Climate Change Vulnerability Assessments in the Appalachian Landscape Conservation Cooperative Region: Phase II results of assessments

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December 2015

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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, completed in 2014, 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. Guided by the recommendations of the Panel, Phase II analyzes the results of 700 existing species assessments, and conducts vulnerability analyses on 41 additional species and 3 habitats. This report summarizes Phase II of this effort.

A compilation of completed species and habitats assessments from a number of researchers in the Appalachian LCC region was initiated in Phase I and included as a supplementary appendix. In Phase II, additional existing assessments were included, and the compiled results were analyzed. The large majority of existing assessments had used Release 2.1 of the NatureServe Climate Change Vulnerability Index tool, which facilitated comparisons. The Appalachian LCC covers a vast amount of diverse territory, and to facilitate analyses, we subdivided the region into three subregions: Central Appalachian, Cumberland – Southern Appalachian, and Interior Low Plateau. 700 species had been assessed, with 392 completed in the Central Appalachians, 275 in the Cumberland – Southern Appalachians, and 134 in the Interior Low Plateau. Of habitat assessments, 15 had been completed in two separate projects in the Central Appalachian subregion; a small portion of the Cumberland – Southern Appalachian subregion was the focus of 16 assessments; the Interior Low Plateau was the focus of only one habitat assessment. Of the species assessments, the number of Extremely or Highly Vulnerable species ranged from 106 species in the Central Appalachian subregion; 58 in the Cumberland – Southern Appalachian subregion, to 30 in the Interior Low Plateau. Vulnerabilities varied among taxonomic groups, with mussels, fishes, amphibians and rare plants among the most vulnerable, and birds among the least vulnerabile. A much higher proportion of aquatic species were vulnerable compared to terrestrial speices. Cave species were largely predicted to not be appreciably affected by climate change, since caves are buffered from surface climate impacts.

We used the recommendations of the Expert Panel, as well as the existing compilation to guide our recommended list of additional species and habitats to be assessed in Phase II. Criteria included a focus on the Interior Low Plateau and on plants, neither of which were well represented in existing assessments, as well as species of high conservation

significance, keystone or species otherwise important to the habitat, and those of high value as indicators of climate change. The proposed list was reviewed several times by different groups, and the final list was approved by the LCC.

We used the updated Release 3.0 of the CCVI for our assessment, an improved version developed from survey results of users of the CCVI. Release 3.0 yielded higher numbers of species ranked as Moderately Vulnerable or above incomparison to results of the same species assessed with Release 2.1. Of the 41 species assessed (23 in the Central Appalachian and 19 in the Interior Low Plateau), 14 were ranked as Highly or Extremely Vulnerable in both subregions. Of the 36 assessments done in the Cumberland – Southern Appalachian subregion, 24 were Highly or Extremely Vulnerable.

We used a rapid assessment tool to assessess habitats, a modification of the NEAFWA (NorthEast Association of Fish and Wildlfe Agencies) Habitat Vulnerability model developed by the Manomet Center of Conservation Sciences. We assessed three habitats, resulting in rankings of Vulnerable for for South-Central Interior Small Stream and Riparian habitat, and Less Vulnerable for both the Southern Interior Low Plateau Dry Mesic Oak Forest and the Central Interior Highlands Calcareous Glades and Barrens.

We reported our species assessments by major habitat, and found that all five species we assessed that are associated with the Central Interior Highlands Calcareous Glades and Barrens were ranked as Highly or Extremely Vulnerable. These ranks were driven largely by dispersal factors, since their ranks changed to Least Vulnerable if dispersal factors were discounted. If the habitat is indeed Least Vulnerable, then dispersal factors may not be relevant to these species that are adapted to hot, dry conditions.

We made the following recommendations as a result of this work:

Capitalize further on the existing species assessments by examining the results by major habitat categories, as we did on the 41 newly assessed species. The extraordinary diversity of this region in particular makes it impossible to focus management on individual species. Focusing management on habitat benefits large numbers of associated species, but in order to be most effective, there must be a greater understanding of species – habitat relationships.

Combine climate vulnerability information with conservation status ranks to inform conservation planning. Our work, and that of other researchers, has revealed that rare species are not always vulnerable to climate change and common species less so. The added vulnerability information should be included in current conservation plans, as the results may have an impact on priorities.

Conduct more in-depth assessment of species and habitats found to be highly or extremely vulnerable. The Expert Panel in Phase I recommended first using coarse filter methods to rapidly identify vulnerabilities of numerous species, then to focus further assessments on those found to be most vulnerable. For species whose ranges appear to be climate-limited, use bioclimatic modeling to estimate how ranges may shift due to climate change. For habitats, use the Habitat Climate Change Vulnerability Index to better understand underlying mechanisms, ecological processes, and vulnerable keystone species that may be influenced by climate change.

Focus on "no regrets" climate smart conservation actions. Specific recommendations by Hanson et al. (2010) include increasing the size and genetic diversity of small populations; protecting large core areas and increasing connectivity; restoring (or simulating) natural ecosystem drivers; improve habitat condition; and employ targeted monitoring and adaptive management. Distribution modeling of species of narrow ecological tolerances, in combination with more detailed analyses of newly available climate data, will identify more specific actions to improve our conservation planning and management capabilities.

Introduction

The Appalachian Landscape Conservation Cooperative (APPLCC) is one of 22 Landscape Conservation Cooperatives forming a network across the United States established to guide conservationists, resource managers, and scientists by providing information that integrates science with management to address landscape and climate change issues. The Appalachian LCC comprises three somewhat distinct biogeographic areas that we refer to in this report as the Central Appalachian, the Cumberland and Southern Appalachian, and the Interior Low Plateau subregions. The topographically diverse landscape comprises mountains and plateaus supporting a high degree of endemism. As a "biodiversity hotspot" (NatureServe 2013a), the Appalachian LCC is home to nearly 200 species that are federally listed as threatened or endangered.

In response to the recognition that climate change is occurring, that it is likely to accelerate over the next few decades, and that these changes pose challenges to the conservation of plant and animal communities, much attention has been focused in recent years on developing and applying methods to evaluate the vulnerabilities of species and natural systems. NatureServe was awarded a grant by the Appalachian LCC to assess the various methods of climate change vulnerability assessment, provide recommendations to the LCC in selecting appropriate methods, and to conduct species and habitats for climate change vulnerability. In devising this project, the LCC seeks to better understand and address major environmental and human-related vulnerabilities of species as they relate to climate change stressors. The approach first identifies species and habitats vulnerable to climate change impacts, then describes vulnerabilities in sufficient detail to inform conservation partners who can then plan adaptive management responses.

Without such vulnerability assessments, it is difficult to know how to develop effective and appropriate conservation responses and allocate limited resources. Beginning in the early 2000s a number of vulnerability assessment models were developed, tested and applied in North America. Some of these focus on species, while a smaller number have focused on habitats. A summary of many of these methods is provided in the report of Phase I of this project (Barrett et al. 2014), which resulted in two products upon which the current project is based. The first, a compilation of all known completed climate change vulnerability assessments in the Appalachian LCC region, resulted in a table of results for over 650 species, and approximately 30 habitats, previously assessed in portions of the LCC. The second is a set of recommendations developed by an Expert Panel who met several times by conference call and once in person at a two-day meeting. The Panel reviewed a broad array of existing climate change vulnerability approaches, developed a set of criteria to aid in choosing additional species and habitats to assess in this phase of the project (Barrett et al. 2014), and provided a set of recommendations:

1. **Conduct an analysis of how the magnitude of ongoing climate change varies spatially across the Appalachian region.** Evaluate where current climate is already departing from historical conditions, and might already be disrupting natural systems. This will narrow the focus of climate vulnerability assessments both geographically and taxonomically. By analyzing long term observations from interpolated weather station data (such as PRISM), the rate, magnitude, spatial and temporal pattern of climatic changes occurring today can be understood. This approach supports community engagement, as stakeholders may be more readily engaged if the issues focus on currently observed climatic changes, rather than dozens of modeled future projections and their associated uncertainties.
2. **Use coarse filter methods to assess the vulnerability of species and habitats occurring in areas experiencing the greatest changes to their climates.** A widely used coarse filter method for species is the Climate Change Vulnerability Index. 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 the method. For habitats, an expert solicitation mechanism yielding descriptive narratives, such as that followed by the North Atlantic LCC, would be appropriate 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. Focus first on those in the high priority groups (endemics or near endemics, and those that pose human health problems).
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, use bioclimatic modeling to estimate how ranges may shift due to climate change. For habitats, use the Habitat Climate Change Vulnerability Index to better understand underlying mechanisms, ecological processes, and vulnerable keystone species that may be influenced by climate change.

Climate change in the Appalachian LCC area

The Third National Climate Assessment (Mellilo et al. 2014) reports the results of modeling future climate change in the southeastern US, an area that includes the

AppLCC. Mellilo et al. (2014) based its climate projections on two main greenhouse gas emissions scenarios: B1, which assumes substantial emissions reductions over the rest of the century, and A2, assuming continued growth in emissions. These should not be viewed as best and worst case scenarios, but as plausible futures (IPCC, 2013). Indeed, current global emissions rates put us on a course that exceeds the B1 scenario by mid-century and comes close to A2 by the end of the current century (IPCC, 2013).

The Appalachian LCC region saw a temperatures ranging from no change in portions of eastern Kentucky to 1.5°F increase in the Central Appalachians between 1895 and 2011, and a 71% increase in extreme precipitation in the northeast (defined as the heaviest 1% of all daily events), and 27% increase between 1958 and 2010. The average length of frost-free season length increased from 6 to 10 days in the Appalachian LCC region between 1991-2012. Mid-century (2050) temperature increases in the southeast are projected to range from approximately 2-5°F in the B1 scenario, to a maximum of 6°F in the A2 scenario.

In summary, the analyses performed during the Third National Assessment indicate that the current trend toward higher temperatures will continue and accelerate. Also, though less certainly, precipitation in the AppLCC will increase by 5-15% and more extreme rainstorms will become more frequent. With the increasing temperatures it is likely that evapotranspiration rates will also increase, resulting in reductions in soil moisture. This, together with the increasing temperatures, will result in a greater frequency and duration of extreme droughts. This, in turn could result in a higher frequency of wildfires. Other extreme events that are likely to become more frequent and intense include floods and windstorms. All of these factors have the potential to enact major changes on the distribution and abundance of plants and animals and their habitats.

Methods

Addressing the Expert Panel recommendations

The first recommendation, determining the current rate of climate change variation across the Appalachian LCC, requires analyses of more detailed climate data that, at the time of our analyses, were not available. Although climate analysis was beyond the scope of this project, NatureServe has since developed a multivariate climate change exposure index for the Appalachian LCC for use in prioritization modeling (Auer 2015). The data and methods generated as a result of Auer (2015) provide a solid base from which to develop the current rate of climate change in the LCC.

Our current project largely focuses on the second Expert Panel recommendation, use coarse filter methods to assess species and habitats in areas experiencing the greatest climate change. These analyses can then set the stage for future implementation of the third recommendation, to perform more in-depth assessments of the species and habitats flagged as highly vulnerable to climate change in the coarse filter analysis.

Selection of assessment targets is a crucial and complex step in the process, but we were fortunate that the Appalachian LCC has been the focus of a number of species and habitat climate change vulnerability assessment studies from different state or regional perspectives in recent years. We compiled all previous climate change vulnerability assessments known to us in the Appalachian LCC region to identify data gaps, and to inform our selection of additional species and habitats to be assessed. We also explored this larger data set to identify trends that may not have been visible in state-based assessments.

Determination of the appropriate assessment area is also an important step in climate change vulnerability assessment. The Appalachian LCC includes all or parts of 15 states[1] and encompasses a great deal of geophysical variability. Assessing a species across its entire range could obscure important information because species of wide distribution are exposed to highly variable environments, and important regional differences can be obscured by a large assessment area. For example, populations of a species occurring at its northern range limits are exposed to different conditions than do populations at the southern range limit. Thus, a species may be vulnerable to climate change in only part of its distribution.

We attempted to conduct our climate change vulnerability assessments in a way that most comprehensively addresses the geophysical, climatic, and biological diversity of the Appalachian LCC region and comparing it to our existing knowledge about species and habitat vulnerability. Using the boundaries derived from Subsection lines as defined by the USFS Ecoregional Units (Keys et al. 1995), we divided the Appalachian LCC region into three subregions to be used as assessment areas: Central Appalachians (includes High Allegheny Plateau and Western Allegheny Plateau), Interior Low Plateau, and Southern Appalachians (includes Cumberlands, Southern Ridge and Valley and Southern

[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

Blue Ridge) (Figure 1). Each subregion is characterized by broadly similar ecological characteristics that differentiates it from the others, and are thus more ecologically uniform than are the assessment areas defined by state boundaries.

We selected 41 species that we assessed using the coarse filter methods of NatureServe's CCVI for species, and three habitats using methods modified from Manomet Center for Conservation Sciences and National Wildlife Federation (2012).

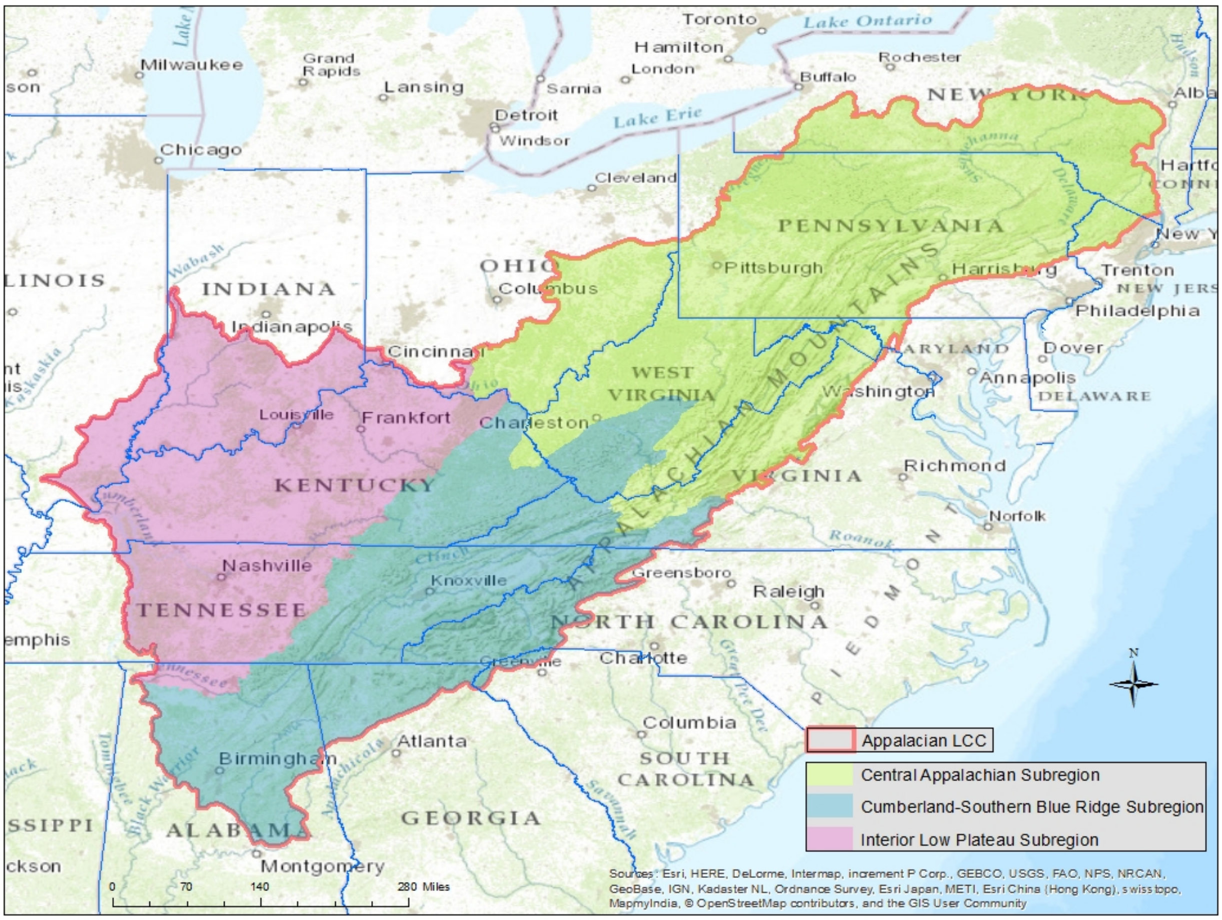

Figure 1 Subregions defined for analysis, modified from Keys et al. (1995)

Compilation and analysis of existing data

Species Assessments

To date, in studies that we are aware of, 700 species assessments have been completed by other researchers in all or part of the LCC region (Byers and Norris 2011; Carroll 2011; Furedi et al. 2011; Kane et al. 2013; Ring et al. 2013; Schlesinger et al. 2011; Virginia Division of Natural Heritage 2010; Walk et al. 2011). The results are largely comparable because most used a single methodology, the NatureServe Climate Change Vulnerability Index (CCVI) version 2.1 (Young et al. 2011). Kane et al. (2013) modeled current and predicted distribution against climate models in Virginia and West Virginia. Their results are presented here as an interpretation of their mapped data in which we noted an apparent increase (range expansions) or decrease (range contraction) within the LCC region mid-century under a moderate emissions scenario. It is important to note that their report includes more nuanced discussion not easily captured in tabular format, so we suggest reference to the original work for further detail. In order to view the wealth of existing data in a meaningful context, we organized the results by subregion.

The results of previous analyses were compiled into a single spreadsheet, included as Appendix I of the Phase I report (Barrett et al. 2014). Since release of the Phase I report, results of analyses conducted in New Jersey were added to the spreadsheet, which is included as a separate attachment (Appendix F) to the current report.

We wanted the data to be useful at the state level, even in those states where no assessments had been done. Because the subregions share broadly similar ecological characteristics, we extrapolated results beyond the original area of assessment to states within the subregion where that species also occurs. This assumes that climate exposure does not vary substantially within subregions, however, so we annotated the extrapolated results with parentheses, to denote a somewhat lower confidence, and noted the origin of the result. Results for each of the subregions are also available spreadsheets that can be downloaded, or used online, allowing the user to examine results by state, higher taxonomy, conservation status rank, vulnerability rank, and by broad habitat type: http://applcc.org/research/climate-change-vulnerability-group/final-narrative-climate-change-vulnerability-assessment/data-access

In the Central Appalachian subregion, state-based species assessments had been completed in Pennsylvania, West Virginia, Virginia, New Jersey, and New York. Over 75% of the land mass of the Central Appalachian Subregion occurs in Pennsylvania and West Virginia. We assumed that results of species assessed in either of these two states could be reasonably extrapolated to the remainder of the subregion. New York, New Jersey, and Virginia make up a smaller portion of the subregion, so those results were not applied beyond the state boundary.

Figure 2 illustrates the study areas of major works completed in the Southern Appalachian subregion. Numerous species had been assessed by Carroll et al. (2011) in two areas, the larger of which is nearly coincident with the Southern Appalachian Subregion, so all species completed within the larger Carroll et al. study area were applied to the entire subregion. A second study (Bruno et al. 2012) assessed species within National

Parks of the Cumberland – Piedmont Network of the National Park Service (Figure 2). We extrapolated the results of species assessments conducted at Cumberland Gap National Historical Park to the Cumberland – Southern Blue Ridge subregion portions of Kentucky. We did similar extrapolations for results of assessments in Russell Cave National Monument and Little River Canyon National Preserve to Alabama, and those of Chickamauga and Chatanooga National Memorial Parks to the Cumberland – Southern Blue Ridge subregion portions of Georgia and Tennessee.

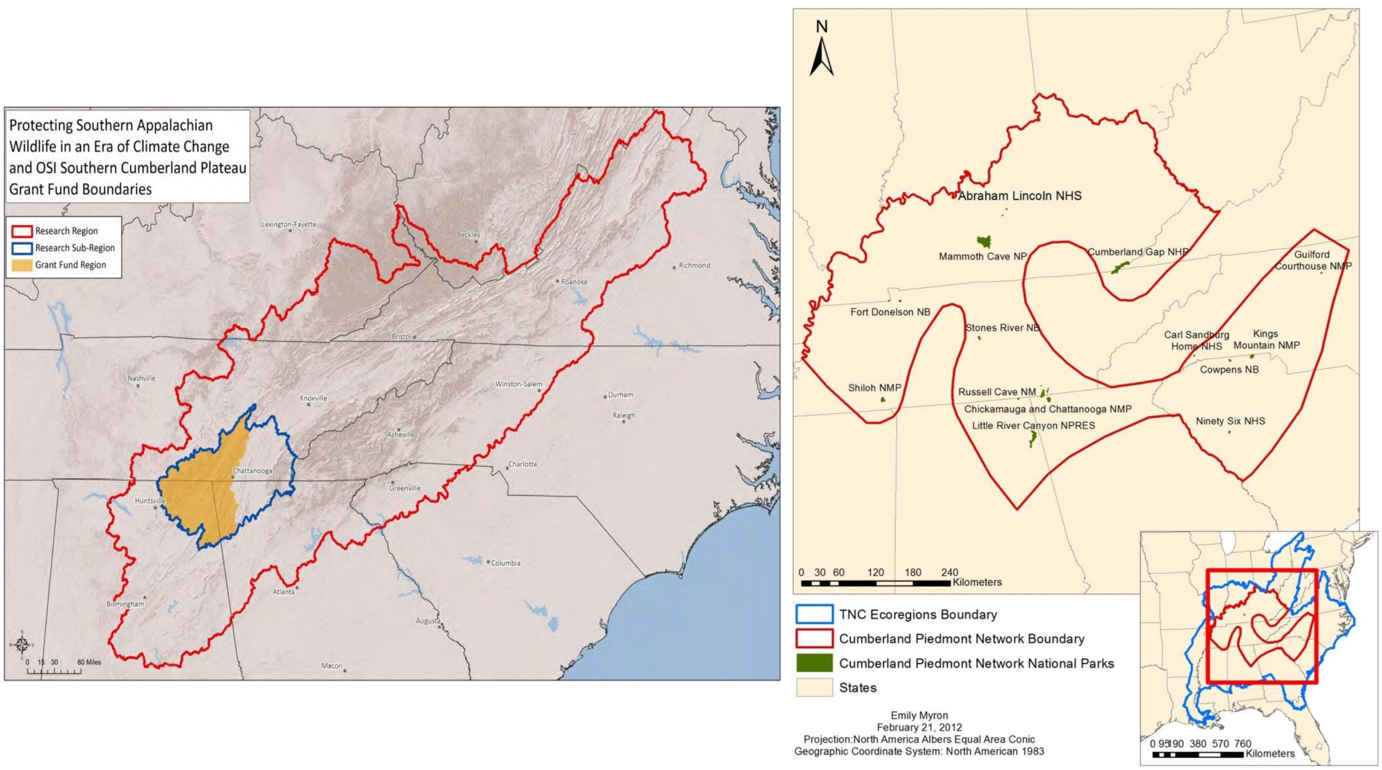

Figure 2 Southern Appalachian and Interior Low Plateau study areas in two regional studies: Carroll et al. (2011) (left) and Bruno et al. 201 (right).

Assessments completed in the Interior Low Plateau subregion included Bruno et al. (2012), and Walk et al. (2011) in Illinois. Results from Bruno et al. (2012) assessments done in Abraham Lincoln National Historical Site and Mammoth Cave National Park were extrapolated to the Interior Low Plateau portion of Kentucky, and those of Fort Donelson were extrapolated to the Interior Low Plateau portion Tennessee.

Although only the extreme southeastern portion of Illinois is included in the Appalachian LCC, Walk et al. conducted multiple assessments of species occurring in natural divisions and in watersheds of the state (Figure 3). We extrapolated results of assessments to the

Interior Low Plateau portions of the appropriate states, i.e. those of the Wabash Border and Shawnee Hills natural divisions to Kentucky, and those of the Wabash Border Indiana. We also extrapolated results of assessments in the Vermillion – Wabash Basin and Embarras Watershed to the Indiana portion of the subregion, as well as those of the Saline and Ohio (Cache) watersheds to the Kentucky portion of the subregion.

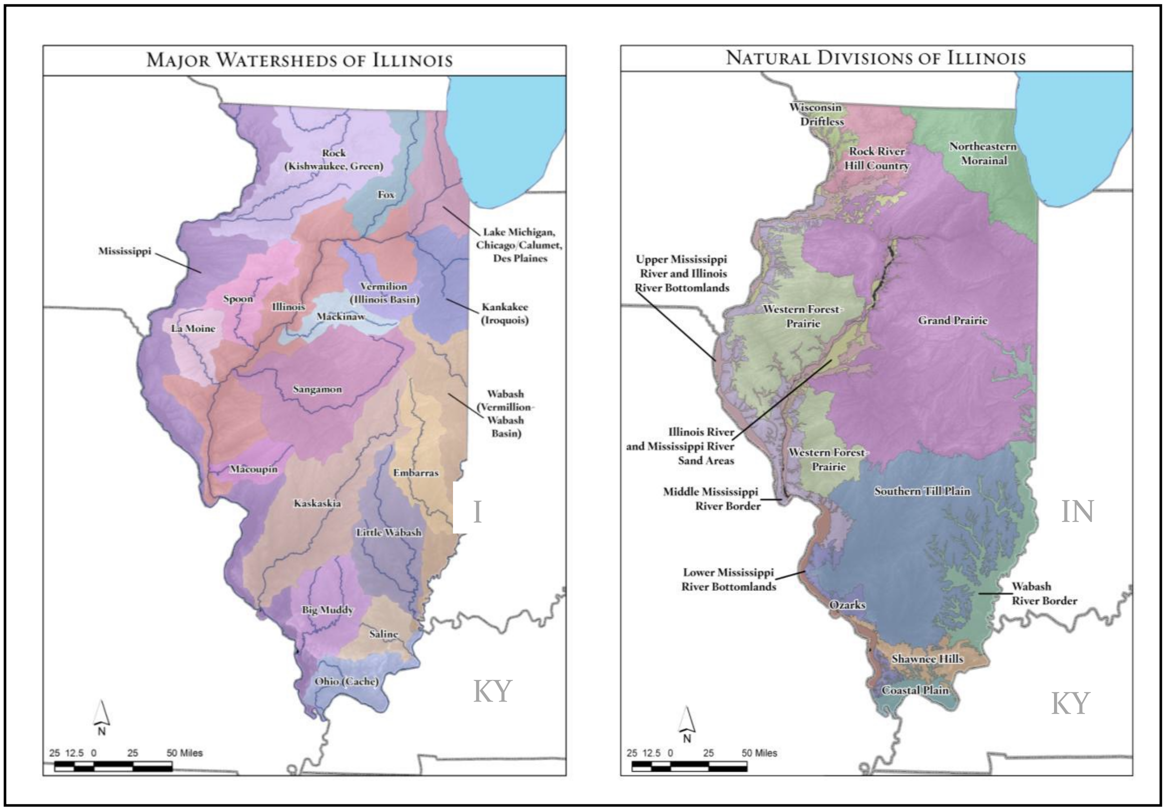

Figure 3 Major watersheds and natural divisions of Illinois (from Walk et al. 2011)

The compiled results are summarized in Tables 1 and 2. Table 1 indicates the numbers of species assessed in each subregion by major taxonomic group, by major habitat, by conservation status ranks[2], and by resulting vulnerability ranks. As noted previously, the data are drawn from five different studies, in which different numbers of species had been selected using different criteria. Of 700 species, 137 were plants, and 563 were animals. Of faunal assessments, the taxonomic group with the largest number of assessments was fishes, 116 in total, followed by birds (88), herpetiles (76), and mussels (76). Terrestrial organisms far outnumbered aquatic species assessed (413 vs 248), and the total number of cave fauna assessed was 39.

