Climate Change Vulnerability Assessment of Species of Concern in West Virginia

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Project Report

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February 14, 2011

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Cover photos (clockwise from upper left): Cheat Mountain Salamander (Plethodon nettingi) photo by Craig Stihler, Northern Saw-whet Owl (Aegolius acadicus) photo by Rob Tallman, Red Spruce (Picea rubens) photo by Robert H. Mohlenbrock. USDA NRCS, Virginia Big-eared Bat (Corynorhinus townsendii virginianus) photo by Jeff Hajenga, Crimson-ringed Whiteface (Leucorrhinia glacialis) photo © Stephen Cresswell www.stephencresswell.com, Pink Mucket (Lampsilis abrupta) photo by Janet Clayton.

Abstract

This project assessed and ranked the relative climate change vulnerability of 185 animal and plant species in West Virginia. Most species were selected based on their status as Species of Greatest Conservation Need within the West Virginia Wildlife Conservation Action Plan. Among the species identified in the state plan, priority was given to globally vulnerable or imperiled species identified by NatureServe (G1-G3), and selected species that are critically imperiled at the state level (S1). A small number of more common species were assessed. More than half of the taxa assessed were scored as vulnerable to climate change. Amphibians were the taxonomic group at highest risk, followed closely by fish, mollusks, and rare plants. Highly mobile taxonomic groups including birds and mammals appear to be somewhat less vulnerable, as are common and widespread habitat foundation plants. Obligate cave invertebrates are predicted to have strong resistance to climate change impacts.

Species with high global Conservation Status Ranks (at risk throughout their range) are statistically only slightly more vulnerable to climate change than globally abundant species. State-level Conservation Status Ranks and climate change vulnerability are more closely correlated, but scores for individual species still vary widely. In other words, rare species are not always vulnerable to climate change, and common species are not necessarily resilient.

Six of the twenty-three risk factors assessed were strongly correlated with vulnerability to climate change across all taxonomic groups in the state. They are (a) natural barriers to movement and dispersal, (b) anthropogenic barriers to movement and dispersal, (c) physiological thermal niche, (d) physiological hydrological niche, (e) genetic variation, and (f) modeled response.

In terms of the relative vulnerability of different geographies in the state, downscaled climate models indicate that species in the northern part of the state may experience slightly greater warming than those at the southern margin. Species dependent on moist habitats or ephemeral streams and wetlands in the eastern and western portions of the state are likely to experience greater drought stress than those in the higher-elevation Allegheny Mountains, but all habitats are likely to face increased drought stress, especially during the summer and early fall. Species on the southern, or “trailing” edge of their global range are more likely to disappear from the state. High elevation species restricted to the cool, moist summits and plateaus of Allegheny Mountain region of the state are at increased risk because they have no possibility of migrating upward, and potential migration northward is blocked by significant low-elevation natural barriers to the north.

Based on the results of the assessment and review of current literature, management recommendations were developed for consideration in the next revision of the West Virginia Wildlife Conservation Action Plan. Key recommendations are to increase habitat connectivity; manage for ecosystem function and habitat integrity; protect natural heritage resources; protect water quality and streamflow; aim for representation, resiliency, and redundancy; consider innovative and unconventional strategies; reduce existing non-climate change ecosystem stressors; monitor, model, and adaptively manage; forge new partnerships; and mitigate.

Acknowledgements

This project would not have been possible without the assistance of several experts who shared their knowledge of particular species or species groups with the authors. Zachary Loughman of West Liberty University provided range maps, natural history information, and worked jointly with the authors to assess West Virginia's crayfish species. Donna Mitchell and David Thorne, of West Virginia Division of Natural Resources (WVDNR) provided distribution and natural history information for bird and fish species, respectively, and worked jointly with the authors to complete the assessments for these groups. Cathy Johnson of the Monongahela National Forest contributed independent assessments of five vertebrate species. Information on species distribution and natural history was provided by WVDNR biologists Sue Olcott (dragonflies and damselflies), Michael Welch (mammals, amphibians, reptiles), Craig Stihler and Jack Wallace (mammals, amphibians), Janet Clayton (mussels), Dan Cincotta (fish), and Mike Shingleton (brook trout). Helpful exchanges of information regarding species vulnerability occurred with the Pennsylvania Natural Heritage Program, the Virginia Natural Heritage Program, and NatureServe. Review comments were kindly provided by Walt Kordek, Jim Vanderhorst, Craig Stihler, Barb Sargent, Michael Welch, and Zac Loughman. Overall project supervision and support were provided by Walt Kordek, Assistant Chief at WVDNR.

