix of natural and administrative boundaries (e.g. watersheds, properties, resource areas, refuges within an LCC). Depending on where the study area is located, some datasets may be comprised of several tiles. Larger study areas (e.g., multi-state regions) may require stitching together several tiles. Small study areas (e.g., a state or national forest) pose challenges to find sufficient resolution of downscaled climate data to capture local climate effects (e.g., 4km grid scale). The spatial extent of the study area may help determine the resolution of the dataset (see *Spatial resolution*). Many available climate datasets exist for the spatial extent of the Appalachian LCC, or for portions (e.g., Klopfer et al. 2012).

Spatial resolution

Spatial resolution depends on both the spatial extent of the study area and the objective of the assessment. The finest resolution available is not necessarily the best resolution because downscaling requires more interpolation of missing values. The fine resolution of some downscaled data can create a false sense of accuracy across a broader scale and may tempt users to read interpolated values on a pixel by pixel basis. Regional trends can often be observed through coarser resolution and are truer to the original dataset, simply because it has been interpolated or manipulated less. The spatial resolution of biological data or impact/process models also influences choices of downscaled climate data. The resolution of all models should be consistent and limited by lowest resolution model used in a suite of models.

For the relatively large area the Appalachia LCC comprises, there are a wide range of spatial climate datasets available, from 800m current PRISM data to 15km dynamically downscaled future projections, that would be informative to use in a climate change vulnerability analysis. Over such a large area, broad patterns of change should be visible even with relatively coarse data. With the strong influence of topography on generating microclimates in the Appalachian region, fine spatial scale data would be highly valuable.

Variables

The vast majority of available downscaled data products offer monthly maximum temperature, monthly minimum temperature, and monthly total precipitation at multiple spatial scales (Tabor and Williams, 2010; Maurer et al 2009). Several other sophisticated data sets offer daily data (e.g., Stoner et al. 2012). Choosing daily or monthly data depends on which variables must be calculated to describe important changes in an ecosystem. Monthly data can suffice to describe monthly, seasonal, or annual trends in minimum and maximum temperature or total precipitation. Daily data, packaged in a much larger dataset, can be queried to examine a host of climate variables important to ecological assessment, including changes in snow fall, solar radiation, vapor pressure deficit, the length of dry periods, the variability in hot or cold spells, or the frequency of frost events. Examining climate extremes (e.g., days over 90°F, or days with precipitation >3 inches) will also require daily data. Increasingly, new downscaled spatial climate datasets are providing summary layers of bioclimatically important variables (Hostetler et al 2012, Wang et al 2012). Some variables may be readily calculated simply using threshold values, whereas others may require manipulation of the data by the modeling group. In choosing a dataset, these needs should be explicitly stated even if the data are not available, so that “demand” can be established. Identification and communication of what climate variables are needed in order to address a biological response will both drive the decision of what dataset to use, but can also inform the funding of new projects to create those variables.

Downscaling method

There are two main categories of downscaling methods: dynamical downscaling and statistical downscaling. Dynamic downscaling uses high-resolution climate models within a GCM that allow for feedback between regional and global processes. Dynamic downscaling is computationally intensive, often relying on multiple statistical and dynamic methods, but can operate without long-term observations. This approach produces a large suite of ecologically relevant variables, such as extreme temperature and precipitation, wind, radiation, and snow, usually at moderate spatial resolution (Hostetler et al 2012). Statistical downscaling uses high-quality, long term historical data from local weather stations to calibrate and evaluate a model based on statistical relationships between observed values and GCM output. Statistical models are influenced by available observations and the scale of the observation network. While statistically downscaled climate data is often limited to monthly, seasonal and annual temperature and precipitation variables, it is usually finer spatial resolution than dynamically downscaled approaches.

Practically speaking, choice of spatial climate dataset is usually driven by available variables, time slices, or spatial resolution, not the downscaling method used. An exception would be if the assessment required special variables, such as humidity, soil moisture, or wind speed, that are usually produced by dynamical downscaling approaches.