Of the 700 species assessed, 52 occurred in both the Central Appalachian and the Cumberland-Southern Appalachian subregion; 23 species were shared by the Central Appalachian and Interior Low Plateau subregions, and 51 were shared by the Cumberland-Southern Appalachian subregion and Interior Low Plateau subregions. The Interior Low Plateau subregion has the fewest species assessments (134), followed by the Cumberland – Southern Appalachian subregion. A total of 392 species assessments were conducted in the Central Appalachian subregion.

The primary selection criterion for vulnerability assessment in each of the previous studies was conservation concern, generally guided by the state's Wildlife Action Plan. Species of greatest conservation need nearly always include those that are rare and threatened throughout their range (those that are federally listed as Threatened or Endangered, including candidates, and species having conservation status ranks of G1-G3), but they also include species of conservation concern at the state level that are not necessarily globally rare (global conservation status ranks of G4-G5). More than twice as many G4 or G5 species as G1-G3 species were selected (474 vs 221) for assessment, although nearly all are considered of conservation concern in at least one state.

Ring et al. (2013) noted that the most important factors contributing to vulnerability in NJ included species at the southern limit of their range, existence of barriers to movement (both anthropogenic as well as the geological complexity of the natural landscape), and species of uncommon habitats.

[2] NatureServe does not use a single term that denotes threat, rarity, or endangerment in relation to conservation status ranks. For simplicity, we chose to use the term "rare" for those species with ranks from G1-G3, and "common" for those with ranks of G4 and G5 in this report. Full definitions of NatureServe conservation status ranks are in Appendix H.

Categories: taxonomic, major habitat, conservation status rank, vulnerability rank		**Total in LCC**	**Subregion**		
			Central Appalachians	Cumberland - Southern Appalachians	Interior Low Plateau
Number of Phyla		14	13	4	6
Number of Families		182	141	82	61
Plants		137	125	8	6
	Trees	24	23	0	1
	Shrubs	14	13	1	0
	Forbs	67	59	6	3
	Graminoids	29	27	1	2
	Fern / Fern allies	2	2	0	0
	Mosses	1	1	0	0
Animals		563	267	267	128
	Mammals	46	15	27	15
	Birds	88	34	55	42
	Fishes	116	32	81	14
	Herptiles	80	40	39	16
	Mussels	76	19	46	29
	Insects	66	63	1	3
	Other invertebrates	91	64	18	9
Major Habitat					
	Terrestrial	413	274	128	80
	Aquatic	248	82	144	53
	Subterranean	39	36	3	1
Conservation Status Rank[3]					
	G1-G3	221	122	94	27
	G4-G5	474	266	181	106
	GNA	2	2	0	0
	Unranked	2	2	0	1
Vulnerabiliy Ranks[4]					
	EV, HV, HV/EV, Decrease		106	58	30
	PS, IL, PS/IL, Increase		157	153	77
	MV		111	53	17
	Total Vulnerable (MV-EV)		217	111	47
	PS/MV, MV/HV		12	7	9
	Other[5]		6	4	1
Total Species		700	392	275	134

Table 1 Summary of results of existing assessments

[3] G1-G3 refers to rare or threatened species; G4-G5 indicates speces are widespread and common
[4] EV= Extremely Vulnerable; HV = Highly Vulnerable; MV = Moderately Vulnerable; PS = Presumed Stable; IL = Increase Likely. Increase / Decrease indicates predicted range expansion / contraction
[5] Ranks spanning more than two categories

Walk et al. (2011) noted a high proportion of mollusks and fishes were Highly or Extremely Vulnerable in Illinois, but in the southern portion of the state, the larger rivers characterizing that region provide a better buffer from temperature fluctuations and flow variations than the do the smaller rivers to the north. The Wabash Border and Shawnee Hills ecoregions in the south of the state are the least altered and have the highest topographic diversity. Southern Illinois also experiences a lower degree of exposure than does the remainder of the state. The authors noted that the most important factors influencing vulnerability included anthropogenic barriers to movement, and uncommon habitats.

Byers and Norris (2011) noted that six factors were strongly correlated with increased vulnerability in West Virginia: natural and anthropogenic barriers, physiological thermal and hydrologic niche, degree of genetic variation, and modeled response to climate change. They noted that rare species were only slightly more vulnerable to climate change than were common ones. They found that the most vulnerable species by taxonomic group included amphibians, fishes, mollusks, and rare plants. Contributing factors to reptile and amphibian vulnerability included barriers to dispersal, poor dispersal capability, and narrow physiological and hydrological niches. Crayfish are somewhat buffered by their generalized diet, but barriers to dispersal and somewhat narrow hydrological niche increase their vulnerability. Odonates and lepidoptera are good dispersers and may shift out of the area, especially those associated with ephemeral wetlands, headwater streams, or have specialized diets. In general, they found that species with lower vulnerability are those that are highly mobile, or foundation plants of common and widespread habitats. Schlesinger et al. (2011) also noted that mobile insects, even those that are cold-adapted, in general ranked Presumed Stable.

Table 2 provides detail of these results for each subregion, by vulnerability rank and conservation status rank by major taxonomic group and by major habitat. Although the results cannot be considered statistically significant due to the non-random selection of species, they suggest trends in greater vulnerabilities in some groups, and less vulnerability in others. Most mammals and birds assessed are common and widespread, with global conservation ranks of G4 or G5. A substantial proportion of birds were ranked Presumed Stable or Increase Likely in each subregion, due largely to their high mobility and ability to migrate to more suitable habitat. A larger proportion of mammals assessed were found to be Presumed Stable in two subregions, but more were ranked Moderately Vulnerable or above in the Central Appalachian subregion. Substantially greater numbers of fishes, mussels, and herpetiles were found to be vulnerable in all subregions. The large majority of plants assessed were in the Central Appalachian subregion, and nearly 75% of those had vulnerability ranks of Moderately Vulnerable or greater.

	Central Appalachian						Cumberland - Southern Appalachian						Interior Low Plateau					
	HV/EV		MV		PS/IL		HV/EV		MV		PS/IL		HV/EV		MV		PS/IL	
	G1-G3	G4-G5	G1-G3	G4-G5	G1-G3	G4-G5	G1-G3	G4-G5	G1-G3	G4-G5	G1-G3	G4-G5	G1-G3	G4-G5	G1-G3	G4-G5	G1-G3	G4-G5
Mammals	0	2	3	4	0	5	0	2	1	2	2	19	0	1	1	0	2	11
Birds	0	3	0	7	1	23	0	0	0	5	1	48	0	0	0	2	1	39
Fishes	4	8	2	10	1	6	6	3	14	16	13	29	0	3	0	5	0	5
Herpetiles	5	10	1	8	1	12	4	1	0	2	3	28	0	1	0	3	0	11
Mussels	8	5	3	3	0	0	30	7	4	5	0	0	14	9	1	4	1	0
Insects	7	3	9	13	13	17	0	0	0	0	0	0	0	0	0	0	1	2
Other Invertebrates	8	2	4	8	30	12	4	1	2	2	3	5	0	2	3	3	0	1
Trees	0	8	0	11	0	4	0	0	0	0	0	0	0	1	0	0	0	0
Shrubs	1	6	2	1	3	0	0	0	0	1	0	0	0	0	0	0	0	0
Forbs	6	14	6	15	4	12	1	2	0	2	1	0	0	0	0	0	3	0
Graminoids	3	9	0	14	1	0	0	0	0	0	1	0	0	0	0	1	0	1
Ferns, Fern Allies	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aquatic	11	17	7	30	1	19	39	12	21	23	16	32	15	17	1	11	2	7
Subterranean	0	0	0	0	35	1	0	0	0	0	0	3	0	1	0	0	0	0
Terrestrial	28	54	24	65	12	86	5	4	4	9	7	98	0	2	1	7	6	62

Table 2 Results of existing assessments for higher taxonomy (rows 1-12), and for major habitat (last 3 rows). Climate change vulnerability ranks are shown in three categories: Highly Vulnerable / Extremely Vulnerable; Moderately Vulnerable, and Presumed Stable / Increase Likely. Results are also reported between "rare" (conservation status ranks of G1, G2, and G3 including range ranks) and "common" (conservation status ranks of G4 or G5). Species assessed by more than one researcher resulting in differences spanning more than two vulnerability categories are not included, nor are species lacking global conservation ranks.

Vulnerability by major habitat revealed a much higher proportion of aquatic species are vulnerable compared to terrestrial species, in all three subregions. The great majority of cave species assessed were in the Central Appalachian subregion, and none were found to be vulnerable, despite the high degree of rarity, largely as a result of their being buffered from surface climate exposure.

Analysis of Existing Habitat Assessments

We identified four studies that included vulnerability assessments of habitats[6] in portions of the LCC. These included six habitats of the northeastern US ranging south to Virginia and West Virginia, a region that closely approximates the Central Appalachian subregion of the LCC (Manomet 2012a and Manomet 2012b). These habitats and their results are listed in Table 3. Butler et al. (2015) completed nine forest ecosystem assessments in the the Central Appalachian and Allegheny Plateau regions of West Virginia, Maryland, and Ohio (Table 4). The third study is that of the North Carolina Natural Heritage Program (2010), providing assessments of 16 habitats of the Southern Blue Ridge region of North Carolina. (Table 5). The fourth includes one applicable result from a larger assessment of climate-sensitive ecosystems of the southeastern US (Costanza et al. 2014) (Table 6).

Habitat name used in assessment	Corresponding natureServe Ecological System Code	Corresponding natureServe Ecological System Name	Rating[1]
Appalachian (Hemlock)-Northern Hardwood Forest	CES202.593	Appalachian (Hemlock)-Northern Hardwood Forest	Highly Vulnerable
Laurentian-Acadian Northern Hardwood Forest	CES201.564	Laurentian-Acadian Northern Hardwood Forest	Highly Vulnerable
Northeastern Interior Dry-Mesic Oak Forest	CES202.592	Northeastern Interior Dry-Mesic Oak Forest	Vulnerable
Central Mixed Oak-Pine Forest	CES202.591	Central Appalachian Dry Oak-Pine Forest	Vulnerable
Central and Southern Appalachian Spruce-Fir Forest	CES202.028	Central and Southern Appalachian Spruce-Fir Forest	Critically Vulnerable
Cold water fish habitat	N/A	N/A	Vulnerable
[1]Rating definitions for assessment area: Critically Vulnerable = likely to be eliminated; Vulnerable = likely to be relatively unaffected; Less Vulnerable = likely to extend range; Least Vulnerable = likely to greatly extend range			

Table 3 Vulnerability assessment of habitats (Ecological Systems) in the Central Appalachian subregion of the Appalachian LCC (NY, PA, WV, VA, MD) Source: Manomet 2012a and 2012b

[6] We use the term "habitat" broadly to refer to a classified community type in the project as defined by the researchers. We then crosswalked the concepts to the Ecological Systems classification of NatureServe.

Habitat name used in assessment	Corresponding NatureServe Ecological System Code(s)	Corresponding natureServe Ecological System Name(s)	Rating[2]
Appalachian (Hemlock)-Northern Hardwood Forest	CES202.593	Appalachian (Hemlock)-Northern Hardwood Forest	High
North-Central Interior Maple/ Beech Forest	CES202.693	North-Central Interior Beech / Maple Forest	Moderate
Mixed Mesophytic and Cove Forest	CES201.564	Southern and Central Appalachian Cove Forest	Moderate
	CES202.887	South-Central Interior Mesophytic Forest	
Dry/Mesic Oak Forest	CES202.029	Northeastern Interior Dry-Mesic Oak Forest	Low-Moderate
Dry Oak and Pine / Oak Forest and Woodland	CES202.373	Central Appalachian Dry Oak-Pine Forest	Low
	CES202.600	Central Appalachian Pine - Oak Rocky Woodland	
Dry Calcareous Forest, Woodland and Glade	CES202.457	Southern Ridge and Valley / Cumberland Dry Calcareous Forest	Moderate-High
	CES202.602	Central Appalachian Alkaline Glade and Woodland	
Large Stream Floodplain and Riparian	CES202.608	Central Appalachian River Floodplain	High
Small Stream Riparian	CES202.609	Central Appalachian Stream and Riparian	Moderate-High
Spruce / Fir Forest	CES202.028	Central and Southern Appalachian Spruce-Fir Forest	High

[2]Vulnerability was determined as a function of low to high adaptive capacity and positive to negative potential impacts.

Table 4 Vulnerability assessment of habitats (Ecological Systems) in the Central Appalachian subregion of the Appalachian LCC (WV, VA, MD) Source: Butler et al. 2015

Habitat name used in assessment	Corresponding NatureServe Ecological System Code	Corresponding NatureServe Ecological System Name	Rating Factors (Likelihood[1]/ Effect[2]/ Magnitude[3])
Grass and Heath Balds	CES202.294	Southern Appalachian Grass and Shrub Bald	Mild Winters (H/N/M); Increased Temp (H/N/M); Fire (H/M/M; Drought (H/M/M)
High Elevation Rock Outcrops	CES202.327	Southern Appalachian Rocky Summit	Wind Damage (M/N/M); Mild Winters (M/N/M); Hot Spells (M/N/M); Fire (L/N/M); Drought (H/N/H)
Mafic Glades and Barrens	CES202.348	Southern and Central Appalachian Mafic Glade and Barrens	Fire (M/P/M); Wind Damage (M/P/L); Drought (H/P/L); Increased Temp (H/N/L)
Montane Cold Water Stream Communities Montane Cool Water Stream Communities	CES202.706	South-Central Interior Small Stream and Riparian	Flooding (H/N/H); Drought (H/N/H); Hot Spells (M/N/M); Increased Temp (H/N/H)
Montane Oak Forests	CES202.596	Central and Southern Appalachian Montane Oak Forest	Wind Damage (H/N/M); Fire (H/M/MN); Drought (H/N/L)
Mountain Bogs and Fens	CES202.300	Southern and Central Appalachian Bog and Fen	Mild winters (H/-/M); Hot Spells (H/N/L); Flooding (H/N/M); Drought (H/M/M)
Mountain Cove Forests	CES202.373	Southern and Central Appalachian Cove Forest	Flooding (M/N/L); Wind Damage (M/N/M); Mild Winters (H/N/L); Increased Temp (H/N/L); Fire (M/N/L); Drought (H/N/M)
Northern Hardwood Forests	CES202.029	Southern Appalachian Northern Hardwood Forest	Wind Damage (H/N/M); Phenological Disruption (H/N/M); Hot Spells (H/N/H); Fire (H/N/M); Drought (H/N/H); Increased Temp (H/N/M)

Table 5 Draft vulnerability assessment of habitats (Ecological Systems) in the Cumberland-Southern Blue Ridge subregion in North Carolina; Source: North Carolina Natural Heritage Program 2010

<table>
<tr><th>Habitat name used in assessment</th><th>Corresponding NatureServe Ecological System Code</th><th>Corresponding NatureServe Ecological System Name</th><th>Rating Factors (Likelihood[1]/ Effect[2]/ Magnitude[3])</th></tr>
<tr><td>Piedmont and Mountain Floodplains</td><td>CES202.705</td><td>South-Central Interior Large Floodplain</td><td>Drought (H/N/M); Mild Winters (M/N/M); Flooding (H/N/M)</td></tr>
<tr><td>Piedmont and Mountain Dry Coniferous Woodlands</td><td>CES202.331</td><td>Southern Appalachian Montane Pine Forest and Woodland</td><td>Wind Damage (H/M/M); Fire (M/M/M); Drought (H/M/M)</td></tr>
<tr><td>Spruce Fir Forests</td><td>CES202.028</td><td>Central and Southern Appalachian Spruce-Fir Forest</td><td>Mild Winters (H/N/M); Wind Damage (M/N/M); Hot Spells (M/N/M); Fire (M/N/H); Drought (H/N/H)</td></tr>
<tr><td>Sparsely Settled Mixed Habitats</td><td rowspan="2">N/A</td><td rowspan="2">Early Successional</td><td rowspan="2">Increased Temp (H/N/L)</td></tr>
<tr><td>Successional and Ruderal Uplands</td></tr>
<tr><td>Successional Wetlands</td><td>N/A</td><td>Wet Meadow - Marsh</td><td>Flooding (H/N/M); Increased Temp (H/M/L); Drought (H/N/L)</td></tr>
<tr><td rowspan="2">Upland Seepages and Spray Cliffs</td><td>CES202.317</td><td>Southern Appalachian Seepage Wetland</td><td rowspan="2">Increased Temp (H/M/M); Wind Damage (M/N/L); Flooding (M/N/L); Drought (H/N/M)</td></tr>
<tr><td>CES202.288</td><td>Southern Appalachian Spray Cliff</td></tr>
</table>

[1]Categories: High (H), Medium (M), Low (L)

[2]Categories: Positive (P), Mix (M), Negative (N)

[3] Categories: High (H), Medium (M), Low (L)

Table 4 Draft vulnerability assessment of habitats (Ecological Systems) in the Cumberland-Southern Blue Ridge subregion in North Carolina; Source: North Carolina Natural Heritage Program 2010 (Continued)

Nashville Basin Limestone Glade and Woodland (CES202.334)			
Sensitivity	**Exposure**	**Adaptive Capacity**	**Vulnerability**
Moderate	Moderate	Low	High

Table 6 Vulnerability assessment of the Nashville Basin Limestone Glade and Woodland (CES202.334) using the modified HCCVI of Comer et al. (2012) (Costanza 2t al. 2014)

Vulnerability rankings of habitats were defined differently by each researcher, so we must use caution when comparing results. When referring to the definitions rather than the ratings themselves, we can see broadly similar results in the higher vulnerability of habitats in cooler temperatures and at higher elevations; Butler et al. (2015) and Manomet (2012a) both assessed Appalachian Hemlock-Hardwood habitats to be of higher vulnerability in the Central Appalachian subregion. Habitats of warmer temperatures varied by habitat structure. Forested habitats of drier and warmer settings are thought to be of lower vulnerability. For example, Manomet (2012a) ranked the Central Mixed Oak-Pine Forest as vulnerable, defined as "likely to be relatively unaffected". Butler et al. (2015) ranked a similar habitat (Dry Oak and Pine / Oak Forest and Woodland) as low in vulnerability. Open habitats such as glades have generally higher localized exposure, rendering them more vulnerable to climate change. Butler et al. (2015) ranked Dry Calcareous Forest, Woodland and Glade as moderate to high in vulnerability in the Central Appalachian subregion. Costanza et al. (2014) ranked Nashville Basin Limestone Glade and Woodland, a habitat of the Interior Low Plateau, as highly vulnerable.

Rankings of habitats by the North Carolina Department of Natural Resources (2010) in the Cumberland – Southern Appalachian subregion applied three categories of ranking (likelihood, effect, and magnitude) to several different vulnerability factors as appropriate to the habitat, including mild winters, wind damage, hot spells, fire, drought, and increased temperatures. In general, montane and cool habitats (spruce-fir forests, northern hardwood forests) were assessed to be negatively impacted by a number of vulnerability factors, with results in general agreement with those of the other researchers. Cove forests were also assessed to be negatively impacted by a number of factors. Mafic glades and barrens (open habitats of stressed by the chemical structure of serpentine bedrock) were assessed to be positively affected by wind and drought, but at relatively low magnitude.

Criteria for selection of additional species to be assessed

In January 2013, an Expert Panel assisted our work to date by developing a set of criteria to aid in our selection of species and habitats to assess. The criteria include species of:

- High conservation significance (rare or endangered; significant portion of range restricted to the LCC; on other established lists)
- Importance to the ecological system (foundation or keystone species – provides structure or modulates conditions for other species; dominant species; important food source)

- High indicator value with respect to climate change (species with known sensitivities)
- High management importance (game or pest species)
- Importance to public health (disease vectors)
- Importance for cultural value (iconic species)

We developed a draft list of species that addressed the criteria, as well as those that filled important data gaps. In consultation with Appalachian LCC staff, we contacted nine potential technical review committee members from state wildlife agencies, natural heritage programs, and NGO's to help us to determine the process of species selection. We provided the list and supporting materials to the four respondents, and held a conference call. Appalachian LCC staff circulated the draft lists for additional review, and based on input from reviewers, we limited the list to species of high conservation concern (all or most of range restricted to the LCC; species on the Appalachian LCC global trust list, southern range limit), those of high importance to the ecological system (keystone or dominant species; important food source, important in many habitats; important wetland indicator, unique habitat indicator), and those with known or suspected climate sensitivities. We also emphasized plants in our analysis: out of 700 total species assessed previously, only 137 were plants, and many of those were recently assessed by a state at the northern limit of the LCC (New Jersey). Other factors affecting our decision to focus more on plants than on animals included: a) plants are more visible and more easily monitored than are most animals; b) decline of plants that are important to the ecosystem, either as dominants, keystone species, or important food sources will have cascading effects on other dependent species; or c) those with high fidelity to a certain habitat can function as an early warning system that an ecosystem is undergoing change and that other associated species not specifically monitored may also be undergoing a change.

Appalachian LCC staff served as arbiters of the final list selected for vulnerability analysis. Table 7 lists the selected species, conservation status rank (global rank), and justification for selection.

Taxonomic Group	Scientific Name	English Name	Global Rank	Selection Justification*
Vascular Plant	*Tsuga caroliniana*	Carolina hemlock	G3	L, R
Mammal	*Reithrodontomys humulis*	Eastern Harvest Mouse	G5	IH
Vascular Plant	*Cladrastis kentuckea*	Yellow-wood	G4	F
Amphibian	*Desmognathus santeetlah*	Santeetlah Dusky salamander	G3G4	L, CS
Amphibian	*Plethodon nettingi*	Cheat Mountain Salamander	G2G3	AL, L, R
Vascular Plant	*Stellaria fontinalis*	Water stitchwort	G3	L, CS, R
Vascular Plant	*Actaea podocarpa*	Mountain bugbane	G4	L
Reptile	*Cemophora coccinea*	Northern Scarletsnake	G5	IH
Vascular Plant	*Neviusia alabamensis*	Alabama Snow-wreath	G2	L, R
Vascular Plant	*Silene regia*	Royal catchfly	G3	L, R
Vascular Plant	*Buckleya distichophylla*	Piratebush	G3	L, R
Vascular Plant	*Jamesianthus alabamensis*	Alabama warbonnet	G3	L, R
Vascular Plant	*Carya carolinae-septentrionalis*	Southern Shagbark Hickory	G5	N, F, L
Vascular Plant	*Eurybia saxicastelli*	Rockcastle wood-aster	G1G2	U, IW, R
Amphibian	*Plethodon hubrichti*	Cheat Mountain Salamander	G2	AL, R
Vascular Plant	*Arabis georgiana*	Georgia rock Cress	G1	L, R
Vascular Plant	*Vaccinium myrtilloides*	Velvetleaf blueberry	G5	K, F
Vascular Plant	*Clintonia borealis*	Bluebead	G5	S, CS
Vascular Plant	*Castilleja coccinea*	Scarlet Indian Paintbrush	G5	L
Vascular Plant	*Helonias bullata*	Swamp Pink	G3	IW, R
Vascular Plant	*Polemonium vanbruntiae*	Bog Jacob's Ladder	G3G4	IW
*Key to justification for selection: keystone or dominant (K); important food source (F); LCC restricted (L); suspected climate sensitive (CS); southern range limit (S); important wetland indicator (IW); important in many habitats (IH); AppLCC list (AL); Unique habitat indicator (U); Rare (R)				

Table 7 Final list of species assessed for climate change vulnerability in Phase II

Taxonomic Group	Scientific Name	English Name	Global Rank	Selection Justification
Vascular Plant	*Xyris tennesseensis*	Tennessee Yellow-eyed grass	G1	L, CS, R
Vascular Plant	*Bouteloua curtipendula*	Sideoats gramma	G5	K, U
Vascular Plant	*Baptisia australis*	Blue wild indigo	G5	F, IW
Vascular Plant	*Cymophyllus fraserianus*	Fraser's sedge	G4	L
Invert-Insect	*Speyaria diana*	Diana fritillary	G3	L, R
Invert-Insect	*Cicindela ancocisconensis*	Appalachian tiger beetle	G3	L, R
Invert-Insect	*Catacola marmorata*	Marbled underwing	G3G4	L
Invert-Insect	*Euphydryas phaeton*	Baltimore checkerspot	G4	CS
Vascular Plant	*Dalea foliosa*	Leafy prairy clover	G2G3	L, R
Vascular Plant	*Astragalus tennesseensis*	Tennessee milkvetch	G3	L, R
Vascular Plant	*Echinacea laevigata*	Smooth purple cone flower	G2G3	L, U, R
Vascular Plant	*Eriogonum allenii*	Shale barren buckwheat	G4	U, L
Vascular Plant	*Gaylussacia brachycera*	Box huckleberry	G3	L, R
Vascular Plant	*Helenium virginicum*	Virginia Sneezeweed	G3	IW, L, R
Vascular Plant	*Helianthus eggertii*	Eggert's sunflower	G3	L, R
Vascular Plant	*Hypericum mitchellianum*	Blue Ridge St. Johnswort	G3	L, R
Vascular Plant	*Leiophyllum buxifolium*	Sand-myrtle	G4	U
Amphibian	*Desmognathus wrighti*	Southern Pygmy salamander	G3	L, R
Amphibian	*Desmognathus imitator*	Imitator salamander	G3G4	L, CS
Vascular Plant	*Parnassia grandifolia*	Largeleaf grass-of-parnassus	G3	IW, R

*Key to justification for selection: keystone or dominant (K); important food source (F); LCC restricted (L); suspected climate sensitive (CS); southern range limit (S); important wetland indicator (IW); important in many habitats (IH); AppLCC list (AL); Unique habitat indicator (U); Rare (R)

Table 7 (continued) Final list of species assessed for climate change vulnerability in Phase II

Criteria for selection of additional habitats to be assessed

The major criterion that we used for selection of habitats was geographic. Our compilation of existing species assessments noted in Table 1, and compilation of existing habitat assessments in Tables 2-4 illustrate a large data gap in the Interior Low Plateau subregion. Approximately 21% of previously assessed species and one of the previously assessed habitats occurs in this subregion. As a result, we chose habitats that are important in the Interior Low Plateau, and that are also broadly different from each other in environmental setting, function, and species composition, and hence support a broad diversity of species.

A standardized classification and distribution map of habitats was key to the selection process. We used the NatureServe Ecological Systems Classification and habitat descriptions for the Central Appalachian and portions of the Cumberland – Southern Appalachian subregions developed from the NatureServe Ecological Systems Classification (Gawler 2008). We relied upon the NatureServe national map of Ecological Systems (Comer et al. 2003, NatureServe 2009, Smyth et al. 2013), that was developed as a result of several different mapping efforts, including LandFire (Rollins et al. 2006, Rollins 2009) and the Southeast Gap Analysis Program (Jennings et al. 2009, Kleiner 2007) map, and updates it periodically with new information. Based on this map and the criteria outlined above, we identified Ecological Systems that are important in the Appalachian LCC region, and annotated them by major categories: a) broad geographic expanse; b) important wetland types; and c) unique to the Appalachian LCC region (Table 8). Ecological Systems that cover large geographic portions of the LCC are denoted as Matrix (M) or Large Patch (LP). Matrix systems form the most extensive vegetation cover, with smaller patches of other systems often embedded. Large Patch Ecological Systems cover 100s to 1000s of hectares, and often form a matrix with other large patch systems. Important wetlands (IW) are those that are characteristic of the LCC region, including floodplain, riparian, sinkhole ponds, fens, bogs and the like. Unique Ecological Systems (U) are those that are more or less restricted to the Appalachian LCC and often support a large number of rare species adapted to the unusual environmental settings characterizing them.