Downscaling resolution

All downscaling efforts require some baseline representation of climate to which GCM outputs are downscaled. Baseline climatologies are derived from weather station data, which may have gaps or other inconsistencies. The spatial resolution of the baseline data usually determines the resolution of the final product. Baseline data sets are in gridded format, produced by interpolation from observations such as weather stations or SNOTEL sites (SNOwpack TELemetry). Gridded data sets are usually averaged over time to fill in missing data for various time periods and geographic areas. Often the choice of baseline product will be driven by the geographic scope of the question, whether it is local or global, and the spatial resolution of the analysis. The most widely used product for climate model downscaling efforts aimed at ecological and resource management use is WorldClim, because of its fine spatial resolution and global coverage (Hijmans et al. 2005).

Baseline time period

Baseline data sets are derived from climatologies, which are many years of climate observation averaged together to represent a defined timespan. For example, WorldClim is a climatology averaged over 50 years, from 1950-1999. Another widely used climatology is PRISM, averaged from 1971-2000 (Daly et al 2002). Downscaled climate data includes a 20th century baseline climatology that characterizes baseline conditions, from which it calculates changes. Detailed analyses of 20th century climate observations suggest a global signal of anthropogenic climate change emerging in the 1980s (Hansen 2012). Therefore many existing downscaled climate data products already incorporate some climate change in their "climate baseline". Since much natural resource management uses climate data to calculate change factors from the 1990's, we may be underestimating the changes in conditions conservation elements are encountering. A baseline of 1950-1980 has been analyzed to 1/2° for the terrestrial surface of the Earth (UK's Climate Research Unit) V3.0 (New 1999, 2002) for a data set covering 1901-2009. Although these data have been used widely, they are quite coarse a scale for most land management purposes. Climate Wizard offers a 1961-1990 baseline for a suite of essential climate and ecological variables at 4km spatial resolution (Girvetz et al 2010). This is excellent resolution for the size of the Appalachian LCC, clearly revealing the interaction of topography and climate.

Number of emissions scenarios

Future greenhouse gas concentrations will continue to be influenced by the burning of fossil fuels in industrial nations around the world, deforestation, inter-governmental policies, mitigation activities, and other social influences. All global climate models are parameterized by a set of greenhouse gas concentrations, and different GCMs exhibit variable rates of warming in response to greenhouse gas behavior. The IPCC developed a set of standardized emissions scenarios that have been widely used by climate modelers (IPCC 2007).

Six different emissions scenarios are commonly used in impact assessments and reports such as the IPCC Fourth Assessment Report: B1, A1T, B2, A1B, A2, and A1FI (IPCC 2007). The A1FI scenario projects the highest greenhouse gas concentrations, while the B1 scenario projects the lowest increase in greenhouse gas emissions. Depending on resources available, emission scenarios may be used to bracket a range of projected greenhouse gas concentrations may be used singularly (i.e., BLM Rapid Ecoregional Assessments, Comer et al 2012), or in ensemble averages of model and scenario combinations.

For the IPCC's 5th Assessment Report of 2013, a new suite of emissions projections were developed (van Vuuren et al 2011). All 5th assessment GCMs have been parameterized by a standardized set of representative concentration pathways (RCP's), defined by the amount of radiative forcing exerted in W/m² in the year 2100. These new GCM outputs will offer modeled futures that more closely track contemporary 'business as usual' emissions rates, which generally are exceeding the highest scenario from previous assessments. In the near future, new sets of downscaled data derived from 5th Assessment Report model runs will be available. For the present, the A1b or the A2 emissions scenarios are generally used the most frequently in ecological impacts assessments, and both of these scenario families have analogues in the upcoming RCP products.