M = matrix; LP= large patch; U = unique habitat; IW = important wetland		Central Appalachians	Cumberland SBR (Southern Appalachian)	Interior Low Plateau
CES202.593	Appalachian (Hemlock)-Northern Hardwood Forest	M		
CES202.598	Appalachian Shale Barrens	U		
CES201.564	Laurentian-Acadian Northern Hardwood Forest	M		
CES202.029	Southern Appalachian Northern Hardwood Forest		M-LP; U	
CES202.373	Southern and Central Appalachian Cove Forest	M	M; U	
CES202.457	Southern Ridge and Valley / Cumberland Dry Calcareous Forest		M-LP	
CES202.359	Allegheny-Cumberland Dry Oak Forest and Woodland		M	
CES202.886	Southern Appalachian Oak Forest		M-LP; U	
CES202.294	Southern Appalachian Grass and Shrub Bald		U	
CES202.591	Central Appalachian Dry Oak-Pine Forest	M-LP		
CES202.887	South-Central Interior Mesophytic Forest	M-LP		M-LP
CES202.898	**Southern Interior Low Plateau Dry-Mesic Oak Forest**			**M**
CES202.692	**Central Interior Highlands Calcareous Glade and Barrens**			**U**
CES202.592	Northeastern Interior Dry-Mesic Oak Forest	M		
CES202.334	Nashville Basin Limestone Glade and Woodland			U
	Early Successional	LP	LP	LP
CES202.608	Central Appalachian River Floodplain	IW		
CES202.609	Central Appalachian Stream and Riparian	IW		
CES202.018	Central Interior Highlands and Appalachian Sinkhole and Depression Pond	IW	IW	IW
CES202.036	Cumberland Riverscour		IW; U	
CES202.069	High Allegheny Wetland	IW; U		

Table 8 Major habitats of the Appalachian LCC

Those chosen for assessment shown in bolded blue

M = matrix; LP= large patch; U = unique habitat; IW = important wetland		Central Appalachians	Cumberland SBR (Southern Appalachian)	Interior Low Plateau
CES202.317	Southern Appalachian Seepage Wetland		IW; U	
CES202.706	**South-Central Interior Small Stream and Riparian**		**IW**	**IW**
CES202.705	South-Central Interior Large Floodplain		IW	IW
CES202.300	Southern and Central Appalachian Bog and Fen	IW; U	IW; U	IW; U
CES202.361	Cumberland Seepage Forest		IW; U	
CES202.604	North-Central Appalachian Acidic Swamp	IW		
CES202.346	Interior Low Plateau Seepage Fen			IW; U
	Wet Meadow - Marsh	IW	IW	IW

Table 8 Major habitats of the Appalachian LCC; those chosen for assessment shown in bolded blue (continued)

Table 8 also indicates the subregion(s) of occurrence for each ecological system, which we derived from the NatureServe map. The three ecological systems chosen for analysis included a matrix forest restricted to the Interior Low Plateau (Southern Interior Low Plateau Dry-Mesic Oak Forest), a unique small-patch habitat restricted to dry calcareous bedrock in the Interior Low Plateau (Central Interior Highlands Calcareous Glade and Barrens), and an important wetland type of broader geographic range but important in the Interior Low Plateau (South-Central Interior Small Stream and Riparian).

Vulnerability assessment methods - Species

Vulnerability rankings were initially calculated using Release 2.1 of the CCVI, in keeping with those done by researchers in the existing assessments. We imported those results into the recently updated CCVI tool, Release 3.0 (Young et al. 2015a). Due to time constraints, we did not conduct any new analyses, nor make use of the new fields in Version 3.0, but the revised weightings incorporated into the newer version resulted in some important differences, generally an increase in vulnerability. Release 3.0 results are reported and discussed in this paper, and we have included a comparison of results from both releases in Appendix G. A detailed description of improvements in Release 3.0 is provided in Young et al. (2015b).

Release 3.0 of the CCVI was developed in response to survey results provided by users of Release 2.1 (Young et al. 2011). The two releases differ in the way factors are scored. The earlier release included Decrease and Somewhat Decrease categories for many of the Section B, C, and D factors. These categories were eliminated in the more recent edition used by NatureServe because it was concluded that, for example, good dispersal ability (formerly a Decrease category) does not offset dependence on snow habitats (an Increase category) with respect to climate change vulnerability. As a result, species that are categorized as Neutral for most of the Section B-D factors will tend to have an overall score of Less Vulnerable and may well increase, either in population density and/or range size within the assessment area. The removal of the Decrease categories has a tendency to result in a higher overall CCVI score for species that were previously categorized in both Decrease and Increase categories for one or more factors. This outcome helps highlight the intrinsic vulnerabilities that species have to climate change.

Additional features of Release 3.0 include:

- additional guidance for assessing plants, including a new factor on plant reproductive systems
- new factor for assessing range of migratory species when not in the assessment area
- replacement of the Presumed Stable and Increase Likely ranks with one rank, Least Vulnerable
- modifications to increase clarity in application to:
    - Physiological hydrologic niche
    - Restriction to uncommon landscape / geological features or derivatives
    - (renamed) Dependence on other species to generate required habitat
    - Dietary versatility
- Added field: Sensitivity to pathogens or natural enemies
- Added field: Sensitivity to competition from native or non-native species
- Information added to Documented or Modeled Response to Climate Change (section D) causes scores in sections B (indirect climate effects) and C (sensitivity and adaptive capacity) to be weighted more heavily
- Algorithm automatically classifies a species as Extremely Vulnerable if its exposure to sea level rise increases its vulnerability, it has strong barriers to dispersal, and is a poor disperser.

Both versions of the CCVI use exposure-weighted scoring of multiple factors that can potentially affect species' vulnerability to climate change (Young et al. 2012). The CCVI is programmed in a Microsoft Excel® workbook and provides a relatively rapid means to assess the vulnerability of plant and animal species within a defined geographic area. Factors are divided into two major components, exposure and sensitivity. Exposure refers to the degree of predicted change in temperature and moisture availability across the species' range within the assessment area. Sensitivity refers to how tightly species are linked to specific microclimates and ecological conditions that might be affected by climate change, as well as the capacity of the species to adapt to these changes.

Climate Exposure

Direct Exposure

In the CCVI, exposure is divided into two factors, direct and indirect. Direct exposure comprises the actual components of climate, temperature, and available moisture that have an explicit impact on species. Indirect exposure (see following section) refers to how the landscape context of a species' range can interact with climate change and have secondary effects on the species.

Direct exposure was measured using the downloaded future projected temperature and moisture data against a digital range map of the species. Each species was assessed within each subregion where it occurs, resulting in up to three assessments per species. Species' ranges were compiled from a variety of sources: NatureServe Explorer (NSX) provides state and province-of-occurrence ranges for all species tracked by natural heritage programs and Canadian Conservation Data Centres (CDC), and NSX includes more detailed shaded range maps for most animal species. Other sources of more detailed range data included the tree species ranges mapped by Little between 1971 and 1977 (digitized by the US Forest Service and available as downloadable shapefiles from http://www.fs.fed.us/nrs/atlas/littlefia/species_table.html#); USDA's Plants database (http://plants.usda.gov/), the Butterflies and Moths of North America (BAMONA) website (http://www.butterfliesandmoths.org/), and the Moth Photographers Group (http://mothphotographersgroup.msstate.edu/). We gratefully acknowledge the assistance and data provided by these organizations.

We used the climate data sets recommended by both versions of the CCVI (Young et al. 2012), ensemble climate predictions that represent a median of 16 major global circulation models (GCMs) and a medium emission scenario (A1B) for mid-century (2050s). We used the Climate Wizard contiguous US data (http://climatewizard.org/, Girvetz et al. 2009), which are available at a resolution of 4 km for current temperatures and precipitation and 12 km for future temperatures and precipitation. These were the most accessible climate data available to us at the beginning of our analysis, but the field of climate change analysis is a rapidly growing one. New climate analyses funded by the Appalachian LCC were recently developed for the region (Auer 2015), and we discuss this further later in this report.

Precipitation data are also available on Climate Wizard, but the amount of rainfall alone does not provide adequate information on available moisture in terrestrial habitats because increased temperatures can increase the rate of evaporation and evapotranspiration. Many areas are predicted to experience net drying in the next 50 years, even those where precipitation is also predicted to increase (Brooks 2009). A more nuanced measure derived from data available from Climate Wizard is the Hamon AET:PET moisture metric (Hamon 1961), a ratio of actual evapotranspiration (AET) to potential evapotranspiration (PET) that integrates temperature and precipitation as they are influenced by total daylight hours and saturated vapor pressure.

Indirect Exposure

Indirect exposure includes three factors in the CCVI: sea level rise, distribution relative to barriers (both natural and anthropogenic), and predicted impact of land use changes resulting from human response to climate change. Examples of the third factor include wind farm placement, biofuel production, and tree planting for carbon sinks. Species' ranges were compared to GIS data on natural and anthropogenic barriers. We used USGS hillshade relief derived from the National Elevation Dataset (USGS 2009) to identify natural barriers to migration, e.g. mountains, lakes, and other features that would pose a natural barrier to dispersal. Our source of anthropogenic barrier data was a landscape condition model (Comer and Hak 2009) in comparison with species' ranges.

Sensitivity

Sensitivity to climate change is assessed using up to 20 individual factors that are grouped into two categories: (1) indirect exposure to climate change, and (2) species-specific sensitivity pertaining to individual species' biology and natural history. The latter includes factors such as genetic diversity, dispersal capability, interspecific interactions, and others indicating potential adaptive capacity of species in the face of climate change.

GIS data were used to compare the historical thermal and hydrological niches of species. These factors are measures of the degree of variation in climate that a species has been exposed to within the past 50 years, as mapped from historical downscaled climate data from Climate Wizard. Figures 4 and 5 are examples of mapped climate projections using these data.

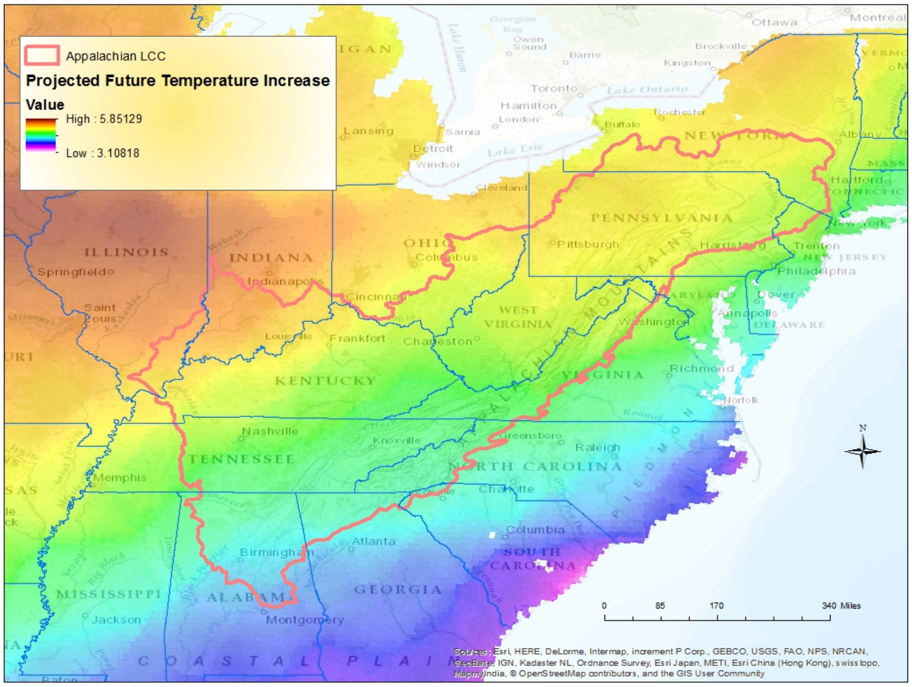

Figure 4. Mid-century (2040-2069) projected increase in temperature in degrees Fahrenheit.
Source: Climate Wizard http://climatewizard.org/ (Girvetz et al. 2009)

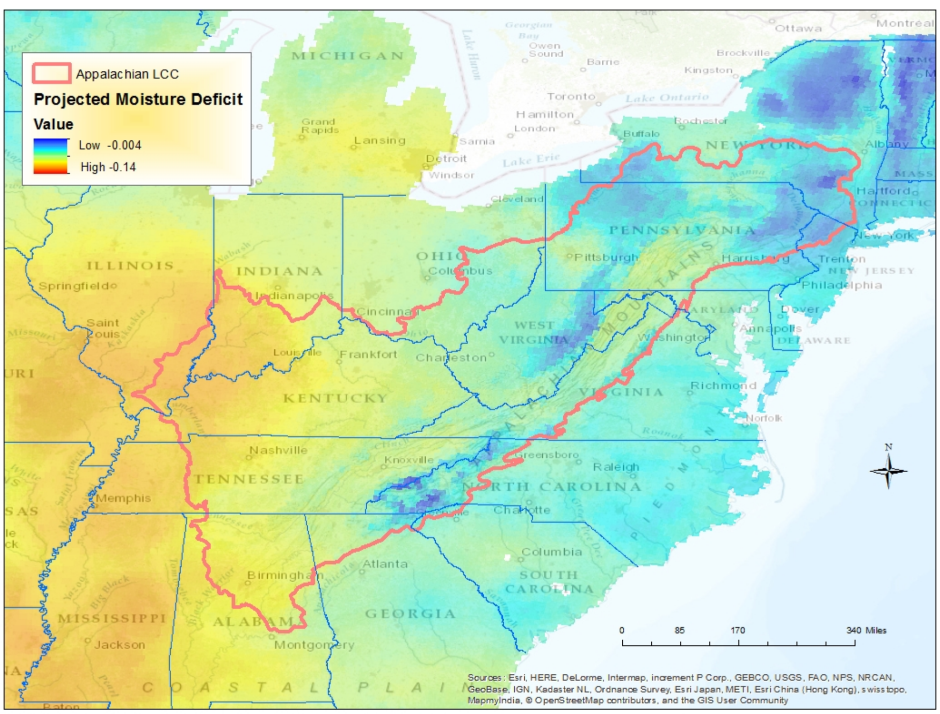

Figure 5 Projected mid-century (2040-2069) Hamon moisture metric (Hamon 1961)
a ratio of actual evapotransporation to potential evapotranspiration (AET:PET). A greater negative value symbolizes net drying. No areas in the LCC are predicted to experience increased moisture.

Natural history information was compiled to assess species-specific responses to climate. Much of this information is housed in NatureServe's Biotics databases, and available through NatureServe Explorer http://www.natureserve.org/explorer/. Some species required additional literature research to obtain the needed information on dispersal, dependence on unusual habitats or other species, factors affecting adaptive capacity such as genetic diversity, documented or modeled responses to climate change, as well as physiological thermal and hydrologic niches. The latter measures the degree to which a species is particularly dependent on a narrow range of climatic variation. For example, species that are dependent on cold climates score higher in thermal physiological niche sensitivity than do species that have wider temperature tolerances. Similarly, species that are restricted to habitats that are dependent on a particular flooding regime, such as vernal pools, also score higher in this category. Atlases for tree (Prasad et al. 2007-ongoing) species for current and projected climates were used to document predicted responses to climate change for these taxa. Natural history information sources are documented in a separate tab of the CCVI tool available with this report.

Vulnerability assessment methods – habitats

Assessment of the vulnerability of habitats to climate change is considerably more complex than for individual species, each of which reacts individually to its environment. As the climate changes, the habitat will not migrate as a distinct unit to a new location; rather, the habitat transforms *in situ* as species migrate into and out of it over time. Assessing the vulnerability of a habitat tells us its degree of resistance to change, where it exists now by examining the degree of exposure to predicted climate change, and evaluating the sensitivity of individual species comprising it. Since we cannot assess the sensitivity of all species dependent on a particular habitat, it is important to understand that of keystone or foundation species that provide habitat (food, shelter, breeding habitat) for other species.

Beginning in the early 2000s a small number of habitat vulnerability assessment models were developed, tested and applied in North America. One habitat model, the HCCVI (Comer et al. 2012), was in development at the start of this project. This model comprises different components that allow the user to evaluate the components independently or in concert, and includes quantitative modeling. One published habitat assessment in the Appalachian LCC region (Costanza et al. 2014) uses the HCCVI. Another habitat model was developed under the auspices of the Northeastern Fish and Wildlife Agencies (NEAFWA), and tested and applied to a number of habitats throughout the 13 states of the Northeastern Region (Manomet 2012a) in individual states, including New York (Hilke and Galbraith, 2013). In that the scope of this project did not allow for quantitative modeling, we adapted and applied the second model in analysis of three important habitats in the LCC region.

Vulnerability model - structure and variables

The form of the original NEAFWA Habitat Vulnerability Model comprised four connected modules. We limited our use of the model to Module 1, which was designed to be used alone if the objective is to initially categorize climate change vulnerabilities, independent of other non-climate stressors. The original model comprises 11 variables and scores the likely vulnerabilities of habitats to future climate change (and the potential interaction between climate and non-climate stressors). Each of the model variable scores was assigned a certainty score: High, Medium, or Low. These approximate confidence levels of >70%, 30-70%, and <30%. They are based on the 5-category scale developed by Moss and Schneider (2000) for the Intergovernmental Panel on Climate Change Third Assessment Report. However, it was believed by the NEAFWA model developers that using a 5-category scoring system would imply a greater level of certainty precision than was defensible, and it was, therefore, collapsed into a 3-category scale.

Another modification to the NEAFWA model was the use of exposure measures. We used the same climate variables for those recommended by the CCVI tool, used by other researchers doing species assessment, and by us in new assessessments of the 41 species for vulnerability to climate change. Within each subregion where the habitat occurs, we estimated the percent of the range of the type against each of the temperature and moisture categories used in the CCVI (Figure 6), placed them in the same 5-category scoring system as was used for other aspects of the model. We then multiplied the range percentages (which summed to 100%) by the numerical category to arrive at the score. We also re-calibrated the score ranges to account for the two additional variables (Table 9).

Most categorizations in the evaluation of AppLCC habitats are based largely on expert judgment and literature review. The narratives that accompany the model results in this report make transparent the thought processes and assumptions that underlie these judgments.

The narratives have three additional important aims:

1) To identify main sources of uncertainty and those areas where additional data might reduce uncertainty.

2) To identify and describe the roles of the main climate change stressors in the estimate of vulnerability of the habitats.
3) To qualitatively describe potential responses of the habitats to climate change and any resulting change in extinction risk.

For each of the variables and scores, the model spreadsheets include individual tabs that explain why the factor is important and provide guidance on how to score each variable (Appendices A-D).

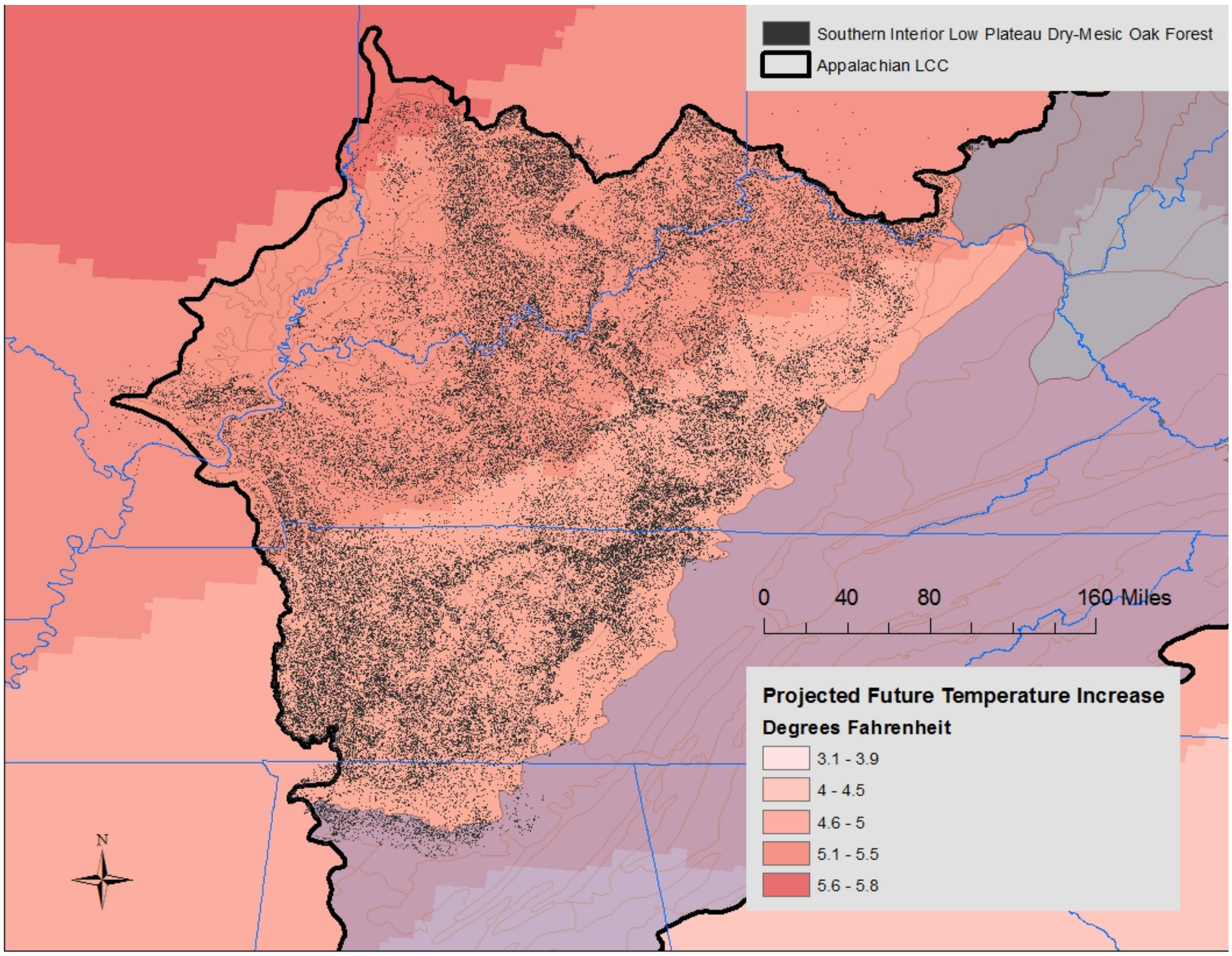

Figure 6 Range of Southern Interior Low Plateau Dry Mesic Oak Forest (in black, in Interior Low Plateau subregion) depicting exposure to projected mid-century (2050s) temperature increase by temperature category

12. Exposure to projected net drying	>-0.119	0%	5	High	3
	"-0.119 - -0.097"	0%	4		2
	"-0.096 - -0.074"	45%	3	Medium	1
	"-0.073 - -0.051"	45%	2		
	"-0.050 - -0.028"	10%	1	Low	
		Score	2.35	**Score**	2

13. Exposure to projected temperature increase	>5.5	0%	5	High	
	5.4-5.1	0%	4		
	5.0-4.5	90%	3	Medium	
	4.4-3.9	10%	2		
	<3.9	0	1	Low	
		Score	2.9	**Score**	2

Total Vulnerability Score		**35.4**	Vulnerable	
Total Certainty Score				**30**

Score range	Vulnerability category	Description
13-23	Least Vulnerable (Vc1)	Habitats that may benefit from climate change and increase their extents greatly (>50%).
24-34	Less Vulnerable (Vc2)	Habitats that may not be at adverse risk from climate change, or that may benefit and increase their extents (<50%)
35-45	Vulnerable (Vc3)	Habitats that are at risk of being significantly reduced in extent (20-50%) by climate change.
45-55	Highly Vulnerable (Vc4)	Habitats that are at high risk of being greatly reduced in area (>50% reduction) by climate change
56-65	Critically Vulnerable (Vc5)	Habitats that are at high risk of being eliminated entirely from area by climate change

Table 9 Climate exposure measures added to the NEAFWA climate change vulnerability assessment model for habitats this example is taken South-Central Interior Small Stream and Riparian habitat in Cumberland and Southern Appalachian subregion; see Appendix B for full model results

Results

Analysis of new data - species

Results of our analysis are stored in the CCVI spreadsheet on the results tab, which includes ratings or measures for each of the factors assessed for each species. There are multiple results for each species, depending on the number of subregions where it occurs. Each has a confidence associated with the vulnerability rank. We also included a tab ("documentation") that notes the data sources for each factor requiring additional research for each species, as well as scoring comments. (Full CCVI results are included in a separate Appendix F, and area also available for download from the Appalachian LCC web site: http://applcc.org/research/climate-change-vulnerability-group/final-narrative-climate-change-vulnerability-assessment/ccva-source-materials/climate-change-vulnerability-assessments-and-documentation-for-41-species/view).

Of the 41 species newly assessed, 30 were found to have ranks spanning MV to EV, indicating vulnerability to climate change. Eleven species were ranked as Extremely Vulnerable; all were plants and all but two are rare. The remaining two are ranked G5 and are at the center of their range in the LCC. 13 species were ranked as Highly Vulnerable; these comprise two plants and two amphibians, and all but two have global ranks in the G1-G3 range. Seventeen species were ranked as Moderately Vulnerable, of which 11 are plants. Only five of the seventeen are rare. Of those species determined to be not vulnerable (Presumed Stable or Increase Likely), only two, both trees, and ranked Increase Likely. The remaining nine species are ranked Presumed Stable, and these include 5 plants, 1 reptile, 1 mammal, and 2 insects. All but two of these species, one plant and one insect, are common, having global ranks in the G4-G5 range.

Table 10 provides a summary of the distribution by taxonomic group, conservation status rank, and vulnerability rank by subregion and as a whole.