Number of GCMs

There has been much debate in the global climate community about determining the "best" climate model, but analysis of these models has concluded that there is no one best climate model. When considering possible future climate conditions, there are three common approaches: ensemble, bookend, and screening. The ensemble approach usually creates an average and standard deviation across a larger number of climate model outputs, which offers both the value for the variables of interest and the degree of agreement among a suite of models. The bookend approach uses a model with relatively low sensitivity to emissions in combination with a model that is more sensitive to emissions to create two ends of a range of projected climate change. Screening approaches look at all possible models to identify some number of the best performing models. Performance is generally evaluated by historical reanalysis, assessing the model's outputs from 1950-2000 to evaluate model capacity to reproduce observed historical climate patterns. This process generally identifies multiple models (i.e. there is no single best), which can be averaged into an ensemble. The ensemble average and associated statistics of screened, well-performing models is a highly robust choice for ecological impacts analysis, if such data are available (i.e., Scenarios Alaska Planning). GCM screening for performance reproducing climate of North America is currently underway for 5th Assessment Report models (Maloney et al in press). Most climate models broadly agree in their range of projections for future temperature, but there is more variability (i.e. disagreement) among model projections for precipitation. Not all models have been run for all emissions scenarios, so if the consideration of emission scenario is important, you will be limited to the models that run the scenario of interest (e.g., only 16 models have been run using the A2 and B1 scenarios). The ensemble average of the 16 models vetted for the 4th assessment report that were run for A2, A1b, and B1 are available at 1/8 degree grid (about 12km grid cells) from Climate Wizard (Girvetz et al 2010)

Future time slices and future time slice intervals

Most downscaled climate models offer 30-year climate projection time slices (Girvetz et al 2010, Tabor and Williams 2010, Wang et al 2012), a near term, mid century, and end century roughly divided as 2010-2040, 2040-2070, and 2070-2100. With time slice averages of less than 20 years, the influence of decadal cycles such as El Niño and La Niña can be confounded with climate change signals. The more distant the time slice, the less agreement is found among models, reflecting variability in model responses, and the many sources of uncertainty about future conditions. Importantly, if current climate trends have been characterized, they can be compared to near term projections to identify concordance between observations and model projections.

Format of raw data or online portal

Downscaled climate datasets are delivered in three main formats: netCDF, GRIB, and HDF. All of these formats are portable and interface with popular geospatial software (e.g., ArcMap). NetCDF files are the most friendly format available to the common user, and can be converted to ascii and text files. Most online portals (e.g., Climate Wizard) will deliver files as text or NetCDF for importation, but larger data requests may require the physical transportation of data on hard drives, due to the limited processing ability of most online servers. Data imported into ArcMap can be displayed in a wide array of color schemes and other options, but data queried directly from an online site may not be in a format that is editable. Examples of climate data portals are the Template for Assessing Climate Change Impacts and Management Options (TACCIMO), the Wisconsin Initiative on Climate Change Impacts (WICCI), and *ClimateWizard.*

Spatial climate data for climate change vulnerability assessments

Performing a climate change vulnerability assessment involves decisions not only about the types of analyses to be conducted, but also the climate model data to be applied. Practically, the choice of climate data will be restricted to available datasets because it is beyond the capacity of most agencies to create region-specific downscaled climate data for impacts assessment.

Mapping the differences (also known as deltas) between a 30-year baseline and a future 30-year time slice for a basic set of variables offers an accessible, first order evaluation of the spatial pattern and nature of climate change that can inform vulnerability assessments. The delta calculations could be calculated either from a bookend of two downscaled GCMs or an ensemble average, run under both the A1B and A2 emissions scenarios, to illustrate the limits of uncertainty in the data. Winter minimum temperatures, summer maximum temperatures, and annual precipitation are simple variables that collectively describe important climate determinants for regional patterns of biodiversity. Climate Wizard offers the ability to compare a 16-GCM ensemble average for temperature and precipitation between a 20th century baseline and either a midcentury or end century time slice for either of those emissions scenarios. Although at

12km the spatial resolution of Climate Wizard projections is somewhat coarse, patterns in the magnitude and distribution of projected changes will be evident across the Appalachian LCC.

Time series spatial climate data for the present and future can be analyzed for trend detection in ways that support ecological forecasts and climate vulnerability assessment for the Appalachian LCC extent. For example, creating a spatial database of the range of values for monthly or seasonal climate variables for the historic, the current, and at least 2 or 3 future time slices derived from an ensemble of downscaled GCMs would offer a solid foundation for understanding basic climate impacts. When available, ecologically relevant, derived variables such as evapotranspiration and moisture deficit can capture the relationship between climate and drivers of biodiversity. Such forecasts can inform monitoring and communication strategies. There is a wealth of data, tools, and collaborative partnerships that can help the Appalachian LCC acquire the appropriate spatial climate data products to achieve its mission of supporting applied science underpinning the protection of biological diversity in the region.

VI. Recommendations

With numerous climate change vulnerability assessment methods available, countless species and habitats upon which to apply these methods, and rapidly evolving data on climate projections, choosing among the many options can seem to be a daunting task. The explanations in this report, together with the appendices, are intended to provide a useful aid when navigating among these choices. Here we list some overarching guidelines that emerged from the Expert Panel discussion.

Identifying the focus for the CCVA and why a CCVA is needed are critical first steps.

Once the focus is selected, the range of possible approaches to vulnerability assessment narrows. Species and habitat identification can also help determine whether downscaled climate data are necessary. If they are, then a review of the ecology and biology of the species and habitat should help inform the necessary spatial and temporal resolution of the downscaled data. It is important to note that conducting a vulnerability assessment may not necessarily be the most appropriate action. Depending on the questions the LCC and its partners want to address, there may be other alternative actions needed.

There are a number of CCVA tools and approaches available, and in many cases more than one tool would be appropriate.

Often a top-level management or conservation goal includes a mix of focal species and habitats. After identifying the focus, select the CCVA tools that work best for each species and habitat to support efforts to meet the overall goal.

No single CCVA approach will be sufficient for all partners in the Appalachian LCC.

The geographical extent of the LCC and the number of partner organizations (and their differing objectives) is such that multiple approaches will be needed to serve varying information needs. One strategy to efficiently cover these needs would be to follow three synergistic methods (not all of which are feasible for the second phase of this project):

a) Develop narratives using a combination of expert solicitation methods and and index approach for priority aquatic and terrestrial habitat types. Assessing habitats on a regional scale will provide information on a wide variety of species' habitats, albeit at a broad scale, and provide input to species-based indices.

b) Apply an index-type approach for priority species as a coarse filter to efficiently assess a large number of species and therefore benefit a many species-based conservation efforts.

c) For the most vulnerable species (determined by index results), perform spatially-explicit modeling to inform long-term monitoring and management. A wide range of data and tools are available to pursue in-depth vulnerability assessments and ecological forecasts. Similarly, use in-depth methods to assess the most vulnerable species assemblages and/or habitats.

d) Use available observation data on past and current climate across the Appalachian region to identify the nature of change that is already occurring and where climate stress is highest. Departures from historical temperature and precipitation regimes can be identified at fine spatial resolution using existing time series datasets, such as the PRISM 800m climate grids for 1895-present.

Specific Methodological Recommendations for Phase II

Species

The recommended method for Phase II of this project is the NatureServe CCVI. Weighing heavily in this recommendation is the ease of use and widespread application of the CCVI already to over 600 species to date. Performing more assessments with the same method will allow for valid comparisons among studies, and will serve to add to a consistent, growing body of climate change vulnerability information available for the Appalachian region. The strengths of the CCVI are:

- A user guide is available with step-by-step instructions, including which climate scenarios to use and where to get the data.
- The exposure calculation considers available moisture rather than simple changes in precipitation.
- The climate data represents an ensemble average across 16 GCMs vetted for the IPCC 4th assessment report.
- The geographic scale of assessment is flexible and need not cover the entire range of the species.
- The method has been peer reviewed (Young et al. 2012).
- The scoring system accounts for numerous sensitivity and adaptive capacity factors.
- Scores are easily updated as new information becomes available.

- The method is the most widely used among U.S. state wildlife agencies (according to a survey by A. Choudhury described at the National Adaptation Forum, Denver, April 2013).
- Provides a way to document the decisions made in assigning subscores, thus encouraging transparency.

The weaknesses of the CCVI are:

- It does not work for marine species (not a concern for the Appalachian LCC).
- It currently does not consider vulnerability across the annual cycle of migratory species such as birds.
- The tool does not provide guidance for species selection.
- The CCVI does not necessarily address climate-induced pests that can cause secondary declines, such as the wooly adelgid impacts on eastern hemlock (*Tsuga canadensis)*.
- The background calculations for weighting are not readily transparent (they are explained only in the Young et al. 2012 paper).
- Caution should be taken in interpreting results. The CCVI focuses on climate change and does not integrate other conservation status factors, because the results were intended to be used in concert with NatureServe G- and S- (conservation status) ranks.
- Assigning subscores can be somewhat subjective, although documentation of reasons behind subscore assignments can provide a transparent means to challenge or support those assignments.