Categories: taxonomic, conservation status rank, vulnerability rank		Total in LCC	Subregion		
			Central Appalachians	Cumberland - Southern Appalachians	Interior Low Plateau
Number of Phyla		4	3	4	3
Number of Families		25	17	24	14
Plants		30	18	27	15
	Trees	3	0	3	1
	Shrubs	4	4	3	1
	Forbs	20	11	17	10
	Graminoids	4	3	4	2
Animals		11	5	9	4
	Mammals	1	1	1	1
	Herptiles	6	1	4	1
	Insects	4	3	4	2
Conservation Status Rank[7]					
	G1-G3	23	11	20	10
	G3G4-G5	18	12	16	9
Vulnerabiliy Ranks					
	EV, HV		14	24	14
	LV		1	6	1
	MV		9	6	4
Total Species		41	23	36	19

Table 10 Summary of assessments by category of 41 newly assessed species

Table 11 provides results of individual species assessments by habitat and subregion. Information about species-habitat associations were drawn from the Southern Appalachian Species Viability Project (2002) and from descriptions of Ecological Systems (NatureServe 2014). Most species analyzed exhibited the same vulnerability score in each of the subregions where they occur. This result is not unexpected, because the natural history information pertaining to a species does not, in most cases, vary markedly across its geography. Eleven species, however, did vary in their vulnerability ranks across the region. This variation can be attributed in large part to the marked difference in predicted exposure (increased temperatures and increased dryness) across the LCC region. The Interior Low Plateau has the highest predicted exposure, the Cumberland – Southern Appalachian subregion the lowest, and that of the Central Appalachian subregion falls between the two. Four of the eleven species (wild blue indigo, northern scarletsnake,

[7] NatureServe conservation status ranks and their definitions are in Appendix G

Fraser's sedge, and box huckleberry, all G4 or G5) are ranked as Moderately Vulnerable in the Interior Low Plateau, but Presumed Stable in either or both the other two subregions. Three species, Eggert's sunflower, royal catchfly, and large-leaved grass-of-Parnassus, are ranked as one category higher in vulnerability than in other subregions: Eggert's sunflower is Highly Vulnerable in the Interior Low Plateau and Moderately Vulnerable in the Cumberland – Southern Appalachian subregion, while large-leaved grass-of-parnassas and royal catchfly are ranked Extremely Vulnerable in the Interior Low Plateau and Highly Vulnerable in the other subregions. Two species, scarlet Indian paintbrush and sideoats gramma, have higher vulnerability ranks in both the Interior Low Plateau and Central Appalachian subregions than in the Cumberland – Southern Appalachian subregion (Extremely Vulnerable vs Highly Vulnerable in the case of scarlet Indian paintbrush, and Highly Vulnerable vs Moderately Vulnerable in sideoats gramma). Of those species occurring in more than one subregion and found to be not vulnerable, Carolina hemlock is ranked as Presumed Stable in the Interior Low Plateau but Increase Likely in the other two subregions.

Two additional montane species outside the Interior Low Plateau have different predicted vulnerabilities in the two subregions where they occur: velvetleaf blueberry is ranked Moderately Vulnerable in the Central Appalachian subregion but Presumed Stable in the Cumberland – Southern Appalachian subregion, and bluebead lily is Highly Vulnerable in the Central Appalachian subregion but Moderately Vulnerable in the Cumberland – Southern Appalachian subregion.

Species	Scientific Name	Habitat Name	Major habitat	Central Appalachian	Cumberland - Southern Blue Ridge	Interior Low Plateau
Mountain bugbane	*Actaea podocarpa*	Southern and Central Appalachian Cove Forest	Upland	MV	HV	
Georgia rock cress	*Arabis georgiana*	Alabama Ketona Glade and Woodland	Upland		HV	
Tennessee milkvetch	*Astragalus tennesseensis*	Nashville Basin Limestone Glade and Woodland	Upland			EV
		Central Interior Highlands Calcareous Glade and Barrens	Upland		EV	EV
Wild blue indigo	*Baptisia australis*	Cumberland Riverscour	Wetland		LV	MV
		Central Appalachian Stream and Riparian	Wetland	MV	LV	
Sideoats gramma	*Bouteloua curtipendula*	Nashville Basin Limestone Glade and Woodland	Upland			EV
		Central Appalachian Alkaline Glade and Woodland	Upland	EV	EV	
		Central Interior Highlands Calcareous Glade and Barrens	Upland			EV
Piratebush	*Buckleya distichophylla*	Southern Appalachian Low-Elevation Pine Forest	Upland	MV	MV	
		Southern Appalachian Oak Forest	Upland		MV	
Southern shagbark hickory	*Carya carolinae-septentrionalis*	Alabama Ketona Glade and Woodland	Upland			LV
		Southern Interior Low Plateau Dry-Mesic Oak Forest	Upland			
		Southern Ridge and Valley Dry Calcareous Forest	Upland		LV	LV
Scarlet Indian paintbrush	*Castilleja coccinea*	Southern and Central Appalachian Bog and Fen	Wetland	EV	EV	
		Central Interior Highlands Calcareous Glade and Barrens	Upland			EV
		Southern and Central Appalachian Mafic Glade and Barrens	Upland		EV	

Table 11 Results of species assessments by habitat and subregion

Species	Scientific Name	Habitat Name	Major habitat	Central Appalachian	Cumberland - Southern Blue Ridge	Interior Low Plateau
Marbled underwing	*Catacola marmorata*	Central Appalachian River Floodplain	Wetland		LV	
		South-Central Interior Large Floodplain	Wetland			HV
		Central Appalachian Stream and Riparian	Wetland		LV	
		South-Central Interior Small Stream and Riparian	Wetland			HV
Northern scarletsnake	*Cemophora coccinea*	Early Successional	Upland		MV	MV
Appalachian tiger beetle	*Cicindela ancocisconensis*	South-Central Interior Large Floodplain	Wetland		HV	HV
		Central Appalachian Stream and Riparian	Wetland		HV	
		Central Appalachian Floodplain	Wetland			HV
		South-Central Interior Small Stream and Riparian	Wetland			HV
Yellow-wood	*Cladrastis kentuckea*	Southern Ridge and Valley / Cumberland Dry Calcareous Forest	Upland		HV	HV
Bluebead	*Clintonia borealis*	Central and Southern Appalachian Spruce-Fir Forest	Upland	HV	MV	
Fraser's sedge	*Cymophyllus fraserianus*	Southern and Central Appalachian Cove Forest	Upland	MV	LV	
Leafy prairie clover	*Dalea foliosa*	Central Interior Highlands Calcareous Glade and Barrens	Upland		EV	EV

Table 11 Results of species assessments by habitat and subregion (continued)

Species	Scientific Name	Habitat Name	Major habitat	Central Appalachian	Cumberland - Southern Blue Ridge	Interior Low Plateau
Imitator salamander	*Desmognathus imitator*	South-Central Interior Large Floodplain	Wetland		HV	
		Southern Appalachian Seepage Wetland	Wetland		HV	
		Cumberland Seepage Forest	Wetland		HV	
		South-Central Interior Mesic Forest	Upland		HV	
Santeetlah dusky salamander	*Desmognathus santeetlah*	Cumberland Seepage Forest	Wetland		HV	
		Central and Southern Appalachian Spruce-Fir Forest	Upland		HV	
Southern pygmy salamander	*Desmognathus wrighti*	Central and Southern Appalachian Spruce-Fir Forest	Upland		HV	
		Central Appalachian Stream and Riparian	Wetland		HV	
Smooth purple cone flower	*Echinacea laevigata*	Southern and Central Appalachian Mafic Glade and Barrens	Upland			EV
		Central Appalachian Alkaline Glade and Woodland	Upland		EV	
Shale barren buckwheat	*Eriogonum allenii*	Appalachian Shale Barrens	Upland		HV	HV
Baltimore checkerspot	*Euphydryas phaeton*	Southern and Central Appalachian Bog and Fen	Wetland	HV	MV	
		Southern Appalachian Seepage Wetland	Wetland		MV	HV
Rockcastle wood-aster	*Eurybia saxicastelli*	Cumberland Riverscour	Wetland		EV	

Table 11 Results of species assessments by habitat and subregion (continued)

Species	Scientific Name	Habitat Name	Major habitat	Central Appalachian	Cumberland - Southern Blue Ridge	Interior Low Plateau
Box huckleberry	*Gaylussacia brachycera*	Central Appalachian Pine-Oak Rocky Woodland	Upland	MV		
		Southern Appalachian Low-Elevation Pine Forest	Upland		LV	
		Allegheny-Cumberland Dry Oak Forest and Woodland	Upland			MV
Virginia sneezeweed	*Helenium virginicum*	Central Interior Highlands and Appalachian Sinkhole and Depression Pond	Wetland	EV		
Eggert's sunflower	*Helianthus eggertii*	Central Interior Highlands Calcareous Glade and Barrens	Upland			HV
		Allegheny-Cumberland Dry Oak Forest and Woodland	Upland		HV	
Swamp Pink	*Helonias bullata*	North-Central Appalachian Acidic Swamp	Wetland	EV		
		Southern Appalachian Seepage Wetland	Wetland		EV	
		Cumberland Seepage Forest	Wetland		EV	
Blue Ridge St. Johnswort	*Hypericum mitchellianum*	Southern Appalachian Grass and Shrub Bald	Upland	HV	HV	
		Southern Appalachian Seepage Wetland	Wetland		HV	
Alabama warbonnet	*Jamesianthus alabamensis*	Central Appalachian Stream and Riparian	Wetland		EV	
		South-Central Interior Small Stream and Riparian	Wetland		EV	

Table 11 Results of species assessments by habitat and subregion (continued)

Species	Scientific Name	Habitat Name	Major habitat	Central Appalachian	Cumberland - Southern Blue Ridge	Interior Low Plateau
Sand-myrtle	*Leiophyllum buxifolium*	Southern Appalachian Rocky Summit	Upland		MV	
		North-Central Appalachian Acidic Cliff and Talus	Upland	MV		
Alabama snow-wreath	*Neviusia alabamensis*	Southern and Central Appalachian Cove Forest	Upland		EV	
		South-Central Interior Mesophytic Forest	Upland			EV
Largeleaf grass-of-parnassus	*Parnassia grandifolia*	Southern and Central Appalachian Bog and Fen	Wetland	HV	EV	
		Interior Low Plateau Seepage Fen	Wetland			EV
Peaks of Otter salamander	*Plethodon hubrichti*	Southern and Central Appalachian Cove Forest	Upland	HV		
		South-Central Central Interior Small Stream and Riparian	Wetland	HV		
Cheat Mountain salamander	*Plethodon nettingi*	Central and Southern Appalachian Spruce-Fir Forest	Upland	HV		
		Central Appalachian Small Stream and Riparian	Wetland	HV		
Bog Jacob's ladder	*Polemonium vanbruntiae*	Southern Appalachian Seepage Wetland	Wetland	MV		
		Southern and Central Appalachian Bog and Fen	Wetland	MV		
		High Allegheny Wetland	Wetland	MV		

Table 11 Results of species assessments by habitat and subregion (continued)

Species	Scientific Name	Habitat Name	Major habitat	Central Appalachian	Cumberland - Southern Blue Ridge	Interior Low Plateau
Eastern harvest mouse	*Reithrodontomys humulis*	Wet Meadow - Marsh	Wetland	MV	HV	HV
Diana fritillary	*Speyaria diana*	Southern and Central Appalachian Cove Forest	Upland	MV	MV	
		South-Central Interior Large Floodplain	Wetland			MV
Royal catchfly	*Silene regia*	Central Interior Highlands Dry Acidic Glade and Barrens	Upland		EV	EV
Water stitchwort	*Stellaria fontinalis*	Interior Low Plateau Seepage Fen	Wetland			EV
Carolina hemlock	*Tsuga caroliniana*	Southern Appalachian Montane Pine Forest and Woodland	Upland	LV	LV	
Velvetleaf blueberry	*Vaccinium myrtilloides*	Central and Southern Appalachian Spruce-Fir Forest			HV	
		High Allegheny Wetland	Wetland	EV		
Tennessee yellow-eyed grass	*Xyris tennesseensis*	Southern and Central Appalachian Bog and Fen	Wetland		HV	HV
		Southern Appalachian Seepage Wetland	Wetland		HV	
		Interior Low Plateau Seepage Fen	Wetland			HV

Table 11 Results of species assessments by habitat and subregion (continued)

We included species in our assessment that exhibit a range of habitat requirements. Species are not usually restricted to a single habitat, and in some cases, their environmental requirements are quite broad. Others are closely tied with a specific habitat. In general, unusual habitats controlled by specific processes or environmental conditions support a number of species that are vulnerable to climate change. Table 12 groups habitats by major environmental characteristics to explore the patterns revealed in vulnerability ranks of the species we assessed that are associated with them. Habitats of shallow, dry soils often lack trees, or if trees are present, they are usually stunted and widely separated. These habitats are either edaphically controlled – soils are too shallow to support trees, or they are maintained in an open condition by frequent fire. Often the combination of both factors is at play. Included in this group of habitats are shale barrens (steep slopes of shale talus), rocky summit and outcrop habitats, cliffs and talus slopes, and glades and barrens on substrates including calcareous, acidic, and mafic rocks (serpentine parent materials). Although species strongly associated with these habitats are adapted to hot, dry conditions, limited dispersal capabilities increase their vulnerability. Of the 12 species we assessed that are associated with these habitats, only one (southern shagbark hickory) was found to be Least Vulnerable. All of the species assessed were plants, including forbs (herbaceous plants), one grass (side-oats gramma), two shrubs (box huckleberry and sand-myrtle), and two trees (yellow-wood and southern shagbark hickory). Nine species were found to be either Highly Vulnerable or Extremely Vulnerable, and two, both shrubs, were Moderately Vulnerable. Seven of these species are essentially restricted to these dry open habitats.

Of the five assessed species associated with dry forests, vulnerability ranks range from Moderately Vulnerable to Increase Likely. Of those, one is ranked as Presumed Stable in the Cumberland – Southern Appalachian subregion. The presence of trees in these forested habitats may provide an ameliorating effect on the microclimate, as opposed to the fully exposed nature of the glades, barrens, cliffs, and other dry open habitats. One of the species assessed was southern shagbark hickory, a tree ranked as Increase Likely. Piratebush, ranked as Presumed Stable, is a shrub of pine-oak / heath woodland communities and is at least moderately adapted to fire (Leahy et al. 2006). Box huckleberry, also a shrub, was ranked as Presumed Stable as well.

Habitats by characteristic	Associated species and their vulnerability ranks
Warm, dry, treeless	
Alabama Ketona Glade and Woodland	*Georgia rockcress, HV; Southern shagbark hickory, LV*
Appalachian Shale Barrens	*Shale barren buckwheat, HV*
Central Appalachian Alkaline Glade and Woodland	*Sideoats gramma, EV; Smooth purple cone flower, EV*
Central Appalachian Pine-Oak Rocky Woodland	*Box huckleberry, MV*
Central Interior Highlands Calcareous Glade and Barrens	*Sideoats gramma, EV; Leafy prairie clover, EV; Eggert's sunflower, HV; Tennessee milkvetch EV; Scarlet Indian paintbrush, EV*
Central Interior Highlands Dry Acidic Glade and Barrens	*Royal catchfly, EV*
Nashville Basin Limestone Glade and Woodland	*Sideoats gramma, EV; Tennessee milkvetch, EV*
Southern and Central Appalachian Mafic Glade and Barrens	*Smooth purple cone flower, EV, Scarlet Indian paintbrush, EV*
Southern Appalachian Rocky Summit	*Sand myrtle, MV*
North-Central Appalachian Acidic Cliff and Talus	*Sand myrtle, MV*
Dry, forested	
Southern Ridge and Valley Dry Calcareous Forest	*Yellow-wood, HV; Southern shagbark hickory, LV*
Allegheny – Cumberland Dry Oak Forest and Woodland	*Box huckleberry, MV, Eggert's sunflower, HV*
Southern Appalachian Low-Elevation Pine Forest	*Piratebush, MV, Box huckleberry, LV*
Southern Appalachian Oak Forest	*Piratebush, MV*
Southern Interior Low Plateau Dry-Mesic Oak Forest	*Southern shagbark hickory, LV*
Cooler, montane	
Central and Southern Appalachian Spruce-Fir Forest	*Southern pygmy salamander, MV; Santeetlah dusky salamander, HV; Cheat Mountain salamander, HV; Bluebead lily, MV, HV; Velvetleaf blueberry, HV, EV*
High Allegheny Wetland	*Bog Jacob's ladder, MV; Velvetleaf blueberry, EV*
Southern Appalachian Grass and Shrub Bald	*Blue Ridge St. Johnswort, HV*
Southern Appalachian Montane Pine Forest and Woodland	*Carolina hemlock, LV*

Table 12 Species vulnerability ranks with their habitats grouped by environmental characteristics

Habitats by characteristic	Associated species and their vulnerability ranks
Riparian and Floodplain	
Central Appalachian River Floodplain	*Appalachian tiger beetle, HV; Marbled underwing, MV*
Central Appalachian Stream and Riparian	*Wild blue indigo, HV; Appalachian tiger beetle, HV; Alabama warbonnet, EV; Marbled underwing, MV; Southern pygmy salamander, HV; Cheat Mountain salamander, HV, Peaks of Otter salamander, HV*
Cumberland Riverscour	*Wild blue indigo,LV; Rock-castle wood-aster, EV*
South-Central Interior Large Floodplain	*Wild blue indigo MV, LV; Diana fritillary, MV; Appalachian tiger beetle, HV; Marbled underwing, HV; Imitator salamander, HV*
South-Central Interior Small Stream and Riparian	*Appalachian tiger beetle, HV; Marbled underwing, HV; Southern pygmy salamander, HV; Peaks of Otter salamander (HV); Cheat Mountain salamander (HV); Alabama warbonnet, EV*
Specialized Open Wetlands	
Central Interior Highlands and Appalachian Sinkhole and Depression Pond	*Virginia sneezeweed, EV*
Interior Low Plateau Seepage Fen	*Largeleaf grass-of-Parnassas, EV; Water stitchwort, EV; Tennessee yellow-eyed grass, HV*
Southern and Central Appalachian Bog and Fen	*Bog Jacob's ladder, MV; Tennessee yellow-eyed grass, HV; Baltimore checkerspot, MV; Largeleaf grass-of-Parnassas, HV*
Southern Appalachian Seepage Wetland	*Swamp pink, EV; Tennessee yellow-eyed grass, HV; Baltimore checkerspot, MV; Imitator salamander, MV; Blue Ridge St. Johnswort, HV; Bog Jacob's ladder, MV*
Wetland Forest	
Cumberland Seepage Forest	*Swamp pink, EV; Santeetlah dusky salamander, HV; Imitator salamander, HV*
North-Central Appalachian Acidic Swamp	*Swamp pink, EV*
Early successional	
Early Successional Upland	*Northern scarletsnake, MV*
Wet Meadow - Marsh	*Eastern harvest mouse, MV, HV*
Mesic Forests	
South-Central Interior Mesophytic Forest	*Santeetlah dusky salamander, HV, Alabama snow-wreath, EV; Imitator salamander, HV;*
Southern and Central Appalachian Cove Forest	*Fraser's sedge, LV, MV; Diana fritillary, MV; Mountain bugbane, MV, HV; Alabama snow-wreath, EV; Peaks of Otter salamander, HV*

Table 12 Species vulnerability ranks with their habitats grouped by environmental characteristics (continued)

Many species characterizing montane habitats are generally vulnerable to climate change, except for those with high mobility and dispersal capabilities. These habitats include high-elevation spruce-fir forests, montane pine forests, shrub balds of the Southern Appalachians, and a number of high-elevation wetlands. As the climate warms, the extent of available cooler habitat upslope decreases or simply ceases to exist. Eight species associated with these habitats were assessed, and all are vulnerable to climate change except Carolina hemlock, which is ranked Least Vulnerable. Velvet-leaf blueberry is Highly Vulnerable in the Cumberland – Southern Appalachian region but Extremely Vulnerable in the Central Appalachian subregion. Vulnerable species associated with spruce-fir forests include three salamanders, one shrub (velvetleaf blueberry) and one forest herb (bluebead lily).

All but one of the ten species we assessed that are associated with floodplain or riparian habitats were found to be Moderately to Extremely Vulnerable, and one of these (wild blue indigo) ranked Least Vulnerable in the South-Central Interior Large Floodplain was ranked as Moderately Vulnerable on the Cumberland Riverscour in the Cumberland – Southern Appalachian subregion. One other species, Diana fritillary, was ranked Moderately Vulnerable in the Central Appalachian subregion, and Highly Vulnerable in the Cumberland – Southern Appalachian subregion. The remaining six species, two plants four salamanders, and one insect (Appalachian tiger beetle) were scored as Highly or Extremely Vulnerable.

Three species associated with wetland forests were assessed, including swamp pink (Extremely Vulnerable), and two salamanders (imitator and Santeetlah dusky), which ranked as Highly Vulnerable.

Ten species associated with what we referred to as "specialized open wetlands" were all found to be vulnerable to climate change. Habitats supporting these species include montane bogs and fens, seepage fens, and sinkhole depression pond wetlands. Groundwater hydrology supporting these habitats is often complex, particularly in sinkhole ponds, which occur in karst landscapes and were formed as the substrate dissolved into solution and collapsed. One species associated with sinkhole ponds was assessed, Virginia sneezeweed, and it was found to be Extremely Vulnerable. The remaining nine species are associated with seepage fens and montane bogs and fens. Two of the species assessed are animals: Baltimore checkerspot (a butterfly) and a salamander (imitator salamander), and were found to be Moderately Vulnerable. The remainder were plants. One plant, bog Jacob's ladder, was ranked as Moderately Vulnerable, and the others ranked either Extremely or Highly Vulnerable.

We assessed seven species commonly found in mesophytic and cove forests. These habitats are highly diverse, found in sheltered valleys and slopes. They are characterized by a diverse tree canopy, and rich moist soils supporting a large number of ferns, graminoids, and leafy forbs. Only one assessed species was ranked Least Vulnerable, Fraser's sedge. This species ranges from the Central Appalachian Subregion, where it was ranked as Moderately Vulnerable. Three salamanders, Santeetlah dusky, Peaks of Otter, and imitator, are ranked Highly Vulnerable. The Diana fritillary was ranked as Moderately Vulnerable. Of the plants, Alabama snow-wreath was ranked as Extremely Vulnerable, and mountain bugbane was ranked as Moderately to Highly Vulnerable.

We assessed only two species commonly associated with early successional habitats; the northern scarletsnake was Moderately Vulnerable. The eastern harvest mouse, commonly associated with Wet Meadow and Marsh, was also ranked as Moderately to Highly Vulnerable.

Analysis of new data - habitats

South Central Interior Small Stream and Riparian (CES202.706)

Distribution: this habitat is largely confined to the Cumberland – Southern Appalachian and Interior Low Plateau subregions of the Appalachian LCC region, extending beyond it only in southwestern Kentucky and western Tennessee (Nature Serve, 2014).

Ecology: this linear floodplain habitat [8]is typically found over a wide range of elevations along small, low to moderate gradient streams in relatively narrow steep-sided valleys. The vegetation is a mosaic of forests, woodlands, shrublands, and herbaceous communities (Nature Serve 2014). Forest canopy cover is variable, reflecting the highly dynamic nature of this habitat. Forest cover is usually characterized by an interrupted canopy of flood-battered trees such as American sycamore, river birch, sweetgum, and oak species, and the shrub and herbaceous layers may comprise mixtures of bushy St. Johnswort, willows and alders, sedges, grasses, and ferns.

Important Community Determinants: (a) topography - characteristic of narrow, steep-sided valleys with only limited potential floodplain; (b) disturbance regime – vegetation

[8] This habitat refers to the bank and floodplain only; the aquatic community of the stream is treated as a separate habitat).

community maintained by regular flood scouring. Scour and disturbance during regular flooding is an important influence on community development, ensuring only limited development of woody vegetation and largely restricting succession to early seral stages.

Model scores are included in Appendix A (Interior Low Plateau subregion) and Appendix B (Cumberland and Southern Blue Ridge subregion).

Location in Geographical Range of Habitat. Largely confined to the Appalachian LCC in range, this habitat occurs in suitable topographies across much of the Interior Low Plateau and Cumberland – Southern Appalachian subregions of the Appalachian LCC. It is not an uncommon habitat, occurring on variable microhabitats that may afford it more protection in some portions of the range, but its full distribution is confined not only to the LCC region, but to the areas of the LCC predicted to be most greatly affected by climate change. For this reason the habitat is scored 5 (High) for this variable. The certainty is scored 3 (High) because we know much about the geographical distribution of the habitat.

Degree of Cold Adaptation. This habitat occurs across a wide range of ambient temperatures and across a range of elevations. Thus, it apparently shows relatively little cold adaptation among its constituents. However, our knowledge of the climate limitations of all of its constituents is incomplete, and where this habitat occurs at higher elevations, some species may exhibit cold-adaptation to a limited degree; to reflect this uncertainty we have assigned a score of 3 (important constituent species limited to cool temperatures) and a certainty score of 2 (medium).

Vulnerability to Extreme Climatic Events. The distribution of this habitat is known to be affected by the occurrence of some severe climatic events – extreme precipitation events and floods. In fact, flooding is an important natural process that tends to maintain the habitat in relatively early seral stages and prevent establishment or further growth of woody species. There is likely to be a threshold of severity and frequency of extreme flooding beyond which this habitat may decline, however, since available habitat is already confined by the banks and slopes of valleys. For this reason we have scored the vulnerability of this habitat as 3 (moderately vulnerable to extreme climatic events), with a certainty score of High.

Vulnerability to Maladaptive Human Responses. We consider it unlikely that this habitat is vulnerable to any societal maladaptive responses since it is not suitable for either agriculture or residential development and there is, therefore, little of "value" for humans to exploit or "protect". However, it is feasible that where this habitat occurs close to human settlements, lower reaches of this riparian habitat might be dammed to control damaging floods exacerbated by climate change. Nevertheless, this is likely to be only a local impact and much of this habitat will remain relatively free from maladaptive responses. For these reasons we have scored this variable as 3 (less vulnerable) with a certainty score of Medium (2).

Location Relative to Highest Elevation. Although this is not strictly a montane habitat and extends across a range of elevations, we have assigned a score of 3 for this variable (which basically assumes that *some* but not all of this habitat may be close to the highest elevation of *some* uplands, and component species may be unable to shift upward in response to increasing temperatures). Because of our uncertainty, we have assigned a certainty score of 2 (Medium).

Intrinsic Adaptive Capacity. We believe that this habitat will have a relatively high intrinsic ability to resist and recover from climate change factors. Many of the constituent species (though not all) are early successional species, that could rebound quickly from sporadic stresses due to floods. Trees that had become established could be eliminated by such extreme events and take longer to become re-established. Thus, we assigned it a vulnerability score of 1 (adaptive capacity likely to be significant), and a certainty score of 2 (Medium).

Dependence on Specific Hydrologic Conditions. This habitat is structured and maintained by frequent flooding that causes scouring and removal of vegetation, leaving open substrate to be colonized by the early successional species that characterize it. The relationship of dependence on specific conditions with the predicted increase in heavy rainfall events, however, may in fact benefit this habitat. For this reason we have scored this variable as 1 (not dependent on specific hydrologic conditions). We assigned a certainty of 2 to reflect the complexity inherent in understanding the interplay between dependence on relatively specific hydrologic conditions, with the predicted increase in precipitation severity.

Vulnerability of Foundation/Keystone Species to Climate Change. So far as we are aware, there are no species that are either foundational or keystone in this habitat. We assessed four species associated with this habitat; three animals were ranked as Highly Vulnerable: Appalachian tiger beetle, marbled underwing, and southern pygmy salamander. The one plant we assessed, Alabama warbonnet, was ranked as Extremely Vulnerable. Because these species are not keystone species, we scored this variable as 1, with a certainty score of 3 (High), but the results of the species assessments suggest a need to explore the vulnerability of other guilds or taxonomic groups associated with this habitat.

Constraints on Latitudinal Range Shifts. This habitat is dependent on specific landforms – relatively steep and narrow valleys. Although this landform certainly exists north of the current range of the habitat (in the Central Appalachians of New York, Vermont, and northwards.), the ability of the component species of the habitat to move north into these areas at the prompting of climate change may be constrained by their current distributional patterns and their dispersal capabilities (Damschen et al., 2012). This habitat is oriented mainly east and west (along streams and valleys extending from the height of the Appalachians downslope). This orientation may impose barriers to northward migration of component species. However, some of the component species (e.g. sweetgum) are also found in upland habitats and could colonize northward into streams; others (e.g. sycamore) are wind-dispersed, so northward migration could be possible. There is significant uncertainty, however, in this appraisal (e.g., Damschen et al., 2012) and we assign it a vulnerability score of 3 (somewhat constrained) and a certainty score of only 1 (Low).