Although beyond the scope of the current project, spatial bioclimatic modeling might be an appropriate next step to further understand, in a spatial context, the vulnerabilities of species that score as highly or extremely vulnerable using the CCVI. In addition to indicating where a species' climatic envelope might shift to in the future, modeling also has the advantages of considering many more climatic variables and weighing more heavily those that appear to drive distributions; having straightforward, repeatable methods (such as MaxEnt or Random Forest algorithms); and providing visually appealing results interpretable by wide audiences. Due to the variability in precipitation projections across GCMs, models should be run using climate data that span the range of values to show the range of possibilities of climate envelope shifts. Disadvantages of spatial bioclimatic models are that running the models requires some level of technical expertise, they focus on exposure and not on sensitivity or adaptive capacity of species, they are correlative and ignore species interactions as determinants of range extents, and the results can be misinterpreted to indicate where ranges will shift rather than where bioclimates might shift. Overall, though, spatial modeling results provide a useful complement to the CCVI vulnerability factor outcomes.

Habitats

Use of expert elicitation to derive descriptive narratives of important habitats occurring where climates have changed most would be a pragmatic starting point in habitat vulnerability assessments. Habitats result from complex interactions among species, disturbances, geochemical processes, and climate. Narratives can focus on the dominant forces acting in habitats to describe vulnerabilities in a manner that broad audiences can comprehend. The method has been tested and refined in assessments for the State of Massachusetts and the Northern Atlantic LCC (Manomet Center for Conservation Sciences and National Wildlife Federation 2012a and b). Carrying out assessments can proceed relatively quickly depending on the availability of both ecologists, to write draft assessments, and experts, to convene at a workshop. Disadvantages are that specific approaches taken by different groups carrying out the method can vary (and therefore the method might not be particularly replicable), individual experts can dominate discussions at workshops and lead to 'groupthink', and that certain aspects of the assessments may not be particularly quantitative. Nevertheless, narratives derived via this method can be broadly useful to a wide audience within the Appalachian LCC.

For a more detailed understanding of highly vulnerable habitats, the Habitat Climate Change Vulnerability Index (HCCVI) is a good alternative (Comer et al. 2012). Despite nomenclatural similarity to the coarse filter CCVI method, the HCCVI is in fact a more in-depth approach. The method combines information about projected climate change, shift in the bioclimatic envelope of the habitat, alterations to dynamic processes that shape the habitat, the effects of landscape condition, the action of invasive species, species diversity within plant and animal functional groups, the vulnerability of specific keystone species, bioclimatic variability, and elevational range to generate a vulnerability score. Due to the comprehensiveness of the data feeding into a HCCVI score, the resulting information is particularly useful for understanding the causes of vulnerability and as a precursor for adaptation planning. A potential shortcoming is the large amount of data required, although any in-depth method will be data intensive. Also, some of the data inputs are readily available as part of national data layers. The method has so far been applied in the Greater Yellowstone region, and is being considered for additional assessment in California. Additional testing will allow for refinement of scoring. The comprehensiveness of the approach will nonetheless provide a detailed understanding of the vulnerabilities of important Appalachian habitats to climate change.

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VIII. Appendices

(Appendices 1,2, and 4 in separate Excel tables)

Appendix 3: A decision support tool for climate change vulnerability assessments

The large number of climate change vulnerability assessments (CCVA's) conducted on natural systems and on species signals an increasing recognition by state and federal agencies, NGO's, and universities that such tools offer a valuable first step in conservation planning during a time of uncertain climate futures. This large number of assessments contains a wide variety of approaches, and nearly all of them have merit under certain circumstances. Conservation planners and managers looking to assess climate change vulnerability of the systems and/or species for which they are responsible have a formidable task wading into this rapidly developing literature. Furthermore, once a particular method is selected, it is likely that decisions made based on that approach will have ramifications for many years to come. Collectively, the wide array of choices facing potential CCVA users and the implications of those choices add up to a daunting, and sometimes overwhelming, obstacle in the path toward addressing climate change. Here, we describe the need for a decision support tool that would, in conjunction with our review of existing approaches, help users navigate these obstacles.

A primary benefit to using a formulaic approach when selecting a climate change vulnerability methodology is to reduce the number of possible approaches in any given assessment scenario. While many assessment types exist, only a small number will be appropriate for a specific set of circumstances. In addition to offering a filter, a decision support tool can yield two other important benefits to those using the CCVA after it has been generated. First, our tool is structured such that particular questions are answered as a means to guide the user toward one or more suggested approaches. Answering these questions will help document decisions taken about the approach used to establish vulnerability of the CCVA species and habitats. Such transparency is valuable to stakeholders who use the results of the project, but were not directly involved in its creation. Second, such a structured approach means the same rationale used to generate one assessment can be repeated once circumstances change (such as when new focal species or habitats are identified or new resources become available to support the assessment). Repeatability in the logic used to derive a CCVA (or series of CCVA's) helps to enhance continuity across assessments and can decrease the workload.

Prior to determining which CCVA method to follow, there must be a clear understanding of the species and habitats of the CCVA. In many cases, the choice may be made obvious because of a pre-existing mandate. In other situations, species and habitats selection may require a series of steps similar to what is described in Section III of this report. Once a focus is identified, it will typically fit into one of four categories (habitat, species, process, or ecosystem). For the purposes of this approach, we use ecosystem to refer to those attributes of systems that are a function of both abiotic and biotic conditions (e.g., primary productivity, nutrient cycling, and succession). When deciding upon a CCVA approach for cases where more than one of these categories is a focus, the decision-making process should be followed with each category separately because methods are often specific to particular categories.

Once species and habitats are selected, the answers to three questions narrow the available methods to consider. These questions address capacity, time, and area of inference, three issues that largely determine the CCVA options available for any given focus. These questions (and suggested categories of answers) are:

- "What is the funding available for the assessment?" (0 - $100,000; $100,000 - $200,000; $200,000 - $500,000; and "proceed without a budget")
- "How much time do you have to plan and conduct the assessment?" (< 1 year; 1 – 2 years; 2 – 5 years; > 5 years)
- "What is the extent of the area being assessed?" (A state; multi-state region or large federal holding; entire range of a multiple/single species; small public holding; unique habitat feature such as cave or drainage).

The end point of the decision support tool will be a recommendation of one or more of five categories of possible CCVA approaches, as described above. These are broad categories, and within any one category there are typically several related implementations.

Following the identification of a focus and answering the three capacity/time/area questions, an additional series of questions in the decision support tool will then lead to one of the five end point recommendations. Although many of the possible paths resulting from answering the questions will track back to overlapping recommendations, we do not have the space to fully outline those alternatives here. We recommend development of the full on-line support tool separately to allow users to work through the CCVA methods selection process based on their own set of circumstances. Below, we describe two scenarios that will provide a general overview of how the tool works, as well as to offer guidance on some of the intermediate decision points (Figures 1 and 2).

Figure 1 illustrates a hypothetical decision tree for a scenario in which an agency wishes to conduct a climate change vulnerability assessment for a single species. In this scenario, the agency conducting the assessment has only $20,000 in resources (for staff time, contracting, and other expenses) and only four months in which to conduct the assessment. Because the need for spatially explicit data was identified, and because the distribution of the species in question is probably influenced by climate, a spatial modeling approach was recommended in conjunction with a qualitative narrative. Because most spatial models done to support CCVAs are largely depictions of exposure, the qualitative narrative will provide a complementary approach to identify key species sensitivities and adaptive capacity.