Likelihood of Managing/Alleviating Climate Change Impacts. Management, restoration, or recreation of this habitat has not been extensively tested and implemented by state, federal or other agencies and our knowledge base about how this could be accomplished is probably poor. Also, so much of the existence of this habitat is determined by factors that are difficult to modify or reproduce (topography and geology, for example) that management is extremely problematic. For these reasons we have scored this variable as 5 (not feasible) with a certainty score of 3 (High).

Potential for Climate Change to Exacerbate Impacts of Non-Climate Stressors, or Vice Versa. The major non-climate change stressors affecting this habitat include construction of dams, dumping materials from mountaintop removal, and exotic species. The first two stressors are so severe in themselves that effects of climate change are not likely to exacerbate them further. Climate change factors may actually benefit this habitat in some instances through the increased scour and opening of substrate caused by flooding events. Exotic species invasion, however, is likely to be compounded to a degree by climate change. Brown and Peet (2003) found that the invasion by exotic species may increase with flood frequency, and Rogers and McCarty (2000) likewise suggest that climate change in the Mid-Atlantic States may act to increase invasion by exotic species in stressed ecosystems. Because climate change is not likely to further compound the already extreme impacts of damming and dumping, and that climate change may benefit this habitat in some instances, we have scored this variable as 1 (Low) with a certainty score of 2 (Medium).

Exposure to net drying and increased temperatures.

- Interior Low Plateau: most of the range of the habitat lies within the mid-range for predicted drying, but a small proportion (10%) lies above this level. A larger proportion of the range compared to that of the Cumberland – Southern Appalachian subregion falls in higher predicted temperature ranges, with 40% exposed to an increase of 4.5-5.0 degrees F, 55% exposed to 5.1-5.4 degrees F, and a small proportion to >5.5 degrees F.
- Cumberland – Southern Appalachian subregion: most of this habitat (85%) lies within the mid-range for projected net drying. Temperature exposure is high, with 90% of the range projected to experience an increase in temperature of 5.4-5.0 degrees F.

Summary. In the Cumberland – Southern Appalachian subregion, this habitat resulted in an overall vulnerability score of 34, and although it falls within the range of Less Vulnerable, the score is very near the threshold for a rating of Vulnerable. The vulnerability score in the Interior Low Plateau did reach the threshold of Vulnerable, with a score of 36 as a result of exposure to greater temperature increases in that subregion, and to a lesser extent, increased net drying. Certainty scores were 29 and 30, respectively, out of a possible 39 points.

Southern Interior Low Plateau Dry-Mesic Oak Forest (CES202.898)

Distribution: This habitat, although widespread in the Interior Low Plateau region of the southeastern U.S., is largely restricted to this region. It is most common in Kentucky, Tennessee, and the southern half of Indiana, reaching just beyond the borders of Ohio, Illinois, and Alabama (Nature Serve 2015).

Ecology: This matrix forest community is found mainly on drier upland ridges and slopes. The actual floristic composition of the community depends largely on aspect and soil moisture, with somewhat different forest compositions being found on north-facing submesic soils than on south-facing well drained soils. Historically, this habitat was likely to have been a mosaic of dry-mesic forest, open canopy woodland, and grasslands maintained by fire.

The canopy is usually dominated by a variety of dry oak species, with chestnut oak dominating over much of the habitat's distributional range, but with chinkapin oak and shumard oak sharing dominance on more basic soils. Other tree species that may be frequent in the canopy include hickories and short-leaf pine. Grasses are common, including big bluestem and little bluestem. Heath shrubs are common on acidic substrates. Canopy closure ranges from closed in submesic areas to more open on drier soils, or in areas that have undergone frequent fire.

Important community determinants: Soil moisture and fire frequency are important factors determining the distribution of this community. It occurs across a spectrum of soil moistures from drier to submesic to mesic. This implies some tolerance for a variety of soil moisture conditions. Projected increased evapotranspiration rates may result in soil drying. With increased frequency, duration and intensity of drought, fire frequency and intensity is a more likely factor that could affect the distribution of this habitat in the future. As in other forested or savanna habitats elsewhere, frequent burning can shift this largely tree dominated habitat to more open grassland or prairie (Barbour and Billings, 1988).

Location in Geographical Range of Habitat. This habitat occurs in suitable topographies across much of the Interior Low Plateau, and although it does not range much beyond it, it grades into similar dry-mesic forests adjacent to it. Allegheny-Cumberland Dry Oak Forest and Woodland to the east, and North-Central Interior Dry-Mesic Oak Forest and Woodland to the north are limited to small patches where there is a suitable environmental setting. To the southwest lies the East Gulf Coastal Plain Northern Dry Upland Hardwood Forest, but in general, dry mesic upland hardwood forests reach their southern limit in the Appalachian LCC (Figure 7). Therefore, they were not exposed to temperature regimes that are likely to be currently warmer than in central or more northern areas of the LCC. For this reason the habitat is scored 5 for this variable, since a suitable environmental setting does not occur north of the LCC boundary except in small patches. Some elimination of this habitat could occur in the more southern parts of the LCC. The certainty is scored 3 (High) because we know much about the geographical distribution of the habitat.

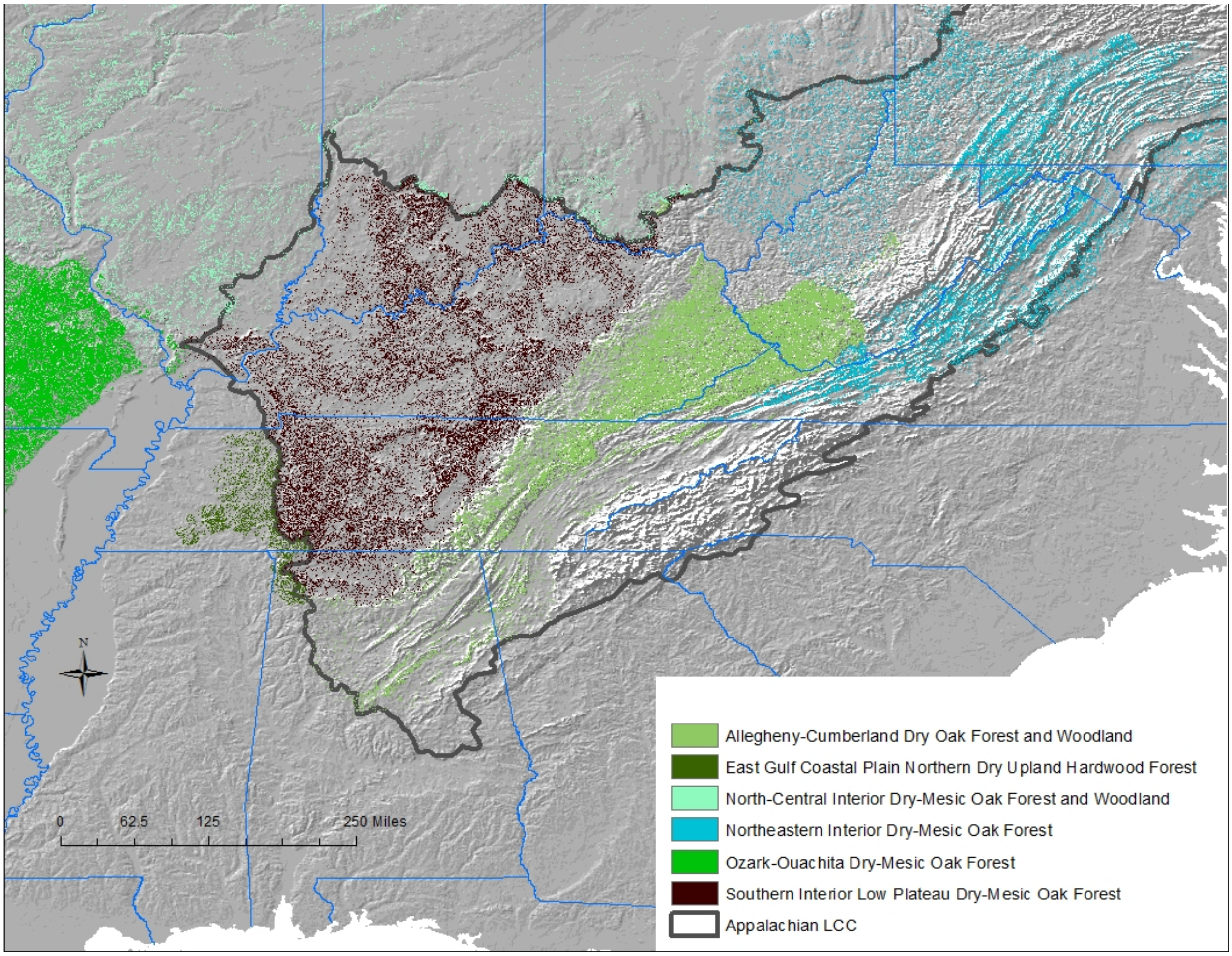

Figure 7 Similar Dry-Mesic forest habitats adjacent to the Southern Interior Low Plateau Dry-Mesic Oak Forest.

Degree of Cold Adaptation. This habitat occurs across a wide range of ambient temperatures, from Ohio south to Alabama, into areas that are relatively warm and temperate throughout the year. Thus, it apparently shows relatively little cold adaptation among its constituents. We have, accordingly, assigned a score of 1 (important constituent species tolerant of warmer temperatures) and a certainty score of 3 (High).

Sensitivity to Extreme Climatic Events. This habitat is likely to be less vulnerable to severe climatic events, and may in fact benefit to some degree. Historically, this habitat may have had a more open canopy as a result of higher fire frequency than experienced today (LandFire 2007). We have, accordingly scored this variable as 1 (not vulnerable to extreme climatic events) and assigned a certainty score of 2 (Medium) to reflect the uncertainty surrounding the projections of extreme events from current climate models.

Vulnerability to Maladaptive Human Responses. We consider it unlikely that this habitat is particularly vulnerable to any maladaptive responses from humans. Indeed, it is difficult to imagine a scenario in which societal responses to climate change could result in wholesale loss or conversion of this habitat. It is most likely that humans may respond to the increased incidence and intensity of wildfire that may accompany climate change by increasing fire suppression programs (see below) that promote fire-intolerant species such as beech and sugar maples, at the expense of fire-tolerant oaks and hickories. Considerable uncertainty surrounds these possibilities and, to err on the side of conservatism, we have scored this variable as 3 (Less likely to be vulnerable), with a certainty score of 2. Depending on the seasonality of the wetter versus drier periods, trees or grasses could benefit greatly, depending on the balance between growing season length and winter precipitation. However, these influences are uncertain.

Location Relative to Highest Elevation. Although this is not a montane habitat and extends across a range of elevations, it is most common on the summits and slopes of the hilly landscape where it occurs. Temperature and precipitation do not increase significantly if at all with increases in elevation in this area of generally low elevations, so its limitation to summits is more likely to be the result of land use (agriculture where the landscape is flat) rather than climate. We have assigned a score of 1 for this variable (which, in this case, assumes that elevation does not play an important part in maintenance of this habitat). We have assigned a certainty score of 2 (Medium) to this variable.

Intrinsic Adaptive Capacity. We predict that this habitat will have some intrinsic ability to resist and recover from climate change factors. It supports a number of species that are adapted to fire, as well as those that require more mesic conditions in sheltered coves or in areas that have experienced lower fire frequency. Increased temperature and dryness could favor a more open canopy presumed to be the historical condition as a result of increased fire. On the other hand, increased fire suppression may favor the establishment or survival of more mesic species, which also characterize this habitat.Thus, we assigned it a vulnerability score of 1 (adaptive capacity likely to be significant), and a certainty score of 2 (Medium).

Dependence on Specific Hydrologic Conditions. The distribution of this habitat is not a function of hydrology - it is not confined to dry areas where one condition prevails at all times. For this reason we have scored this variable as 1 (less dependent on specific hydrologic conditions), with a certainty of 3.

Vulnerability of Foundation/Keystone Species to Climate Change. The main foundational species in this habitat (dry oaks and hickories) are tolerant of dry conditions and fire. One species associated with this habitat, southern shagbark hickory, we ranked as Least Vulnerable using the CCVI. Increased fire severity could kill trees, causing the habitat to revert to grassland or open woodland. However, a patchy mosaic of grassland, woodland, and closed forest more closely resembles the historic condition. Thus, we have scored this variable as 1, with a certainty score of 2 (Medium).

Constraints on Latitudinal Range Shifts. Habitats do not shift their ranges as a distinct unit. There is wide variation in the environmental niches of species comprising any habitat, so latitudinal shifts in range would pertain only to species. Climate envelope modeling is beyond the cope of this project, but such modeling would provide a more precise prediction of conditions suitable to support these species. The major impediment to the northward migration of species comprising this habitat is unsuitable environment and incompatible land use (Figure 8). There is some uncertainty, however, in this appraisal and while we assign it a vulnerability score of 3 (somewhat constrained) we also assign a certainty score of 2 (Medium).

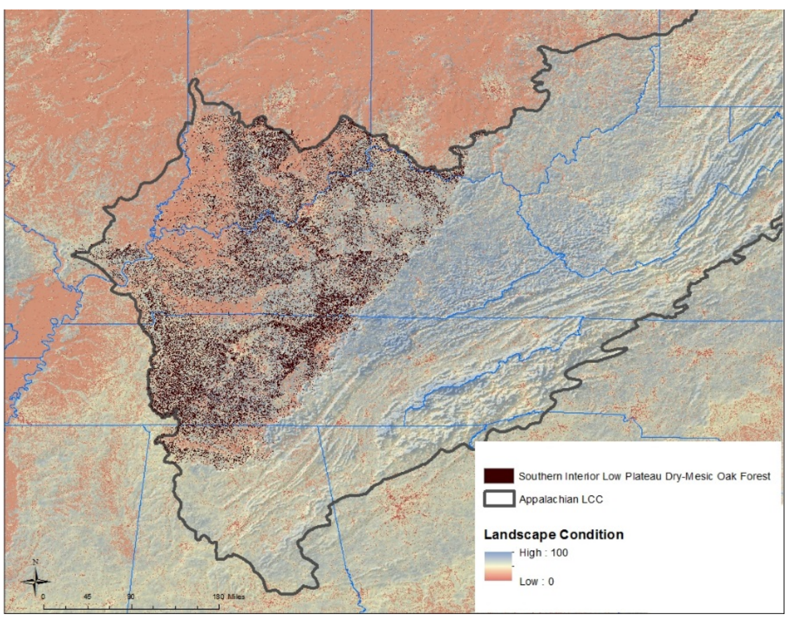

Figure 8 Landscape condition in and around the Appalachian LCC. Pink indicates poor condition (Comer and Hak 2009)

Likelihood of Managing/Alleviating Climate Change Impacts. One of the main vulnerabilities of this habitat may not occur through the direct effects of a changing climate, but through increased frequencies and intensities of fire. Appropriate fire management efforts could return the landscape to its former condition of open woodland. For this reason, we have assigned a variable score of 1 (Feasible), with a certainty score of 3 (High).

Potential for Climate Change to Exacerbate Impacts of Non-Climate Stressors, or Vice Versa. As stated above, a major indirect effect of climate change on this habitat may occur through the increased frequency and severity of fire, which could have the result of changing this tree-dominated habitat into a mosaic of open woodland and grassland. Some fire may promote open conditions which favor the regeneration of oaks, and prevent or at least slow the increase in abundance of fire-intolerant species (such as sugar maple and beech). These effects could be at a regional scale. For this reason we have scored this variable as 1, with a certainty score of 2 (Medium).

Exposure to net drying and increased temperatures: The great majority (98%) of this habitat occurs in the mid-ranges of net drying (98%) and temperature increase (90%) (5.0-4.5 degrees F).

Summary. This is a habitat that is, apparently, tolerant of high ambient temperatures, drought and semi-drought conditions. It can be managed and it is not particularly vulnerable to extreme events or maladaptive human responses. Therefore, this habitat should be relatively insensitive to climate change. For example, there could be some dynamic relationship within the habitat, with the effects of fire being expressed more in the shrub layer and less so in the more resistant canopy species, such as oaks, which may be more resilient to fire. On balance, we have scored the vulnerability of this habitat as 26 (Less Vulnerable). We think that it is safer to assume that this habitat could, indeed, be vulnerable to the changing climate (for the reasons discussed above) and that the end result of this could be localized habitat loss and modification. Regarding certainty scoring, it scored a total of 31 out of a potential 39, indicating a relatively high level of certainty. Appendix C provides full model results.

Central Interior Highlands Calcareous Glade and Barrens (CES202.691)

Distribution: This small patch grassland habitat occurs mainly in the Interior Highlands of the Ozark, Ouachita and Interior Low Plateau regions, and is largely restricted to the western portion of the Interior Low Plateau subregion of the LCC region, extending discontinuously to southwestern Ohio and south to Alabama.

Ecology: This habitat occurs mainly on south- or west-facing moderate or steep slopes with basic soils and underlying geology (limestone or dolomitic formations or calcareous shales). Soils are typically well-drained, drying out in the summer months, but with high moisture content during wetter winter or spring months.

Calcareous glades and barrens is primarily a grassland ecosystem that was maintained historically by fire and grazing by megafauna, by nutrient limitations and edaphic factors. (Currently, they are often maintained by planting of native species to oust invasive fescues, and by controlled burning). The habitat is dominated by graminoids including the prairie grasses: yellow Indian grass, little bluestem, and big bluestem. Other herbaceous species are typically calcicolous grasses, sedges and herbs. On areas that have not been recently burned, stunted trees including chinkapin oak and junipers may occur in an open savanna canopy cover of less than 30% (http://www.apsu.edu/herbarium/prairies-barrens).

Important community determinants: The distribution of this habitat is primarily a function of bedrock and the resulting basic soils, soil drainage, and fire. Without regular burning it is likely that these grassland communities would be replaced by a more closed canopy shrub or tree dominated community. Also, the potential for geographical shifts of this habitat in response to the changing climate is constrained by the distribution of suitable solid geologies and soil types.

Model Scores

Location in Geographical Range of Habitat. This habitat occurs on small patches of specialized environmental conditions, and the southern range limit of this habitat is reached in the LCC in Alabama. It ranges to the northwest and west of the LCC, so is not restricted to this LCC region. However, dispersal of component species to suitable habitat in the event of warming is complicated by the geographic isolation of individual patches, and by current land use. We assigned a score of 5, with a certainty score of 3 (High) because we know much about the geographical distribution of the habitat.

Degree of Cold Adaptation. This habitat occurs across a wide range of ambient temperatures, from north to south. Thus, it apparently shows relatively little cold adaptation among its constituents. To reflect this we have assigned a score of 1 (constituent species tolerant of warmer temperatures) and a certainty score of 3 (High).

Sensitivity to Extreme Climatic Events. So far as is known, this habitat is not known to be dependent on the occurrence of severe climatic events – extreme precipitation events and floods. Indeed, it also seems to be able to withstand frequent and severe droughts, without harm. For these reasons we have scored the vulnerability of this habitat as 1 (not vulnerable to extreme climatic events), with a certainty score of 2 (Medium) to reflect the fact that our knowledge of the potential effects of extreme events may be incomplete.

Vulnerability to Maladaptive Human Responses. We consider it unlikely that this habitat is highly vulnerable to any maladaptive responses from humans. Large areas of this habitat are currently being managed to maintain it in its native floristic condition and prevent establishment by invasive species. If one result of the changing climate was to be that fewer resources be allocated to this effort, it could mean the loss or modification of the habitat. Nevertheless, this is likely to be only a local impact and much of this habitat will remain free from maladaptive responses. For these reasons we have scored this variable as 3 (less vulnerable) with a certainty score of Medium (2). We did not assign larger vulnerabilities or greater certainty because there may be situations where the potential for maladaptive responses may be greater.

Location Relative to Highest Elevation. This is not a montane habitat and is typically restricted to lower elevations. We have, therefore, assigned a score of 1 for this variable (which basically assumes that much of this habitat may be able, at least in theory, to shift upward in response to increasing temperatures). We have assigned a certainty score of 3 (High) to this score.

Intrinsic Adaptive Capacity. We believe that this habitat will have relatively high intrinsic ability to resist and recover from climate change factors. It is an early successional habitat dominated by graminoids and herbs and could, therefore, rebound quickly from sporadic stresses imposed by climate change (fire, etc.). Thus, we assigned it a vulnerability score of 1 (adaptive capacity likely to be significant), and a certainty score of 3 (High).

Dependence on Specific Hydrologic Conditions. Although this is not a hydrology-dominated habitat, it is nevertheless affected by soil moisture regime growing in areas that are arid during the summer months, but wetter in the winter. We think it unlikely that climate change will disrupt this sequence of conditions – higher temperatures and evapotranspiration rates will maintain low soil moisture during the summer months, but higher precipitation rates will ensure higher soil moisture at other times. Thus, we have scored this variable as 1 (less dependent on specific hydrologic conditions), with a certainty score of 3 (High).

Vulnerability of Foundation/Keystone Species to Climate Change. We assessed a number of species associated with this habitat using the CCVI: side-oats gramma, purple coneflower, leafy prairie clover, Tennessee milkvetch, and scarlet Indian paintbrush were ranked as Extremely Vulnerable; Eggert's sunflower was ranked Highly Vulnerable. Side-oats gramma, a prairie grass, can arguably function as a keystone species; for this reason and the degree of vulnerability of the other species we assessed, we assigned a variable score of 5 and a confidence score of 3.

Constraints on Latitudinal Range Shifts. This habitat is found mainly in areas with specific bedrock (limestone or dolomite) and with well drained porous and basic soils. While it might otherwise be possible for species of this habitat to shift northward or upward in elevation in response to climate change, these geologic and pedologic constraints, as well as the distance between patches limit dispersal possibilities. For this reason we have assigned a variable score of 5 (severely constrained in its ability to shift), with a certainty score of 2 (Medium).

Likelihood of Managing/Alleviating Climate Change Impacts. Although all of the species we assessed that are associated with this habitat were ranked as Highly to Extremely Vulnerable, individual scores regarding dispersal contributed substantially to those scores. Species of this habitat are adapted to frequent fire and drought. Management by burning and removal of invasives in situ, although challenging, would be possible. Limited introduction of plants in restoration efforts have had mixed results (Albrecht and McCue 2010), however. Thus we scored this variable as 1 (feasible) with a certainty score of 2 (Medium).

Potential for Climate Change to Exacerbate Impacts of Non-Climate Stressors, or Vice Versa. The most likely effect of climate change on non-climate stressors would likely be to increase the frequency of fire. This, however is likely to only benefit this community type, which relies for its existence on frequent burning. We have, therefore scored the potential vulnerability to this variable as 1 (low), with a certainty score of 3 (High).

Exposure to net drying and increased temperatures: The majority of the range of this habitat in the Interior low Plateau is in the upper range of net drying (90%), with a mid-range of temperature increase (90% of the range faces temperature increases of 4.5-5.0 degrees F). These scored 4 and 3, respectively, with certainty scores of 2 for each.

Summary. This habitat was ranked as Less Vulnerable, but edging toward Vulnerable. We do not think that this habitat will benefit from climate change by range extension of component species (since that is a function of topographic and geologic factors), but it is unlikely that climate change poses a serious risk to it within its current range. Regarding certainty scoring, it scored a total of 32 out of a potential 39, indicating a relatively high level of certainty.

Discussion

Sources of uncertainty

Uncertainty is inherent in many of the outcomes of this study. The CCVI rankings themselves imply uncertainty, for example, “presumed stable” as opposed to “not vulnerable". The term "vulnerability" also implies that there is cause for concern, but it is not an absolute prediction. Some uncertainty is simply the result of an unprecedented degree and rapidity of climate change, and our past trend data are sometimes too coarse to model the extreme complexities of climate processes and how they play out in ecosystems. Other sources of uncertainty, however, are the result of current data that are too coarse but could be refined substantially with the proper resources.

Species range maps, for example, are often crude interpolations of incomplete distributional data. Mapping inaccuracies and lack of precision have direct effects on exposure calculations in the CCVI. In dealing with generalist species that are wide-ranging, a high degree of mapping precision is usually unnecessary. However, imprecision of range data can have a substantial effect on exposure estimations for species with narrow ecological tolerances and limited dispersal capacity, such as many amphibians and plants. Discrepancies in species range data was evident in the bird and tree atlas data (Matthews et al. 2011; Prasad et al. 2007-ongoing) in comparison with published range maps developed for trees (Little 1971; Little 1977), and other species (NatureServe Explorer 2013). Bird atlas data of Matthews et al. (2011) are based on breeding bird survey data, and the tree atlas data of Prasad et al. (2007) are based on Forest Inventory and Analysis data, both of which are likely to be under-representations of actual ranges. More precision in species' ranges can be gained through species distribution modeling, using the environmental characteristics of known locations to predict the location of potential habitat using GIS analyses (Hernandez et al. 2008).

Other factors to consider

Some individual factors for species ranked "presumed stable" were noted to increase vulnerability. These species may still face threats from climate change, but the threats did not reach the calculated threshold that indicated vulnerability to climate change over all. Species that are limited but not completely restricted in dispersal capability, or are experiencing greater than average temperature or hydrological fluctuations than they have historically, may still be ranked Presumed Stable. For example, aquatic species or species dependent on river habitats may have very good dispersal capability, but the general south-trending direction of riverine flow in the eastern US may work against some aquatic species' reaching cooler climates to the north as a result of having to disperse against the current. Monitoring of a subset of species ranked initially as Least Vulnerable would allow for detection of trends toward vulnerability.

Limitations of the assessment methods

The interaction of species, habitats, and climate is extraordinarily complex. Despite our best efforts, methods used to assess species and habitat vulnerabilities invariably have various shortcomings. Although Release 3.0 of the CCVI includes numerous improvements added as a result of input from users, there remain limits to the use of this tool. Factors are assessed independently of each other, but there are important interactions among factors that are not easily accounted for. For example, climate-induced changes in phenology have a direct impact on the availability of crucial food sources during migration. Another example assumes that cave fauna are almost universally impervious to climate change because they are buffered from surface conditions, but degradation of water quality caused by pollution and runoff from extreme precipitation events could have a significant impact on these highly specialized organisms.

The role of dispersal

The Manomet habitat models are similarly constrained by the choice of individual factors used in assessment. Since habitats will not disperse as a discrete unit, we generaly focus on the degree to which the habitat can resist climate change in its current manifestation. Understanding the dispersal capabilities of the component species is not necessarily relevant if the habitat is highly resistant to climate change.

As an example, the results of the six species associated with the Central Interior Highlands Calcareous Glade and Barrens (Moderately Vulnerable to Extremely vulnerable) may be somewhat unexpected, given that they are adapted to warm, dry conditions and periodic droughts, and that the habitat itself was ranked as Less Vulnerable. This seeming contradiction can be explained by examining the individual scores in the CCVI. The factors pertaining to barriers to dispersal (anthropogenic as well as natural), and dispersal capability were scored as Greatly Increasing or Increasing vulnerability; changing these scores to neutral resulted in a ranking of Presumed Stable. In other words, if the habitat is resistant to climate change, low dispersal capability will not appreciably affect the vulnerability of these species.

The impact of dispersal is difficult to ascertain, as seen in the northeast, which was repeatedly glaciated during the Pleistocene Epoch. In at least 23 separate glacial cycles, all species currently north of the Pennsylvania border were completely removed, pushed southward to refugia, and migrated northward once again during the interglacial periods, each of which lasted an average of 20,000 years. One could say this is good evidence that all species of the glaciated region are effective dispersers. However, observed individual dispersal events of plants range from several hundred meters by those dispersed by wind or birds, to less than 5 cm, as in the case of purple pitcher plant. Given 20,000 years, it seems implausible that purple pitcher plant was ever able to reach so far north (central Canada) following glacial recession, in such a specialized habitat (bogs) isolated from each other by inhospitable habitat. And yet it is there, a reliable component of acidic peatlands. This seeming contradiction in apparent dispersal capability and the great distances that plants successfully achieved has been termed "Reid's paradox" after a nineteenth century British botanist's observations. Ellison and Parker (2002) noted that rare long-distance dispersal events can likely account for the presence of purple pitcher plant in bogs of northern latitudes, as it very likely applies to the wealth of species with evidently limited dispersal capability. Understanding the role of long-distance dispersal by storms, wind, water, birds, and other animals, as well as how anthropogenic land use changes influence the likelihood of these events will help us to better plan for adaptation to climate change (Vitt and Havens 2009).

Climate exposure index

The field of climate change assessment is constantly changing, with new data becoming available at a rapid rate. The climate data we used for the assessments in this paper have been improved since the analyses were conducted. Auer et al. (2015) produced a climate change exposure index for the Appalachian LCC region using a dissimilarity metric that represents magnitude of change for a set of climate variables, relative to their baseline variability (Figure 9). The index integrates correlation between variables, and identifies areas that are outside the range of variability, both in terms of magnitude of change as and in novel combinations of climate variables.

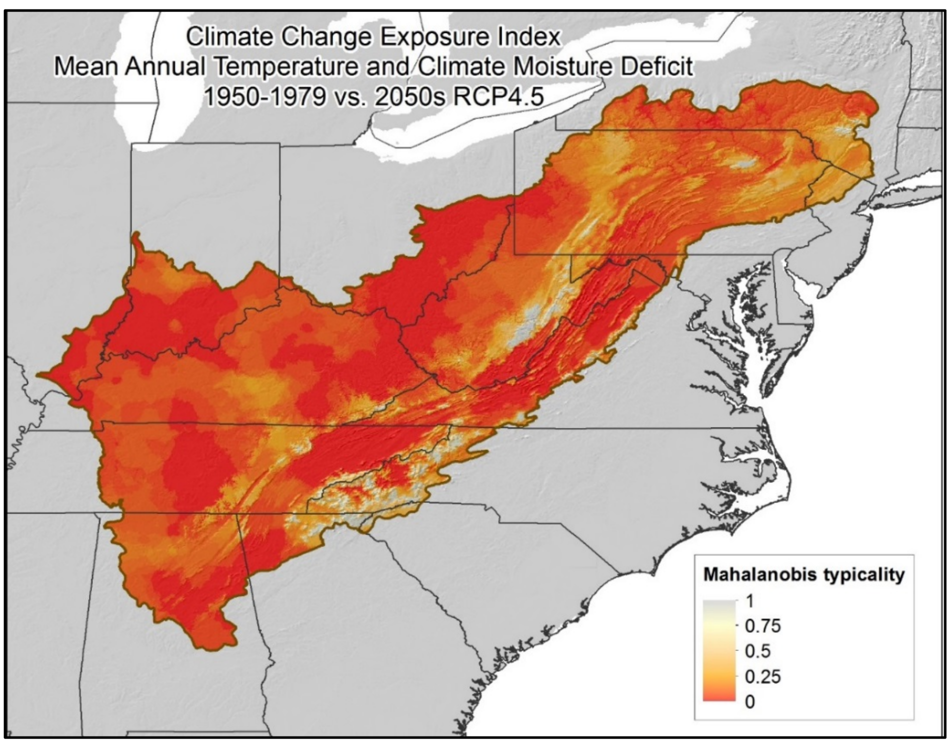

Figure 9 Climate change exposure index of the Appalachian LCC region; red (approaching zero) indicates departure (nontypicality) from current conditions

The lighter orange areas (less departure from current conditions) on Figure 9 coincide with the montane portions of the LCC, and portions of the mountains in West Virginia suggest minimal predicted (mid-century) departure in current climate conditions. This suggests that high-elevation spruce forests of the central and southern Appalachians may not be as vulnerable as initially thought. Radial growth of high-elevation red spruce has been noted in the southern Appalachians (LeBlanc et al. 1992), and possible contributing factors were noted to include acid deposition (McLaughlin and Tjoelker 1992), but the interaction with climate change requires additional study.

Adaptation and adaptive capacity

As a result of individual response to climate change, species are expected to assemble into new biological communities that have no historical analog (Urban et al. 2012). Our study focused on the potential vulnerability of species currently living in the Appalachian LCC region. We did not assess species that do not currently live in the Appalachian LCC region but may migrate from the south as climate warms. It would be wise to consider how these new arrivals may interact with resident species not affected by climate change, and how they adapt to their new environments. It is likely that we will be faced with new biological communities, but it is also possible that some species turnover will happen in a more predictable way as species find their way to similar habitats from the south. Forest habitats in particular that are dominated by, and presumably ameliorated by, long-lived canopy trees that are tolerant of climate change may provide localized microhabitats for species newly arriving to the habitat.

There is greatly increased interest by the scientific community in the adaptive capacity of plants and animals in light of climate change, both in the extent that phenotypic plasticity aids species in adapting to their environment, and in the potential for genetic response over time (Brautigam et al. 2013). A review of phenological adaptation in trees, insects, and birds suggests that both long-lived and short-lived species are responding to climate change by changing phenotype (Rutishauser et al. 2009; Menzel et al. 2006). It remains to be seen whether selection for fitness traits will be necessary for long-term survival. Better understanding of the potential for phenotypic response to temperature increase will allow us to determine when those limits are approached, and when to begin migitation measures (Donnelly et al. 2012).

Conclusions and Recommendations

We are facing an unprecedented change in our climate in the coming years. The inherent complexity of climate processes, the complexity of biological response to climate, and the need to act quickly makes planning exceedingly challenging. Yet the cost of inaction to the natural world is likely to be dire, especially when so much of our biodiversity is already under threat on a number of fronts. It is important to note that the results of the CCVI present our assessment of a species' vulnerability to climate change, independent of other factors. The challenge is how to interpret and apply these results in the context of other threats that species already face. We must use the best available science to make educated predictions, to make decisions based on those predictions, to monitor efficiently, and to make course corrections as needed.

Encourage additional data collection on climate change vulnerability of species and habitats in the Interior Low Plateau. This work has revealed that the Interior Low Plateau portion of the LCC is the subregion with the least amount of existing data, and it is facing the greatest warming and drying of the three subregions. Exposure in the Cumberland-Southern Appalachian subregion is predicted to be lower than in either the Interior Low Plateau or the Central Appalachians subregions, and exposure to the north of the Interior Low Plateau is considerably greater, complicating the assumption that mobile species can migrate north to avoid warming and drying.

Capitalize further on the existing species assessments by examining the results by major habitat categories, as we did on the 41 newly assessed species. The extraordinary diversity of this region in particular makes it impossible to focus management on individual species. Focusing management on habitat benefits large numbers of associated species, but in order to be most effective, there must be a greater understanding of species – habitat relationships.

Combine climate vulnerability information with conservation status ranks to inform conservation planning. Our work, and that of other researchers, has revealed that rare species are not always vulnerable to climate change and common species less so. The added vulnerability information should be included in current conservation plans, as the results may have an impact on priorities.

Conduct more in-depth assessment of species and habitats found to be highly or extremely vulnerable. The Expert Panel in Phase I recommended first using coarse filter methods to rapidly identify vulnerabilities of numerous species, then to focus further assessments on those found to be most vulnerable. For species whose ranges appear to be climate-limited, use bioclimatic modeling to estimate how ranges may shift due to climate change. For habitats, use the Habitat Climate Change Vulnerability Index to better understand underlying mechanisms, ecological processes, and vulnerable keystone species that may be influenced by climate change.

Focus on "no regrets" climate smart conservation actions. Specific recommendations by Hanson et al. (2010) include increasing the size and genetic diversity of small populations; protecting large core areas and increasing connectivity; restoring (or simulating) natural ecosystem drivers; improve habitat condition; and employ targeted monitoring and adaptive management. Distribution modeling of species of narrow ecological tolerances, in combination with more detailed analyses of newly available climate data, will identify more specific actions to improve our conservation planning and management capabilities.

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Habitat: South-Central Interior Small Stream and Riparian, Interior Low Plateau

		Vulnerability		Certainty	
1. Location in geographical range of habitat				High	3
	Close to (<200 kms) southern limit of habitat distribution	High	5	Medium	2
	More distant from southern limit of habitat distribution	Low	1	Low	1
		Score	5	**Score**	3
		Vulnerability		**Certainty**	
2. Degree of cold-adaptation	Important constituent species limited to cold-temperature areas	High	5	High	3
	Important constituent species limited to cool temperature areas	Medium	3	Medium	2
	Important constituent species tolerant of warmer temperatures	Low	1	Low	1
		Score	3	**Score**	2
		Vulnerability		**Certainty**	
3. Sensitivity to extreme climatic events (e.g., drought, floods, windstorms, icestorms)	Highly vulnerable to extreme climatic events	High	5	High	3
	Less vulnerable to extreme climatic events	Medium	3	Medium	2
	Not vulnerable to extreme climatic events	Low	1	Low	1
		Score	3	**Score**	3
		Vulnerability		**Certainty**	
4. Vulnerability to maladaptive human responses	Highly vulnerable to maladaptive human responses	High	5	High	3
	Less vulnerable to maladaptive human responses	Medium	3	Medium	2
	Not vulnerable to maladaptive human responses	Low	1	Low	1
		Score	3	**Score**	2
		Vulnerability		**Certainty**	
5. Location relative to highest elevation	Mountain summit habitat confined to within 1,000 feet of the highest elevations	High	5	High	3
	High elevation habitat mainly occurring between 1,000 and 2,000 feet below the highest mountain tops	Medium	3	Medium	2
	Lower elevation habitat that should be able to move upslope	Low	1	Low	1
		Score	3	**Score**	2

Appendix A Vulnerability and certainy scores for South-Central Interior Small Stream and Riparian in the Interior Low Plateau subregion

		Vulnerability		Certainty	
6. Intrinsic adaptive capacity	Unlikely to be significant	High	5	High	3
	Likely to be significant	Low	1	Medium	2
				Low	1
		Score	1	**Score**	3
		Vulnerability		**Certainty**	
7. Dependence on specific hydrologic conditions	Habitats that are dependent on specific hydrologic conditions	High	5	High	3
	Habitats less dependent on specific hydrologic conditions	Low	1	Medium	2
				Low	1
		Score	1	**Score**	2
		Vulnerability		**Certainty**	
8. Vulnerability of Foundation/Keystone species to climate change	Foundation/keystone spp. Likely to be particularly vulnerable to climate change	High	5	High	3
	Foundation/keystone spp. Unlikely to be vulnerable to climate change	Low	1	Medium	2
				Low	1
		Score	1	**Score**	3
		Vulnerability		**Certainty**	
9. Constraints on latitudinal range shifts	Highly constrained	High	5	High	3
	Somewhat constrained	Medium	3	Medium	2
	Low level of constraint	Low	1	Low	1
		Score	3	**Score**	1
		Vulnerability		**Certainty**	
10. Likelihood of managing/alleviating climate change impacts	Not feasible	High	5	High	3
	feasible	Low	1	Medium	2
				Low	1
		Score	5	**Score**	3

Appendix A Vulnerability and certainy scores for South-Central Interior Small Stream and Riparian in the Interior Low Plateau subregion (continued)

		Vulnerability		Certainty	
11. Potential for climate change to exacerbate impacts of non-climate stressors, or vice versa	Potential for large increase in stressor impacts	High	5	High	3
	Potential low	Low	1	Medium	2
				Low	1
		Score	1	**Score**	2

12. Exposure to projected net drying	>-0.119	0	5	High	3
	"-0.119 - -0.097"	10%	4	Medium	2
	"-0.096 - -0.074"	85%	3	Low	1
	"-0.073 - -0.051"	5%	2		
	"-0.050 - -0.028"	0	1		
		Score	3	**Score**	2

13. Exposure to projected temperature increase	>5.5	5%	5		
	5.4-5.1	55%	4		
	5.0-4.5	40%	3		
	4.4-3.9	0	2		
	<3.9	0	1		
		Score	4	**Score**	2

Total Vulnerability Score		**36**	**Vulnerable**	
Total Certainty Score				**30**

Appendix A Vulnerability and certainy scores for South-Central Interior Small Stream and Riparian in the Interior Low Plateau subregion (continued)

Score range	Vulnerability category	Description
13-23	Least Vulnerable (Vc1)	Habitats that may benefit from climate change and increase their extents greatly (>50%).
24-34	Less Vulnerable (Vc2)	Habitats that may not be at adverse risk from climate change, or that may benefit and increase their extents (<50%)
35-45	Vulnerable (Vc3)	Habitats that are at risk of being significantly reduced in extent (20-50%) by climate change.
45-55	Highly Vulnerable (Vc4)	Habitats that are at high risk of being greatly reduced in area (>50% reduction) by climate change
56-65	Critically Vulnerable (Vc5)	Habitats that are at high risk of being eliminated entirely from area by climate change

Appendix A Vulnerability and certainy scores for South-Central Interior Small Stream and Riparian in the Interior Low Plateau subregion (concluded)

Habitat: South-Central Interior Small Stream and Riparian, Cumberland – Southern Blue Ridge Subregion

		Vulnerability		Certainty	
1. Location in geographical range of habitat				High	3
	Close to (<200 kms) southern limit of habitat distribution	High	5	Medium	2
	More distant from southern limit of habitat distribution	Low	1	Low	1
		Score	5	**Score**	3
		Vulnerability		**Certainty**	
2. Degree of cold-adaptation	Important constituent species limited to cold-temperature areas	High	5	High	3
	Important constituent species limited to cool temperature areas	Medium	3	Medium	2
	Important constituent species tolerant of warmer temperatures	Low	1	Low	1
		Score	3	**Score**	2
		Vulnerability		**Certainty**	
3. Sensitivity to extreme climatic events (e.g., drought, floods, windstorms, icestorms)	Highly vulnerable to extreme climatic events	High	5	High	3
	Less vulnerable to extreme climatic events	Medium	3	Medium	2
	Not vulnerable to extreme climatic events	Low	1	Low	1
		Score	3	**Score**	3
		Vulnerability		**Certainty**	
4. Vulnerability to maladaptive human responses	Highly vulnerable to maladaptive human responses	High	5	High	3
	Less vulnerable to maladaptive human responses	Medium	3	Medium	2
	Not vulnerable to maladaptive human responses	Low	1	Low	1
		Score	3	**Score**	2
		Vulnerability		**Certainty**	
5. Location relative to highest elevation	Mountain summit habitat confined to within 1,000 feet of the highest elevations	High	5	High	3
	High elevation habitat mainly occurring between 1,000 and 2,000 feet below the highest mountain tops	Medium	3	Medium	2
	Lower elevation habitat that should be able to move upslope	Low	1	Low	1
		Score	3	**Score**	2

Appendix B Vulnerability and certainy scores for South-Central Interior Small Stream and Riparian habitat in the Cumberland – Southern Blue Ridge subregion

		Vulnerability		Certainty	
6. Intrinsic adaptive capacity	Unlikely to be significant	High	5	High	3
	Likely to be significant	Low	1	Medium	2
				Low	1
		Score	1	**Score**	2

		Vulnerability		Certainty	
7. Dependence on specific hydrologic conditions	Habitats that are dependent on specific hydrologic conditions	High	5	High	3
	Habitats less dependent on specific hydrologic conditions	Low	1	Medium	2
				Low	1
		Score	1	**Score**	2

		Vulnerability		Certainty	
8. Vulnerability of Foundation/Keystone species to climate change	Foundation/keystone spp. Likely to be particularly vulnerable to climate change	High	5	High	3
	Foundation/keystone spp. Unlikely to be vulnerable to climate change	Low	1	Medium	2
				Low	1
		Score	1	**Score**	3

		Vulnerability		Certainty	
9. Constraints on latitudinal range shifts	Highly constrained	High	5	High	3
	Somewhat constrained	Medium	3	Medium	2
	Low level of constraint	Low	1	Low	1
		Score	3	**Score**	1

		Vulnerability		Certainty	
10. Likelihood of managing/alleviating climate change impacts	Not feasible	High	5	High	3
	feasible	Low	1	Medium	2
				Low	1
		Score	5	**Score**	3

Appendix B Vulnerability and certainy scores for South-Central Interior Small Stream and Riparian habitat in the Cumberland – Southern Blue Ridge subregion (continued)

		Vulnerability		Certainty	
11. Potential for climate change to exacerbate impacts of non-climate stressors, or vice versa	Potential for large increase in stressor impacts	High	5	High	3
	Potential low	Low	1	Medium	2
				Low	1
		Score	1	**Score**	2

12. Exposure to projected net drying	>-0.119	0%	5	High	3
	"-0.119 - -0.097"	0%	4		2
	"-0.096 - -0.074"	45%	3	Medium	1
	"-0.073 - -0.051"	45%	2		
	"-0.050 - -0.028"	10%	1	Low	
		Score	2	**Score**	2

13. Exposure to projected temperature increase	>5.5	0%	5	High	
	5.4-5.1	0%	4		
	5.0-4.5	90%	3	Medium	
	4.4-3.9	10%	2		
	<3.9	0	1	Low	
		Score	3	**Score**	2

Total Vulnerability Score		**34**	**Vulnerable**	
Total Certainty Score				**29**

Appendix B Vulnerability and certainy scores for South-Central Interior Small Stream and Riparian habitat in the Cumberland – Southern Blue Ridge subregion (continued)

Score range	Vulnerability category	Description
13-23	Least Vulnerable (Vc1)	Habitats that may benefit from climate change and increase their extents greatly (>50%).
24-34	Less Vulnerable (Vc2)	Habitats that may not be at adverse risk from climate change, or that may benefit and increase their extents (<50%)
35-45	Vulnerable (Vc3)	Habitats that are at risk of being significantly reduced in extent (20-50%) by climate change.
45-55	Highly Vulnerable (Vc4)	Habitats that are at high risk of being greatly reduced in area (>50% reduction) by climate change
56-65	Critically Vulnerable (Vc5)	Habitats that are at high risk of being eliminated entirely from area by climate change

Appendix B Vulnerability and certainy scores for South-Central Interior Small Stream and Riparian habitat in the Cumberland – Southern Blue Ridge subregion (concluded)

Habitat: Habitat: Southern Interior Low Plateau Dry Mesic Oak Forest

		Vulnerability		Certainty	
1. Location in geographical range of habitat				High	3
	Close to (<200 kms) southern limit of habitat distribution	High	5	Medium	2
	More distant from southern limit of habitat distribution	Low	1	Low	1
		Score	5	**Score**	3
		Vulnerability		**Certainty**	
2. Degree of cold-adaptation	Important constituent species limited to cold-temperature areas	High	5	High	3
	Important constituent species limited to cool temperature areas	Medium	3	Medium	2
	Important constituent species tolerant of warmer temperatures	Low	1	Low	1
		Score	1	**Score**	3
		Vulnerability		**Certainty**	
3. Sensitivity to extreme climatic events (e.g., drought, floods, windstorms, icestorms)	Highly vulnerable to extreme climatic events	High	5	High	3
	Less vulnerable to extreme climatic events	Medium	3	Medium	2
	Not vulnerable to extreme climatic events	Low	1	Low	1
		Score	1	**Score**	3
		Vulnerability		**Certainty**	
4. Vulnerability to maladaptive human responses	Highly vulnerable to maladaptive human responses	High	5	High	3
	Less vulnerable to maladaptive human responses	Medium	3	Medium	2
	Not vulnerable to maladaptive human responses	Low	1	Low	1
		Score	3	**Score**	2
		Vulnerability		**Certainty**	
5. Location relative to highest elevation	Mountain summit habitat confined to within 1,000 feet of the highest elevations	High	5	High	3
	High elevation habitat mainly occurring between 1,000 and 2,000 feet below the highest mountain tops	Medium	3	Medium	2
	Lower elevation habitat that should be able to move upslope	Low	1	Low	1
		Score	1	**Score**	2

Appendix C Vulnerability and certainty scores for Southern Interior Low Plateau Dry Mesic Oak Forest

		Vulnerability		Certainty	
6. Intrinsic adaptive capacity	Unlikely to be significant	High	5	High	3
	Likely to be significant	Low	1	Medium	2
				Low	1
		Score	1	**Score**	2

		Vulnerability		Certainty	
7. Dependence on specific hydrologic conditions	Habitats that are dependent on specific hydrologic conditions	High	5	High	3
	Habitats less dependent on specific hydrologic conditions	Low	1	Medium	2
				Low	1
		Score	1	**Score**	3

		Vulnerability		Certainty	
8. Vulnerability of Foundation/Keystone species to climate change	Foundation/keystone spp. Likely to be particularly vulnerable to climate change	High	5	High	3
	Foundation/keystone spp. Unlikely to be vulnerable to climate change	Low	1	Medium	2
				Low	1
		Score	1	**Score**	2

		Vulnerability		Certainty	
9. Constraints on latitudinal range shifts	Highly constrained	High	5	High	3
	Somewhat constrained	Medium	3	Medium	2
	Low level of constraint	Low	1	Low	1
		Score	3	**Score**	2

		Vulnerability		Certainty	
10. Likelihood of managing/alleviating climate change impacts	Not feasible	High	5	High	3
	feasible	Low	1	Medium	2
				Low	1
		Score	1	**Score**	3

Appendix C Vulnerability and certainy scores for Southern Interior Low Plateau Dry Mesic Oak Forest (continued)

		Vulnerability		Certainty	
11. Potential for climate change to exacerbate impacts of non-climate stressors, or vice versa	Potential for large increase in stressor impacts	High	5	High	3
	Potential low	Low	1	Medium	2
				Low	1
		Score	1	**Score**	2

12. Exposure to projected net drying	>-0.119	0%	5	High	3
	"-0.119 - -0.097"	1%	4		2
	"-0.096 - -0.074"	98%	3	Medium	1
	"-0.073 - -0.051"	1%	2		
	"-0.050 - -0.028"	0%	1	Low	
		Score	3	**Score**	2

13. Exposure to projected temperature increase	>5.5	0%	5	High	
	5.4-5.1	0%	4		
	5.0-4.5	90%	3	Medium	
	4.4-3.9	10%	2		
	<3.9	0	1	Low	
		Score	4	**Score**	2

Total Vulnerability Score		**26**	**Less Vulnerable**
Total Certainty Score			**31**

Appendix C Vulnerability and certainy scores for Southern Interior Low Plateau Dry Mesic Oak Forest (continued)

Score range	Vulnerability category	Description
13-23	Least Vulnerable (Vc1)	Habitats that may benefit from climate change and increase their extents greatly (>50%).
24-34	Less Vulnerable (Vc2)	Habitats that may not be at adverse risk from climate change, or that may benefit and increase their extents (<50%)
35-45	Vulnerable (Vc3)	Habitats that are at risk of being significantly reduced in extent (20-50%) by climate change.
45-55	Highly Vulnerable (Vc4)	Habitats that are at high risk of being greatly reduced in area (>50% reduction) by climate change
56-65	Critically Vulnerable (Vc5)	Habitats that are at high risk of being eliminated entirely from area by climate change

Appendix C Vulnerability and certainy scores for Southern Interior Low Plateau Dry Mesic Oak Forest (continued)

Habitat: Habitat: Central Interior Highlands Calcareous Glades and Barrens

		Vulnerability		Certainty	
1. Location in geographical range of habitat				High	3
	Close to (<200 kms) southern limit of habitat distribution	High	5	Medium	2
	More distant from southern limit of habitat distribution	Low	1	Low	1
		Score	5	Score	3
		Vulnerability		Certainty	
2. Degree of cold-adaptation	Important constituent species limited to cold-temperature areas	High	5	High	3
	Important constituent species limited to cool temperature areas	Medium	3	Medium	2
	Important constituent species tolerant of warmer temperatures	Low	1	Low	1
		Score	1	Score	3
		Vulnerability		Certainty	
3. Sensitivity to extreme climatic events (e.g., drought, floods, windstorms, icestorms)	Highly vulnerable to extreme climatic events	High	5	High	3
	Less vulnerable to extreme climatic events	Medium	3	Medium	2
	Not vulnerable to extreme climatic events	Low	1	Low	1
		Score	1	Score	2
		Vulnerability		Certainty	
4. Vulnerability to maladaptive human responses	Highly vulnerable to maladaptive human responses	High	5	High	3
	Less vulnerable to maladaptive human responses	Medium	3	Medium	2
	Not vulnerable to maladaptive human responses	Low	1	Low	1
		Score	3	Score	2
		Vulnerability		Certainty	
5. Location relative to highest elevation	Mountain summit habitat confined to within 1,000 feet of the highest elevations	High	5	High	3
	High elevation habitat mainly occurring between 1,000 and 2,000 feet below the highest mountain tops	Medium	3	Medium	2
	Lower elevation habitat that should be able to move upslope	Low	1	Low	1
		Score	1	Score	3

Appendix D Vulnerability and certainy scores for Central Interior Highlands Calcareous Glades and Barrens

		Vulnerability		Certainty	
6. Intrinsic adaptive capacity	Unlikely to be significant	High	5	High	3
	Likely to be significant	Low	1	Medium	2
				Low	1
		Score	1	**Score**	3
		Vulnerability		**Certainty**	
7. Dependence on specific hydrologic conditions	Habitats that are dependent on specific hydrologic conditions	High	5	High	3
	Habitats less dependent on specific hydrologic conditions	Low	1	Medium	2
				Low	1
		Score	1	**Score**	3
		Vulnerability		**Certainty**	
8. Vulnerability of Foundation/Keystone species to climate change	Foundation/keystone spp. Likely to be particularly vulnerable to climate change	High	5	High	3
	Foundation/keystone spp. Unlikely to be vulnerable to climate change	Low	1	Medium	2
				Low	1
		Score	5	**Score**	3
		Vulnerability		**Certainty**	
9. Constraints on latitudinal range shifts	Highly constrained	High	5	High	3
	Somewhat constrained	Medium	3	Medium	2
	Low level of constraint	Low	1	Low	1
		Score	5	**Score**	2
		Vulnerability		**Certainty**	
10. Likelihood of managing/alleviating climate change impacts	Not feasible	High	5	High	3
	feasible	Low	1	Medium	2
				Low	1
		Score	1	**Score**	2

Appendix D Vulnerability and certainy scores for Central Interior Highlands Calcareous Glades and Barrens (continued)

		Vulnerability		Certainty	
11. Potential for climate change to exacerbate impacts of non-climate stressors, or vice versa	Potential for large increase in stressor impacts	High	5	High	3
	Potential low	Low	1	Medium	2
				Low	1
		Score	1	**Score**	3

12. Exposure to projected net drying	>-0.119	10%	5	High	3
	"-0.119 - -0.097"	90%	4		2
	"-0.096 - -0.074"	0%	3	Medium	1
	"-0.073 - -0.051"	0%	2		
	"-0.050 - -0.028"	0%	1	Low	
		Score	4	**Score**	2