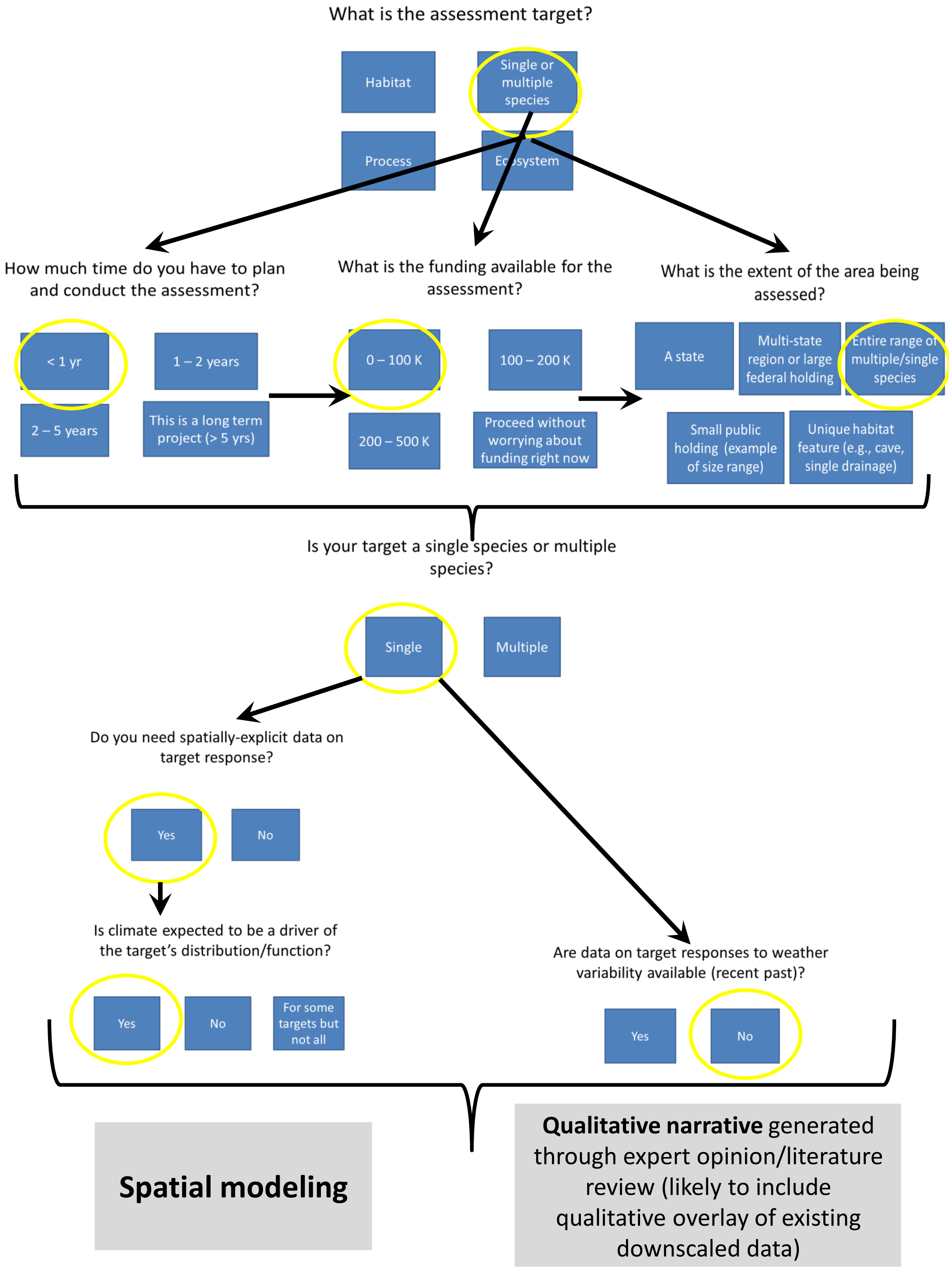

Figure 2 Hypothetical decision tree to assess single species

Figure 2 illustrates a scenario in which an agency wishes to conduct a CCVA for an ecosystem process, specifically assessing the vulnerability of nutrient cycling processes over the course of four years in large national park. The funding level for this assessment is $450,000. Spatial data are not required, but information on historical variations in both weather patterns and parameters relating to stream nutrient loads is available. Because historical data are available, a synthesis of those data is recommended. Such syntheses have been used successfully in other CCVA efforts as a way to overcome hesitation from some stakeholders regarding uncertainty (Enquist & Gori 2008). Given the available funding level, relatively long time-line of the assessment, and because decision making is contingent upon details associated with known species sensitivities to climate change, empirical data collection is also a reasonable option. In this case, as in nearly any other scenario we can envision, a qualitative narrative is recommended after a thorough review of existing relevant literature and/or conversations with experts.