13. Exposure to projected temperature increase	>5.5	0%	5	High	
	5.4-5.1	0%	4		
	5.0-4.5	90%	3	Medium	
	4.4-3.9	10%	2		
	<3.9	0	1	Low	
		Score	3	**Score**	2

Total Vulnerability Score		**32**	**Less Vulnerable**
Total Certainty Score			**32**

Appendix D Vulnerability and certainty scores for Central Interior Highlands Calcareous Glades and Barrens (continued)

Score range	Vulnerability category	Description
13-23	Least Vulnerable (Vc1)	Habitats that may benefit from climate change and increase their extents greatly (>50%).
24-34	Less Vulnerable (Vc2)	Habitats that may not be at adverse risk from climate change, or that may benefit and increase their extents (<50%)
35-45	Vulnerable (Vc3)	Habitats that are at risk of being significantly reduced in extent (20-50%) by climate change.
45-55	Highly Vulnerable (Vc4)	Habitats that are at high risk of being greatly reduced in area (>50% reduction) by climate change
56-65	Critically Vulnerable (Vc5)	Habitats that are at high risk of being eliminated entirely from area by climate change

Appendix D Vulnerability and certainty scores for Central Interior Highlands Calcareous Glades and Barrens (continued)

Appendix E Factor scores for 41 species assessed using Version 3.0 of the CCVI

					Temperature Scope					
Taxonomic Group	**Species**	**English Name**	**Geographic Area**	**GRank**	**A >6.0F**	**A 5.5F**	**A 5.1F**	**A 4.5F**	**A 3.9F**	**A <3.9F**
Vascular Plant	*Tsuga caroliniana*	Carolina hemlock	Central Appalachians	G3	0	0	0	100	0	0
Vascular Plant	*Tsuga caroliniana*	Carolina hemlock	Cumberland and Southern Appalachians	G3	0	0	0	100	0	0
mammal	*Reithrodontomys humulis*	Eastern Harvest Mouse	Central Appalachians	G5	0	36	6	58	0	0
mammal	*Reithrodontomys humulis*	Eastern Harvest Mouse	Cumberland and Southern Appalachians	G5	0	0	10	80	10	0
mammal	*Reithrodontomys humulis*	Eastern Harvest Mouse	Interior Low Plateau	G5	0	22	14	64	0	0
Vascular Plant	*Cladrastis kentuckea*	Yellow-wood	Interior Low Plateau	G4	0	0	0	0	75	25
Vascular Plant	*Cladrastis kentuckea*	Yellow-wood	Cumberland and Southern Appalachians	G4	0	0	0	0	75	25
Amphibian	*Desmognathus santeetlah*	Santeetlah Dusky salamander	Cumberland and Southern Appalachians	G3G4	0	0	0	100	0	0
Amphibian	*Plethodon nettingi*	Cheat Mountain Salamander	Central Appalachians	G2G3	0	91	0	9	0	0
Vascular Plant	*Stellaria fontinalis*	Water stitchwort	Interior Low Plateau	G3	0	4	2	94	0	0
Vascular Plant	*Actaea podocarpa*	Mountain bugbane	Central Appalachians	G4	0	26	32	42	0	0
Vascular Plant	*Actaea podocarpa*	Mountain bugbane	Cumberland and Southern Appalachians	G4	0	0	0	100	0	0
Reptile	*Cemophora coccinea*	Northern Scarletsnake	Interior Low Plateau	G5	0	17	14	69	0	0
Reptile	*Cemophora coccinea*	Northern Scarletsnake	Cumberland and Southern Appalachians	G5	0	0	14	72	14	0
Vascular Plant	*Neviusia alabamensis*	Alabama Snow-wreath	Cumberlands and Southern Appalachians	G2	0	0	25	65	10	0
Vascular Plant	*Neviusia alabamensis*	Alabama Snow-wreath	Interior Low Plateau	G2	0	0	0	100	0	0
Vascular Plant	*Silene regia*	Royal catchfly	Cumberland Southern Appalachians	G3	0	0	20	75	5	0

					Temperature Scope					
Taxonomic Group	**Species**	**English Name**	**Geographic Area**	**GRank**	**A >6.0F**	**A 5.5F**	**A 5.1F**	**A 4.5F**	**A 3.9F**	**A <3.9F**
Vascular Plant	*Silene regia*	Royal catchfly	Interior Low Plateau	G3	0	37	52	11	0	0
Vascular Plant	*Buckleya distichophylla*	Piratebush	Central Appalachians	G3	0	0	0	100	0	0
Vascular Plant	*Buckleya distichophylla*	Piratebush	Cumberland and Southern Appalachians	G3	0	0	0	100	0	0
Vascular Plant	*Jamesianthus alabamensis*	Alabama warbonnet	Cumberland and Southern Appalachians	G3	0	0	48	34	18	0
Vascular Plant	*Carya carolinae-septentrionalis*	Southern Shagbark Hickory	Cumberland and Southern Appalachians	G5	0	0	20	73	7	0
Vascular Plant	*Carya carolinae-septentrionalis*	Southern Shagbark Hickory	Interior Low Plateau	G5	0	17	1	82	0	0
Vascular Plant	*Eurybia saxicastelli*	Rockcastle wood-aster	Cumberland and Southern Appalachians	G1G2	0	0	0	100	0	0
Amphibian	*Plethodon hubrichti*	Cheat Mountain Salamander	Central Appalachians	G2	0	0	0	100	0	0
Vascular Plant	*Arabis georgiana*	Georgia rock Cress	Cumerland and Southern Appalachians	G1	0	0	16	44	40	0
Vascular Plant	*Vaccinium myrtilloides*	Velvetleaf blueberry	Central Appalachians	G5	0	27	49	24	0	0
Vascular Plant	*Vaccinium myrtilloides*	Velvetleaf blueberry	Cumberland and Southern Appalachians	G5	0	0	0	100	0	0
Vascular Plant	*Clintonia borealis*	Bluebead	Cumberland and Southern Appalachians	G5	0	1	0	99	0	0
Vascular Plant	*Clintonia borealis*	Bluebead	Central Appalachians	G5	0	23	53	24	0	0
Vascular Plant	*Castilleja coccinea*	Scarlet Indian Paintbrush	Central Appalachians	G5	0	29	34	37	0	0
Vascular Plant	*Castilleja coccinea*	Scarlet Indian Paintbrush	Cumberland and Southern Appalachians	G5	0	1	6	87	6	0
Vascular Plant	*Castilleja coccinea*	Scarlet Indian Paintbrush	Interior Low Plateau	G5	0	40	17	43	0	0
Vascular Plant	*Helonias bullata*	Swamp Pink	Cumberland and Southern Appalachians	G3	0	0	0	100	0	0

					Temperature Scope					
Taxonomic Group	**Species**	**English Name**	**Geographic Area**	**GRank**	**A >6.0F**	**A 5.5F**	**A 5.1F**	**A 4.5F**	**A 3.9F**	**A <3.9F**
Vascular Plant	*Helonias bullata*	Swamp Pink	Central Appalachians	G3	0	0	0	100	0	0
Vascular Plant	*Polemonium vanbruntiae*	Bog Jacob's Ladder	Central Appalachians	G3G4	0	42	42	16	0	0
Vascular Plant	*Xyris tennesseensis*	Tennessee Yellow-eyed grass	Cumberland and Southern Appalachians	G1	0	0	27	45	28	0
Vascular Plant	*Xyris tennesseensis*	Tennessee Yellow-eyed grass	Interior Low Plateau	G1	0	0	0	100	0	0
Vascular Plant	*Bouteloua curtipendula*	Sideoats gramma	Interior Low Plateau	G5	0	21.65	33.69	44.66	0	0
Vascular Plant	*Bouteloua curtipendula*	Sideoats gramma	Cumberland and Southern Appalachians	G5	0	3.42	94.44	2.14	0	0
Vascular Plant	*Bouteloua curtipendula*	Sideoats gramma	Central Appalachians	G5	0	38.87	24.73	36.4	0	0
Vascular Plant	*Baptisia australis*	wild blue indigo	Interior Low Plateau	G5	0	27.93	37.72	34.35	0	0
Vascular Plant	*Baptisia australis*	wild blue indigo	Cumberland and Southern Appalachians	G5	0	1	7	90	2	0
Vascular Plant	*Baptisia australis*	wild blue indigo	Central Appalachians	G5	0	22	51	27	0	0
Vascular Plant	*Cymophyllus fraserianus*	Fraser's sedge	Cumberlands and Southern Appalachians	G4	0	2	0	98	0	0
Vascular Plant	*Cymophyllus fraserianus*	Fraser's sedge	Central Appalachians	G4	0	41	11	48	0	0
Invert-Insect	*Speyaria diana*	Diana fritillary	Central Appalachians	G3	0	34	1	65	0	0
Invert-Insect	*Speyaria diana*	Diana fritillary	Cumberland and Southern Appalachians	G3	0	1	10	83	6	0
Invert-Insect	*Speyaria diana*	Diana fritillary	Interior Low Plateau	G3	0	0	0	100	0	0
Invert-Insect	*Cicindela ancocisconensis*	Appalachian tiger beetle	Central Appalachians	G3	0	38	28	34	0	0
Invert-Insect	*Cicindela ancocisconensis*	Appalachian tiger beetle	Cumberlands and Southern Appalachians	G3	0	0	0	68	29	3

					Temperature Scope					
Taxonomic Group	**Species**	**English Name**	**Geographic Area**	**GRank**	**A >6.0F**	**A 5.5F**	**A 5.1F**	**A 4.5F**	**A 3.9F**	**A <3.9F**
Invert-Insect	*Catacola marmorata*	Marbled underwing	Cumberlands and Southern Appalachians	G3G4	0	0	0	100	0	0
Invert-Insect	*Catacola marmorata*	Marbled underwing	Interior Low Plateau	G3G4	0	22	77	1	0	0
Invert-Insect	*Euphydryas phaeton*	Baltimore checkerspot	Central Appalachians	G4	0	0	0	53	46	1
Invert-Insect	*Euphydryas phaeton*	Baltimore checkerspot	Cumberland and Southern Appalachians	G4	0	0	21	57	20	2
Invert-Insect	*Euphydryas phaeton*	Baltimore checkerspot	Interior Low Plateau	G4	0	33	32	35	0	0
Vascular Plant	*Dalea foliosa*	Leafy prairy clover	Interior Low Plateau	G2G3	0	0	100	0	0	0
Vascular Plant	*Dalea foliosa*	Leafy prairy clover	Cumberland and Southern Appalachian	G2G3	0	0	83	17	0	0
Vascular Plant	*Astragalus tennesseensis*	Tennessee milkvetch	Interior Low Plateau	G3	0	0	0	100	0	0
Vascular Plant	*Astragalus tennesseensis*	Tennessee milkvetch	Cumberland and Southern Appalachians	G3	0	0	0	100	0	0
Vascular Plant	*Echinacea laevigata*	Smooth purple cone flower	Cumberland and Southern Appalachians	G2G3	0	0	19	78	3	0
Vascular Plant	*Echinacea laevigata*	Smooth purple cone flower	Central Appalachians	G2G3	0	0	0	80	20	0
Vascular Plant	*Eriogonum allenii*	Shale barren buckwheat	Central Appalachians	G4	0	0	0	82	17	1
Vascular Plant	*Eriogonum allenii*	Shale barren buckwheat	Cumberland and Southern Appalachians	G4	0	0	0	77	23	0
Vascular Plant	*Gaylussacia brachycera*	Box huckleberry	Cumberlands and Southern Appalachians	G3	0	0	0	100	0	0
Vascular Plant	*Gaylussacia brachycera*	Box huckleberry	Interior Low Plateau	G3	0	0	0	100	0	0
Vascular Plant	*Gaylussacia brachycera*	Box huckleberry	Central Appalachians	G3	0	26	11	63	0	0
Vascular Plant	*Helenium virginicum*	Virginia Sneezeweed	Central Appalachians	G3	0	0	0	95	5	0

					Temperature Scope					
Taxonomic Group	**Species**	**English Name**	**Geographic Area**	**GRank**	**A >6.0F**	**A 5.5F**	**A 5.1F**	**A 4.5F**	**A 3.9F**	**A <3.9F**
Vascular Plant	*Helianthus eggertii*	Eggert's sunflower	Cumberland and Southern Appalachians	G3	0	0	59	33	6	2
Vascular Plant	*Helianthus eggertii*	Eggert's sunflower	Interior Low Plateau	G3	0	17	3	80	0	0
Vascular Plant	*Hypericum mitchellianum*	Blue Ridge St. Johnswort	Cumberlands and Southern Appalachians	G3	0	0	0	100	0	0
Vascular Plant	*Hypericum mitchellianum*	Blue Ridge St. Johnswort	Central Appalachians	G3	0	0	21	79	0	0
Vascular Plant	*Leiophyllum buxifolium*	Sand-myrtle	Cumberlands and Southern Appalachians	G4	0	0	0	100	0	0
Vascular Plant	*Leiophyllum buxifolium*	Sand-myrtle	Central Appalachians	G4	0	13	0	87	0	0
Amphibian	*Desmognathus wrighti*	Southern Pygmy salamander	Cumberland and Southern Appalachian	G3	0	0	0	100	0	0
Amphibian	*Desmognathus imitator*	Imitator salamander	Cumberland and Southern Appalachian	G3G4	0	0	0	100	0	0
Vascular Plant	*Parnassia grandifolia*	Largeleaf grass-of-parnassus	Central Appalachians	G3	0	9	0	91	0	0
Vascular Plant	*Parnassia grandifolia*	Largeleaf grass-of-parnassus	Cumberlands and Southern Appalachians	G3	0	0	25	65	10	0
Vascular Plant	*Parnassia grandifolia*	Largeleaf grass-of-parnassus	Interior Low Plateau	G3	0	0	0	100	0	0
Amphibian	*Plethodon hubrichti*	Peaks of Otter Salamander	Central Appalachians	G2	0	0	0	100	0	0

		Hamon AET:PET Moisture Metric Scope						Sea level	Natl barriers	Anth barriers	CC mitigation	Dispersal/Movement	Hist. thermal niche	Physiol. thermal niche	Hist. hydrol. niche	Physiol. hydrol. niche	Disturbance
English Name	**Geographic Area**	**< -0.119**	**-0.119**	**-0.096**	**-0.073**	**-0.05**	**>-0.028**	**B1**	**B2a**	**B2b**	**B3**	**C1**	**C2ai**	**C2aii**	**C2bi**	**C2bii**	**C2c**
Carolina hemlock	Central Appalachians	0	0	0	100	0	0	N	N	N	U	N	N	SI	SI	N	N
Carolina hemlock	Cumberland and Southern Appalachians	0	0	0	39	56	5	N	N	N	U	N	N	SI	N	N	N
Eastern Harvest Mouse	Central Appalachians	0	0	0	97	3	0	N	SI	N	N	GI	N	N	N	N	Inc-SI
Eastern Harvest Mouse	Cumberland and Southern Appalachians	0	0	33	58	9	0	N	SI	N	N	GI	N	N	SI	N	Inc-SI
Eastern Harvest Mouse	Interior Low Plateau	0	0	82	18	0	0	N	SI	N	N	GI	N	N	SI	N	Inc-SI
Yellow-wood	Interior Low Plateau	0	0	50	25	25	0	N	SI	Inc	U	N	N	SI	N	SI	N
Yellow-wood	Cumberland and Southern Appalachians	0	0	50	25	25	0	N	SI	Inc	U	N	N	SI	N	SI	N
Santeetlah Dusky salamander	Cumberland and Southern Appalachians	0	0	0	58	30	12	N	SI	SI	N	Inc	N	SI	N	SI	N
Cheat Mountain Salamander	Central Appalachians	0	0	0	2	67	31	N	GI	Inc	N	GI-Inc	N	GI	SI	GI	N
Water stitchwort	Interior Low Plateau	0	100	0	0	0	0	N	GI-Inc	GI-Inc	SI	Inc	N	N	SI	SI	Inc
Mountain bugbane	Central Appalachians	0	0	0	65	34	1	N	N	N	N	Inc	N	SI	N	N	N
Mountain bugbane	Cumberland and Southern Appalachians	0	0	7	62	27	4	N	N	N	N	Inc	N	SI	SI	N	N
Northern Scarletsnake	Interior Low Plateau	0	2	97	1	0	0	N	SI-N	SI-N	SI	N	N	N	N	N	N
Northern Scarletsnake	Cumberland and Southern Appalachians	0	0	51	44	4	1	N	SI-N	SI-N	SI	N	N	N	N	N	N

		Hamon AET:PET Moisture Metric Scope						Sea level	Natl barriers	Anth barriers	CC mitigation	Dispersal/Movement	Hist. thermal niche	Physiol. thermal niche	Hist. hydrol. niche	Physiol. hydrol. niche	Disturbance
English Name	**Geographic Area**	**< -0.119**	**-0.119**	**-0.096**	**-0.073**	**-0.05**	**>-0.028**	**B1**	**B2a**	**B2b**	**B3**	**C1**	**C2ai**	**C2aii**	**C2bi**	**C2bii**	**C2c**
Alabama Snow-wreath	Cumberlands and Southern Appalachians	0	0	70	28	2	0	N	GI	Inc	U	GI	N	N	N	N	Inc
Alabama Snow-wreath	Interior Low Plateau	0	0	98	2	0	0	N	GI	Inc	U	GI	N	N	SI	N	Inc
Royal catchfly	Cumberland Southern Appalachians	0	0	41	59	0	0	N	SI	GI-Inc	SI	Inc	N	N	SI	N	SI-N
Royal catchfly	Interior Low Plateau	0	16	84	0	0	0	N	SI	GI-Inc	SI	Inc	N	N	SI	N	SI-N
Piratebush	Central Appalachians	0	0	0	100	0	0	N	SI	SI	U	SI	N	N	N	N	N
Piratebush	Cumberland and Southern Appalachians	0	0	0	64	33	3	N	SI	SI	U	SI	N	N	N	N	N
Alabama warbonnet	Cumberland and Southern Appalachians	0	0	95	5	0	0	N	SI	SI	N	GI-Inc	N	N	Inc	SI	SI
Southern Shagbark Hickory	Cumberland and Southern Appalachians	0	0	47	49	4	0	N	N	N	N	N	N	N	U	N	N
Southern Shagbark Hickory	Interior Low Plateau	0	0	98	2	0	0	N	N	N	N	N	N	N	U	SI	N
Rockcastle wood-aster	Cumberland and Southern Appalachians	0	0	69	31	0	0	N	Inc-SI	N	N	SI	N	N	SI	GI	Inc
Cheat Mountain Salamander	Central Appalachians	0	0	0	100	0	0	N	GI	Inc	N	GI-Inc	N	GI	Inc	GI	N
Georgia rock Cress	Cumerland and Southern Appalachians	0	0	59	41	0	0	N	GI	GI	U	Inc	N	N	Inc	N	SI
Velvetleaf blueberry	Central Appalachians	0	0	0	38	59	3	N	N	N	U	N	N	GI	N	N	N
Velvetleaf blueberry	Cumberland and Southern Appalachians	0	0	0	85	15	0	N	N	N	U	N	N	GI	N	N	N
Bluebead	Cumberland and Southern Appalachians	0	0	0	55	39	6	N	N	N	N	Inc-SI	N	GI-Inc	N	N	N

		Hamon AET:PET Moisture Metric Scope						Sea level	Natl barriers	Anth barriers	CC mitigation	Dispersal/Movement	Hist. thermal niche	Physiol. thermal niche	Hist. hydrol. niche	Physiol. hydrol. niche	Disturbance
English Name	Geographic Area	< -0.119	-0.119	-0.096	-0.073	-0.05	>-0.028	B1	B2a	B2b	B3	C1	C2ai	C2aii	C2bi	C2bii	C2c
Bluebead	Central Appalachians	0	0	0	39	59	2	N	N	N	N	Inc-SI	N	GI-Inc	N	N	N
Scarlet Indian Paintbrush	Central Appalachians	0	0	0	60	38	2	N	Inc-SI	Inc-SI	U	Inc-SI	N	N	N	GI-Inc	N
Scarlet Indian Paintbrush	Cumberland and Southern Appalachians	0	0	26	44	27	3	N	Inc-SI	Inc-SI	U	Inc-SI	N	N	N	GI-Inc	N
Scarlet Indian Paintbrush	Interior Low Plateau	0	7	74	19	0	0	N	Inc-SI	Inc-SI	U	Inc-SI	N	N	N	GI-Inc	N
Swamp Pink	Cumberland and Southern Appalachians	0	0	0	21	71	8	N	GI-Inc	GI-Inc	U	GI-Inc	N	N	N	GI-Inc	SI
Swamp Pink	Central Appalachians	0	0	0	54	46	0	N	GI-Inc	GI-Inc	U	GI-Inc	N	N	Inc	GI-Inc	SI
Bog Jacob's Ladder	Central Appalachians	0	0	0	17	79	4	N	SI	N	U	N	N	SI	N	Inc-SI	SI-N
Tennessee Yellow-eyed grass	Cumberland and Southern Appalachians	0	0	56	44	0	0	N	Inc	Inc	U	SI	N	N	N	Inc-SI	SI
Tennessee Yellow-eyed grass	Interior Low Plateau	0	0	100	0	0	0	N	Inc	Inc	U	SI	N	N	GI	Inc-SI	SI
Sideoats gramma	Interior Low Plateau	0	3.3	84.56	12.14	0	0	N	Inc	SI	U	Inc	N	N	SI	N	N
Sideoats gramma	Cumberland and Southern Appalachians	0	0	9.83	86.04	2.99	1.14	N	Inc	SI	U	Inc	N	N	N	N	N
Sideoats gramma	Central Appalachians	0	0	0	70.52	28.4	1.08	N	Inc	SI	U	Inc	N	N	N	N	N
Wild blue indigo	Interior Low Plateau	0	4.93	88.58	6.49	0	0	N	N	SI-N	SI-N	N	N	N	SI	SI	SI
Wild blue indigo	Cumberland and Southern Appalachians	0	0	29	59	11	1	N	N	SI-N	SI-N	N	N	N	N	SI	SI
Wild blue indigo	Central Appalachians	0	0	62	0	38	0	N	N	SI-N	SI-N	N	N	N	N	SI	SI

		Hamon AET:PET Moisture Metric Scope						Sea level	Natl barriers	Anth barriers	CC mitigation	Dispersal/Movement	Hist. thermal niche	Physiol. thermal niche	Hist. hydrol. niche	Physiol. hydrol. niche	Disturbance
English Name	**Geographic Area**	**< -0.119**	**-0.119**	**-0.096**	**-0.073**	**-0.05**	**>-0.028**	**B1**	**B2a**	**B2b**	**B3**	**C1**	**C2ai**	**C2aii**	**C2bi**	**C2bii**	**C2c**
Fraser's sedge	Cumberlands and Southern Appalachians	0	0	3	68	26	3	N	N	N	N	Inc-SI	N	N	N	N	N
Fraser's sedge	Central Appalachians	0	0	54	0	43	3	N	SI	GI	N	Inc-SI	N	N	N	N	N
Diana fritillary	Central Appalachians	0	0	0	53	43	4	N	N	N	N	Inc-SI	N	N	N	N	SI
Diana fritillary	Cumberland and Southern Appalachians	0	0	20	64	15	1	N	N	N	N	Inc-SI	N	N	N	N	SI
Diana fritillary	Interior Low Plateau	0	0	94	6	0	0	N	N	N	N	Inc-SI	N	N	SI	N	SI
Appalachian tiger beetle	Central Appalachians	0	0	0	48	48	4	N	N	Inc-SI	N	N	N	SI	N	SI	SI
Appalachian tiger beetle	Cumberlands and Southern Appalachians	0	3	0	97	0	0	N	N	Inc-SI	N	N	N	SI	N	SI	SI
Marbled underwing	Cumberlands and Southern Appalachians	0	0	55	40	0	5	N	N	SI	N	N	N	N	N	N	N
Marbled underwing	Interior Low Plateau	0	6	82	12	0	0	N	N	SI	N	N	N	N	Inc	N	N
Baltimore checkerspot	Central Appalachians	0	26	52	22	0	0	N	N	N	U	N	N	SI	N	SI	SI
Baltimore checkerspot	Cumberland and Southern Appalachians	0	0	10	88	2	0	N	N	N	U	N	N	SI	N	SI	SI
Baltimore checkerspot	Interior Low Plateau	0	2	86	12	0	0	N	N	N	U	N	N	SI	N	SI	SI
Leafy prairy clover	Interior Low Plateau	0	0	0	100	0	0	N	GI	GI	SI-N	Inc-SI	N	N	Inc	N	N
Leafy prairy clover	Cumberland and Southern Appalachian	0	0	23	62	15	0	N	GI	GI	SI-N	Inc-SI	N	N	SI	N	N

		Hamon AET:PET Moisture Metric Scope						Sea level	Natl barriers	Anth barriers	CC mitigation	Dispersal/Movement	Hist. thermal niche	Physiol. thermal niche	Hist. hydrol. niche	Physiol. hydrol. niche	Disturbance
English Name	**Geographic Area**	**< -0.119**	**-0.119**	**-0.096**	**-0.073**	**-0.05**	**>-0.028**	**B1**	**B2a**	**B2b**	**B3**	**C1**	**C2ai**	**C2aii**	**C2bi**	**C2bii**	**C2c**
Tennessee milkvetch	Interior Low Plateau	0	0	100	0	0	0	N	GI	GI-SI	SI	Inc	N	N	Inc	N	N
Tennessee milkvetch	Cumberland and Southern Appalachians	0	0	100	0	0	0	N	GI	GI-SI	SI	Inc	N	N	Inc	N	N
Smooth purple cone flower	Cumberland and Southern Appalachians	0	0	58	32	10	0	N	GI	GI	SI-N	GI	N	N	N	N	N
Smooth purple cone flower	Central Appalachians	0	2	0	98	0	0	N	GI	GI	SI-N	GI	N	N	SI	N	N
Shale barren buckwheat	Central Appalachians	0	14	0	86	0	0	N	GI	N	N	GI	U	N	N	N	N
Shale barren buckwheat	Cumberland and Southern Appalachians	0	0	0	100	0	0	N	GI	N	N	GI	N	N	SI	N	N
Box huckleberry	Cumberlands and Southern Appalachians	0	0	53	42	5	0	N	N	SI	N	SI	N	N	N	N	N
Box huckleberry	Interior Low Plateau	0	0	100	0	0	0	N	N	SI	N	SI	N	N	Inc	N	N
Box huckleberry	Central Appalachians	0	0	0	93	7	0	N	N	GI-Inc	N	SI	N	N	N	N	N
Virginia Sneezeweed	Central Appalachians	0	9	91	0	0	0	N	GI	N	N	Inc-SI	N	N	N	Inc	N
Eggert's sunflower	Cumberland and Southern Appalachians	0	11	81	8	0	0	N	SI	GI	U	SI-N	N	N	N	U	SI-N
Eggert's sunflower	Interior Low Plateau	0	0	98	2	0	0	N	SI	GI	U	SI-N	N	N	SI	U	SI-N
Blue Ridge St. Johnswort	Cumberlands and Southern Appalachians	0	0	0	54	40	6	N	GI-Inc	SI	Inc	U	SI-N	Inc	N	N	N
Blue Ridge St. Johnswort	Central Appalachians	0	0	0	18	67	15	N	GI-Inc	SI	Inc	U	N	Inc	N	N	N

		Hamon AET:PET Moisture Metric Scope						Sea level	Natl barriers	Anth barriers	CC mitigation	Dispersal/Movement	Hist. thermal niche	Physiol. thermal niche	Hist. hydrol. niche	Physiol. hydrol. niche	Disturbance
English Name	**Geographic Area**	**< -0.119**	**- 0.119**	**- 0.096**	**- 0.073**	**-0.05**	**>- 0.028**	**B1**	**B2a**	**B2b**	**B3**	**C1**	**C2ai**	**C2aii**	**C2bi**	**C2bii**	**C2c**
Sand-myrtle	Cumberlands and Southern Appalachians	0	0	4	43	44	9	N	N	SI	N	Inc-SI	SI-N	N	N	N	N
Sand-myrtle	Central Appalachians	0	0	0	0	96	4	N	N	SI	N	Inc-SI	N	N	Inc	N	N
Southern Pygmy salamander	Cumberland and Southern Appalachian	0	0	0	49	45	6	N	GI	SI	N	Inc	SI-N	Inc	N	Inc	N
Imitator salamander	Cumberland and Southern Appalachian	0	0	0	54	33	13	N	Inc	SI	N	Inc	N	Inc	N	Inc	N
Largeleaf grass-of-parnassus	Central Appalachians	0	0	0	96	4	0	N	GI-Inc	N	N	Inc	N	N	N	Inc	N
Largeleaf grass-of-parnassus	Cumberlands and Southern Appalachians	0	0	70	28	2	0	N	GI-Inc	N	N	Inc	N	N	N	Inc	N
Largeleaf grass-of-parnassus	Interior Low Plateau	0	0	99	1	0	0	N	GI-Inc	N	N	Inc	N	N	Inc	Inc	N
Peaks of Otter Salamander	Central Appalachians	0	0	0	100	0	0	N	GI	Inc	N	GI-Inc	N	GI	Inc	GI	N

English Name	Geographic Area	Ice/snow C2d	Phys habitat C3	Other spp for hab C4a	Diet C4b	Pollinators C4c	Other spp disp C4d	Pathogens/enemies C4e	Competition C4f	Other spp interaction C4g	Genetic var C5a	Gen bottleneck C5b	Reproductive system C5c	Phenol response C6	Doc response D1	Modeled change D2	Modeled overlap D3	Protected Areas D4	Index	Confidence
Carolina hemlock	Central Appalachians	N	N	N	N/A	N	N	U	U	U	N	N/A	N/A	N	U	N	U	U	LV	VH
Carolina hemlock	Cumberland and Southern Appalachians	N	N	N	N/A	N	N	U	U	U	N	N/A	N/A	N	U	N	U	U	LV	VH
Eastern Harvest Mouse	Central Appalachians	N	N	N	N	N/A	N	U	U	U	U	N	N/A	N	N	GI	U	U	MV	VH
Eastern Harvest Mouse	Cumberland and Southern Appalachians	N	N	N	N	N/A	N	U	U	U	U	N	N/A	N	N	GI	U	U	HV	Low
Eastern Harvest Mouse	Interior Low Plateau	N	N	N	N	N/A	N	U	U	U	U	N	N/A	N	N	GI	U	U	HV	VH
Yellow-wood	Interior Low Plateau	N	SI	N	N/A	N	SI	U	U	U	U	N	N/A	U	U	U	U	U	HV	VH
Yellow-wood	Cumberland and Southern Appalachians	N	SI	N	N/A	N	SI	U	U	U	U	N	N/A	U	U	U	U	U	HV	VH
Santeetlah Dusky salamander	Cumberland and Southern Appalachians	N	N	N	N	N/A	N	U	U	N	Inc-SI	N/A	N/A	U	N	GI	U	U	HV	VH
Cheat Mountain Salamander	Central Appalachians	SI	Inc	N	N	N/A	U	U	U	SI	U	SI	N/A	N	SI	U	U	U	HV	VH
Water stitchwort	Interior Low Plateau	N	Inc	U	N/A	N	N	U	U	U	U	N	N/A	N	U	U	U	U	EV	VH
Mountain bugbane	Central Appalachians	N	SI	N	N/A	N	SI	U	U	SI	U	N	N/A	U	U	U	U	U	MV	VH
Mountain bugbane	Cumberland and Southern Appalachians	N	SI	N	N/A	N	SI	U	U	SI	U	N	N/A	U	U	U	U	U	HV	VH

		Ice/snow	Phys habitat	Other spp for hab	Diet	Pollinators	Other spp disp	Pathogens/enemies	Competition	Other spp interaction	Genetic var	Gen bottleneck	Reproductive system	Phenol response	Doc response	Modeled change	Modeled overlap	Protected Areas	Index	Confidence
English Name	**Geographic Area**	**C2d**	**C3**	**C4a**	**C4b**	**C4c**	**C4d**	**C4e**	**C4f**	**C4g**	**C5a**	**C5b**	**C5c**	**C6**	**D1**	**D2**	**D3**	**D4**		
Northern Scarletsnake	Interior Low Plateau	N	Inc	N	Inc-SI	N/A	N	U	U	U	U	N	N/A	U	U	U	U	U	MV	Low
Northern Scarletsnake	Cumberland and Southern Appalachians	N	Inc	N	Inc-SI	N/A	N	U	U	U	U	N	N/A	U	U	U	U	U	MV	Low
Alabama Snow-wreath	Cumberlands and Southern Appalachians	N	SI	N	N/A	Inc	N	U	U	U	U	SI	N/A	N	U	U	U	U	EV	VH
Alabama Snow-wreath	Interior Low Plateau	N	SI	N	N/A	Inc	N	U	U	U	U	SI	N/A	N	U	U	U	U	EV	VH
Royal catchfly	Cumberland Southern Appalachians	N	SI	N	N/A	Inc	N	U	U	U	N	N/A	N/A	U	U	U	U	U	EV	VH
Royal catchfly	Interior Low Plateau	N	SI	N	N/A	Inc	N	U	U	U	N	N/A	N/A	U	U	U	U	U	EV	VH
Piratebush	Central Appalachians	N	SI	SI	N/A	N	SI	U	U	U	U	N	N/A	U	U	U	U	U	MV	VH
Piratebush	Cumberland and Southern Appalachians	N	SI	SI	N/A	N	SI	U	U	U	U	N	N/A	U	U	U	U	U	MV	VH
Alabama warbonnet	Cumberland and Southern Appalachians	N	Inc	N	N/A	N	N	U	U	N	U	U	U	U	U	U	U	U	EV	VH
Southern Shagbark Hickory	Cumberland and Southern Appalachians	N	N	N	N/A	N	N	U	U	U	U	N	N/A	U	N	N	U	U	LV	VH
Southern Shagbark Hickory	Interior Low Plateau	N	N	N	N/A	N	N	U	U	U	U	N	N/A	U	N	N	U	U	LV	VH

		Ice/snow	Phys habitat	Other spp for hab	Diet	Pollinators	Other spp disp	Pathogens/enemies	Competition	Other spp interaction	Genetic var	Gen bottleneck	Reproductive system	Phenol response	Doc response	Modeled change	Modeled overlap	Protected Areas	Index	Confidence
English Name	**Geographic Area**	**C2d**	**C3**	**C4a**	**C4b**	**C4c**	**C4d**	**C4e**	**C4f**	**C4g**	**C5a**	**C5b**	**C5c**	**C6**	**D1**	**D2**	**D3**	**D4**		
Rockcastle wood-aster	Cumberland and Southern Appalachians	SI-N	Inc	N	N/A	N	N	U	U	U	U	U	U	N	U	U	U	U	EV	VH
Cheat Mountain Salamander	Central Appalachians	SI	N	N	N	N/A	U	U	U	N	U	SI	N/A	N	SI	U	U	U	HV	VH
Georgia rock Cress	Cumerland and Southern Appalachians	N	Inc	N	N/A	N	U	U	U	Inc	Inc	N/A	N/A	U	SI	U	U	U	HV	VH
Velvetleaf blueberry	Central Appalachians	GI	N	N	N/A	N	N	U	U	N	Inc	N/A	N/A	U	U	U	U	U	EV	VH
Velvetleaf blueberry	Cumberland and Southern Appalachians	GI	N	N	N/A	N	N	U	U	N	Inc	N/A	N/A	U	U	U	U	U	HV	VH
Bluebead	Cumberland and Southern Appalachians	N	N	N	N/A	N	N	U	U	Inc	U	N	N/A	U	U	U	U	U	MV	Mod
Bluebead	Central Appalachians	N	N	N	N/A	N	N	U	U	Inc	U	N	N/A	U	U	U	U	U	HV	VH
Scarlet Indian Paintbrush	Central Appalachians	N	Inc-SI	SI	N/A	SI	U	U	U	SI	U	N	N/A	U	U	U	U	U	EV	VH
Scarlet Indian Paintbrush	Cumberland and Southern Appalachians	N	Inc-SI	SI	N/A	SI	U	U	U	SI	U	N	N/A	U	U	U	U	U	EV	VH
Scarlet Indian Paintbrush	Interior Low Plateau	N	Inc-SI	SI	N/A	SI	U	U	U	SI	U	N	N/A	U	U	U	U	U	EV	VH
Swamp Pink	Cumberland and Southern Appalachians	N	Inc	N	N/A	N	N	U	U	SI	Inc	N/A	N/A	U	U	U	U	U	EV	VH
Swamp Pink	Central Appalachians	N	Inc	N	N/A	N	N	U	U	SI	Inc	N/A	N/A	U	U	U	U	U	EV	VH

		Ice/snow	Phys habitat	Other spp for hab	Diet	Pollinators	Other spp disp	Pathogens/enemies	Competition	Other spp interaction	Genetic var	Gen bottleneck	Reproductive system	Phenol response	Doc response	Modeled change	Modeled overlap	Protected Areas	Index	Confidence
English Name	**Geographic Area**	**C2d**	**C3**	**C4a**	**C4b**	**C4c**	**C4d**	**C4e**	**C4f**	**C4g**	**C5a**	**C5b**	**C5c**	**C6**	**D1**	**D2**	**D3**	**D4**		
Bog Jacob's Ladder	Central Appalachians	N	SI	N	N/A	SI	N	U	U	U	N	N/A	N/A	U	U	U	U	U	MV	Mod
Tennessee Yellow-eyed grass	Cumberland and Southern Appalachians	N	Inc	N	N/A	N	N	U	U	U	U	SI	N/A	U	U	N	U	U	HV	VH
Tennessee Yellow-eyed grass	Interior Low Plateau	N	Inc	N	N/A	N	N	U	U	U	U	SI	N/A	U	U	N	U	U	HV	VH
Sideoats gramma	Interior Low Plateau	N	Inc	N	N/A	N	SI	U	U	U	U	U	U	U	U	U	U	U	EV	VH
Sideoats gramma	Cumberland and Southern Appalachians	N	Inc	N	N/A	N	SI	U	U	U	U	U	U	U	U	U	U	U	EV	VH
Sideoats gramma	Central Appalachians	N	Inc	N	N/A	N	SI	U	U	U	U	U	U	U	U	U	U	U	EV	VH
Blue wild indigo	Interior Low Plateau	N	N	N	N/A	N	N	U	U	N	U	U	U	U	U	U	U	U	MV	Mod
Blue wild indigo	Cumberland and Southern Appalachians	N	N	N	N/A	N	N	U	U	U	U	U	U	U	U	U	U	U	LV	Mod
Blue wild indigo	Central Appalachians	N	N	N	N/A	N	N	U	U	U	U	U	U	U	U	U	U	U	MV	Mod
Fraser's sedge	Cumberlands and Southern Appalachians	N	N	N	N/A	N	U	U	U	U	N	N/A	N/A	U	U	U	U	U	LV	VH
Fraser's sedge	Central Appalachians	N	N	N	N/A	N	U	U	U	U	N	N/A	N/A	U	U	U	U	U	MV	Low
Diana fritillary	Central Appalachians	N	N	N	Inc	N/A	N	U	U	U	N	N/A	N/A	N	N	Inc-SI	N	U	MV	VH

		Ice/snow	Phys habitat	Other spp for hab	Diet	Pollinators	Other spp disp	Pathogens/enemies	Competition	Other spp interaction	Genetic var	Gen bottleneck	Reproductive system	Phenol response	Doc response	Modeled change	Modeled overlap	Protected Areas	Index	Confidence
English Name	**Geographic Area**	**C2d**	**C3**	**C4a**	**C4b**	**C4c**	**C4d**	**C4e**	**C4f**	**C4g**	**C5a**	**C5b**	**C5c**	**C6**	**D1**	**D2**	**D3**	**D4**		
Diana fritillary	Cumberland and Southern Appalachians	N	N	N	Inc	N/A	N	U	U	U	N	N/A	N/A	N	N	Inc-SI	N	U	MV	VH
Diana fritillary	Interior Low Plateau	N	N	N	Inc	N/A	N	U	U	U	N	N/A	N/A	N	N	Inc-SI	N	U	MV	VH
Appalachian tiger beetle	Central Appalachians	N	Inc	N	N	N/A	N	U	U	U	U	U	U	N	U	U	U	U	HV	VH
Appalachian tiger beetle	Cumberlands and Southern Appalachians	Inc	Inc	N	N	N/A	N	U	U	U	U	U	U	N	U	U	U	U	HV	VH
Marbled underwing	Cumberlands and Southern Appalachians	N	N	N	Inc	N/A	N	U	U	U	U	U	U	N	U	U	U	U	LV	VH
Marbled underwing	Interior Low Plateau	N	N	N	Inc	N/A	N	U	U	U	U	U	U	N	U	U	U	U	HV	VH
Baltimore checkerspot	Central Appalachians	N	N	N	Inc	N/A	N	U	U	U	SI	N/A	N/A	U	N	Inc	U	U	HV	VH
Baltimore checkerspot	Cumberland and Southern Appalachians	N	N	N	Inc	N/A	N	U	U	U	SI	N/A	N/A	U	N	Inc	U	U	MV	VH
Baltimore checkerspot	Interior Low Plateau	N	N	N	Inc	N/A	N	U	U	U	SI	N/A	N/A	U	N	Inc	U	U	HV	VH
Leafy prairy clover	Interior Low Plateau	N	Inc	N	N/A	N	U	U	U	U	SI	N/A	N/A	U	U	U	U	U	EV	VH
Leafy prairy clover	Cumberland and Southern Appalachian	N	Inc	N	N/A	N	U	U	U	U	SI	N/A	N/A	U	U	U	U	U	EV	VH
Tennessee milkvetch	Interior Low Plateau	N	Inc	N	N/A	N	N	U	U	U	SI	N/A	N/A	U	U	U	U	U	EV	VH

English Name	Geographic Area	C2d Ice/snow	C3 Phys habitat	C4a Other spp for hab	C4b Diet	C4c Pollinators	C4d Other spp disp	C4e Pathogens/enemies	C4f Competition	C4g Other spp interaction	C5a Genetic var	C5b Gen bottleneck	C5c Reproductive system	C6 Phenol response	D1 Doc response	D2 Modeled change	D3 Modeled overlap	D4 Protected Areas	Index	Confidence
Tennessee milkvetch	Cumberland and Southern Appalachians	N	Inc	N	N/A	N	N	U	U	U	SI	N/A	N/A	U	U	U	U	U	EV	VH
Smooth purple cone flower	Cumberland and Southern Appalachians	N	Inc	N	N/A	N	N	U	U	U	N	N/A	N/A	U	U	U	U	U	EV	VH
Smooth purple cone flower	Central Appalachians	N	Inc	N	N/A	N	N	U	U	U	N	N/A	N/A	U	U	U	U	U	EV	VH
Shale barren buckwheat	Central Appalachians	N	Inc	N	N/A	N	N	U	U	U	U	U	U	U	U	U	U	U	HV	VH
Shale barren buckwheat	Cumberland and Southern Appalachians	N	Inc	N	N/A	N	N	U	U	U	U	U	U	U	U	U	U	U	HV	VH
Box huckleberry	Cumberlands and Southern Appalachians	N	N	N	N/A	N	N	U	U	U	SI	N/A	N/A	U	U	U	U	U	LV	VH
Box huckleberry	Interior Low Plateau	N	N	N	N/A	N	N	U	U	U	SI	N/A	N/A	U	U	U	U	U	MV	VH
Box huckleberry	Central Appalachians	N	N	N	N/A	N	N	U	U	U	SI	N/A	N/A	U	U	U	U	U	MV	VH
Virginia Sneezeweed	Central Appalachians	N	Inc	N	N/A	N	N	U	U	U	N	N/A	N/A	U	U	U	U	U	EV	VH
Eggert's sunflower	Cumberland and Southern Appalachians	N	Inc-SI	N	N/A	N	N	U	U	U	U	U	U	U	U	U	U	U	HV	Mod
Eggert's sunflower	Interior Low Plateau	N	Inc-SI	N	N/A	N	N	U	U	U	U	U	U	U	U	U	U	U	HV	Low
Blue Ridge St. Johnswort	Cumberlands and Southern Appalachians	N	N	N	N/A	N	U	U	U	U	N	N/A	N/A	U	U	U	U	U	HV	Mod

		Ice/snow	Phys habitat	Other spp for hab	Diet	Pollinators	Other spp disp	Pathogens/enemies	Competition	Other spp interaction	Genetic var	Gen bottleneck	Reproductive system	Phenol response	Doc response	Modeled change	Modeled overlap	Protected Areas	Index	Confidence
English Name	**Geographic Area**	**C2d**	**C3**	**C4a**	**C4b**	**C4c**	**C4d**	**C4e**	**C4f**	**C4g**	**C5a**	**C5b**	**C5c**	**C6**	**D1**	**D2**	**D3**	**D4**		
Blue Ridge St. Johnswort	Central Appalachians	N	N	N	N/A	N	U	U	U	U	N	N/A	N/A	U	U	U	U	U	HV	VH
Sand-myrtle	Cumberlands and Southern Appalachians	N	N	N	N/A	N	U	U	U	U	Inc	N/A	N/A	U	U	U	U	U	MV	VH
Sand-myrtle	Central Appalachians	N	N	N	N/A	N	U	U	U	U	Inc	N/A	N/A	U	U	U	U	U	MV	VH
Southern Pygmy salamander	Cumberland and Southern Appalachian	N	N	U	N	N/A	N	U	U	N	N	N/A	N/A	U	N	GI	U	U	HV	VH
Imitator salamander	Cumberland and Southern Appalachian	N	N	N	N	N/A	N	U	U	N	U	U	U	U	N	GI	U	U	HV	VH
Largeleaf grass-of-parnassus	Central Appalachians	N	Inc	N	N/A	N	U	U	U	U	U	U	U	U	U	U	U	U	HV	VH
Largeleaf grass-of-parnassus	Cumberlands and Southern Appalachians	N	Inc	N	N/A	N	U	U	U	U	U	U	U	U	U	U	U	U	EV	VH
Largeleaf grass-of-parnassus	Interior Low Plateau	N	Inc	N	N/A	N	U	U	U	U	U	U	U	U	U	U	U	U	EV	VH
Peaks of Otter Salamander	Central Appalachians	SI	N	N	N	N/A	U	U	U	N	U	SI	N/A	N	SI	U	U	U	HV	VH

Appendix F Compiled results of 700 species previously assessed by researchers in portions of the Appalachian LCC (companion document)

The results of previous species vulnerability assessments are compiled in a separate spreadsheet accompanying this document; results by subregion can also be found online at http://applcc.org/research/climate-change-vulnerability-group/final-narrative-climate-change-vulnerability-assessment/data-access.

Appendix G Comparison of species vulnerability ranks using Release 2.1 vs Release 3.0 of the CCVI

Scientific Name	Common Name	Subregion	Release 2.1 results	Release 3.0 results
Neviusia alabamensis	Alabama Snow-wreath	Cumberland and Southern Appalachians	EV	EV
Neviusia alabamensis	Alabama Snow-wreath	Interior Low Plateau	EV	EV
Jamesianthus alabamensis	Alabama warbonnet	Cumberland and Southern Appalachians	EV	EV
Cicindela ancocisconensis	Appalachian tiger beetle	Central Appalachians	MV	HV
Cicindela ancocisconensis	Appalachian tiger beetle	Cumberland and Southern Appalachians	MV	HV
Euphydryas phaeton	Baltimore checkerspot	Central Appalachians	MV	HV
Euphydryas phaeton	Baltimore checkerspot	Cumberland and Southern Appalachians	MV	MV
Euphydryas phaeton	Baltimore checkerspot	Interior Low Plateau	MV	HV
Hypericum mitchellianum	Blue Ridge St. Johnswort	Cumberlands and Southern Appalachians	HV	HV
Hypericum mitchellianum	Blue Ridge St. Johnswort	Central Appalachians	HV	HV
Baptisia australis	Blue wild indigo	Interior Low Plateau	MV	MV
Baptisia australis	Blue wild indigo	Cumberland and Southern Appalachians	PS	LV
Baptisia australis	Blue wild indigo	Central Appalachians	PS	MV
Clintonia borealis	Bluebead	Cumberland and Southern Appalachians	MV	MV
Clintonia borealis	Bluebead	Central Appalachians	HV	HV
Polemonium vanbruntiae	Bog Jacob's Ladder	Central Appalachians	MV	MV
Gaylussacia brachycera	Box huckleberry	Cumberlands and Southern Appalachians	PS	LV
Gaylussacia brachycera	Box huckleberry	Interior Low Plateau	MV	MV
Gaylussacia brachycera	Box huckleberry	Central Appalachians	PS	MV
Tsuga caroliniana	Carolina hemlock	Central Appalachians	IL	LV
Tsuga caroliniana	Carolina hemlock	Cumberland and Southern Appalachians	IL	LV
Plethodon nettingi	Cheat Mountain Salamander	Central Appalachians	HV	HV
Plethodon hubrichti	Cheat Mountain Salamander	Central Appalachians	HV	HV
Speyaria diana	Diana fritillary	Central Appalachians	PS	MV
Speyaria diana	Diana fritillary	Cumberland and Southern Appalachians	PS	MV
Speyaria diana	Diana fritillary	Interior Low Plateau	PS	MV
Reithrodontomys humulis	Eastern Harvest Mouse	Central Appalachians	PS	MV
Reithrodontomys humulis	Eastern Harvest Mouse	Cumberland and Southern Appalachians	PS	HV
Reithrodontomys humulis	Eastern Harvest Mouse	Interior Low Plateau	PS	HV

Scientific Name	Common Name	Subregion	Release 2.1 results	Release 3.0 results
Helianthus eggertii	Eggert's sunflower	Cumberlands and Southern Appalachians	MV	HV
Helianthus eggertii	Eggert's sunflower	Interior Low Plateau	HV	HV
Cymophyllus fraserianus	Fraser's sedge	Cumberland and Southern Appalachians	PS	LV
Cymophyllus fraserianus	Fraser's sedge	Central Appalachians	MV	MV
Arabis georgiana	Georgia rock Cress	Cumberland and Southern Appalachians	HV	HV
Desmognathus imitator	Imitator salamander	Cumberlands and Southern Appalachians	MV	HV
Parnassia grandifolia	Largeleaf grass-of-parnassus	Central Appalachians	HV	HV
Parnassia grandifolia	Largeleaf grass-of-parnassus	Cumberlands and Southern Appalachians	HV	EV
Parnassia grandifolia	Largeleaf grass-of-parnassus	Interior Low Plateau	EV	EV
Dalea foliosa	Leafy prairy clover	Interior Low Plateau	EV	EV
Dalea foliosa	Leafy prairy clover	Cumberland and Southern Appalachians	EV	EV
Catacola marmorata	Marbled underwing	Cumberland and Southern Appalachians	PS	LV
Catacola marmorata	**Marbled underwing**	**Interior Low Plateau**	**PS**	**HV**
Actaea podocarpa	Mountain bugbane	Central Appalachians	MV	MV
Actaea podocarpa	Mountain bugbane	Cumberland and Southern Appalachians	MV	HV
Cemophora coccinea	Northern Scarletsnake	Interior Low Plateau	MV	MV
Cemophora coccinea	Northern Scarletsnake	Cumberland and Southern Appalachians	PS	MV
Buckleya distichophylla	Piratebush	Central Appalachians	PS	MV
Buckleya distichophylla	Piratebush	Cumberland and Southern Appalachians	PS	MV
Eurybia saxicastelli	Rockcastle wood-aster	Cumberland and Southern Appalachians	EV	EV
Silene regia	Royal catchfly	Cumberland and Southern Appalachians	HV	EV
Silene regia	Royal catchfly	Interior Low Plateau	EV	EV
Leiophyllum buxifolium	Sand-myrtle	Cumberlands and Southern Appalachians	MV	MV
Leiophyllum buxifolium	Sand-myrtle	Central Appalachians	MV	MV
Desmognathus santeetlah	Santeetlah Dusky salamander	Cumberland and Southern Appalachians	MV	HV
Castilleja coccinea	Scarlet Indian Paintbrush	Central Appalachians	EV	EV
Castilleja coccinea	Scarlet Indian Paintbrush	Cumberland and Southern Appalachians	HV	EV
Castilleja coccinea	Scarlet Indian Paintbrush	Interior Low Plateau	EV	EV

Scientific Name	Common Name	Subregion	Release 2.1 results	Release 3.0 results
Eriogonum allenii	Shale barren buckwheat	Central Appalachians	HV	HV
Eriogonum allenii	Shale barren buckwheat	Cumberland and Southern Appalachians	HV	HV
Bouteloua curtipendula	Sideoats gramma	Interior Low Plateau	HV	EV
Bouteloua curtipendula	Sideoats gramma	Cumberland and Southern Appalachians	MV	EV
Bouteloua curtipendula	Sideoats gramma	Central Appalachians	HV	EV
Echinacea laevigata	Smooth purple cone flower	Cumberland and Southern Appalachians	HV	EV
Echinacea laevigata	Smooth purple cone flower	Central Appalachians	HV	EV
Desmognathus wrighti	Southern Pygmy salamander	Cumberlands and Southern Appalachians	MV	HV
Carya carolinae-septentrionalis	Southern Shagbark Hickory	Cumberland and Southern Appalachians	IL	LV
Carya carolinae-septentrionalis	Southern Shagbark Hickory	Interior Low Plateau	IL	LV
Helonias bullata	Swamp Pink	Cumberland and Southern Appalachians	EV	EV
Helonias bullata	Swamp Pink	Central Appalachians	EV	EV
Astragalus tennesseensis	Tennessee milkvetch	Interior Low Plateau	EV	EV
Astragalus tennesseensis	Tennessee milkvetch	Cumberland and Southern Appalachians	EV	EV
Xyris tennesseensis	Tennessee Yellow-eyed grass	Cumberland and Southern Appalachians	HV	HV
Xyris tennesseensis	Tennessee Yellow-eyed grass	Interior Low Plateau	HV	HV
Vaccinium myrtilloides	Velvetleaf blueberry	Central Appalachians	MV	EV
Vaccinium myrtilloides	**Velvetleaf blueberry**	Cumberland and Southern Appalachians	**PS**	**HV**
Helenium virginicum	Virginia Sneezeweed	Central Appalachians	EV	EV
Stellaria fontinalis	Water stitchwort	Interior Low Plateau	EV	EV
Cladrastis kentuckea	Yellow-wood	Interior Low Plateau	MV	HV
Cladrastis kentuckea	Yellow-wood	Cumberland and Southern Appalachians	MV	HV