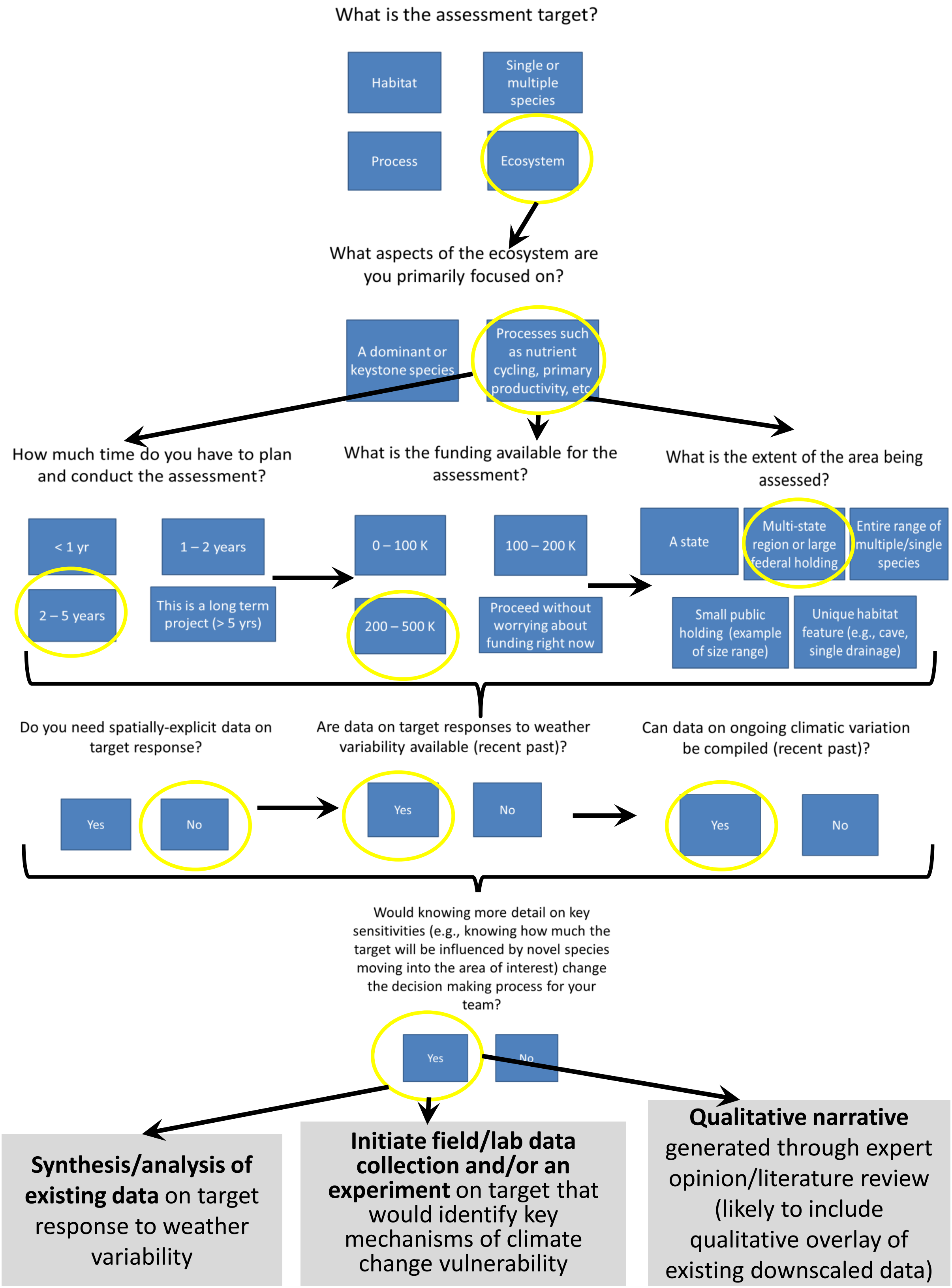

Figure 3 Hypothetical Decision Tree for Assessment of Process