Introduction

Ongoing climate change will have major impacts on wildlife and wildlife habitats in West Virginia, including range shifts, population declines or expansions, and extinctions. While some of the most visible impacts of climate change such as sea level rise, ocean acidification, and melting glaciers are not of immediate concern to West Virginia wildlife managers, climate change nevertheless is bringing severe stresses to wildlife in the form of increasing temperatures, potential net drying of habitats, an increase in the frequency and intensity of extreme events, and changes in atmospheric composition (IPCC 2007, TWS 2008, BPC 2009, Young et al. in press). Some of the most sensitive taxonomic groups, such as amphibians, are already being negatively impacted by climate change (Pauley 2006).

West Virginia Division of Natural Resources (WVDNR) is currently revising its state Wildlife Conservation Action Plan. The Association of Fish and Wildlife Agencies (AFWA) has provided voluntary guidance for states to incorporate climate change into their wildlife action plans. Vulnerability assessment is a critical part of this guidance. Identifying which species and habitats are vulnerable and understanding the factors contributing to their vulnerability are key to developing effective adaptation strategies. The relative vulnerability of species or habitats can be used to set goals, determine management priorities, and to direct resources where they will be most effective (AFWA 2009, Glick et al. 2011).

Climate change is only one of the many stresses that species and habitats are currently experiencing. In many cases, the management strategies that would ameliorate negative impacts of climate change are the same as those needed to address conventional threats to biodiversity. However, the particular species and habitats most at risk may shift as the climate changes, and some new or re-emphasized strategies may become more important as habitats change. There are likely to be "geographies of risk" that emerge as a result of climate change as well, especially in our mountainous state with its steep precipitation and temperature gradients. Adaptation to climate change will involve strategic conservation of terrestrial and freshwater habitats and the ecological functions that sustain them, within larger connected landscapes.

Methods

This project assessed and ranked the relative climate change vulnerability of 185 animal and plant species in West Virginia. The project was conducted in six consecutive steps:

1. Select species for assessment: Animal species were selected based on their status as Species of Greatest Conservation Need within the West Virginia Wildlife Conservation Action Plan. Among the 517 animal species identified in the state plan, priority was given to globally vulnerable or imperiled species identified by NatureServe (G1-G3), species that are critically imperiled at the state level (S1), and rare species with a center of distribution in West Virginia. Rare plant species were selected based on NatureServe ranks (G1-G3, S1). A small number of more common species were assessed. Some of the common species, *e.g.*, brook trout (*Salvelinus fontinalis*) and red spruce (*Picea rubens*), were selected based on their perceived vulnerability to the impacts of climate change. Other common species, such as red oak (*Quercus rubra*) and white oak (*Quercus alba*), were selected because they are important habitat foundation species upon which many other species depend.

2. Assemble natural history and distribution information: WVDNR and other state natural heritage programs within the NatureServe network have developed extensive information about the distribution, natural history, and conservation status of rare species and habitats. Following review of the existing information, data gaps were identified and a literature search and/or expert consultation were conducted as needed for particular species. References used in the assessments are listed at the end of this report.

3. Assess the relative vulnerability of species: Vulnerability assessment involves describing the severity and scope of the exposure that species experience, and combining this with species' sensitivity and capacity to adapt to climate change. NatureServe's newly developed Climate Change Vulnerability Index (Young et al. 2010) provides a rapid, scientifically defensible assessment of species' vulnerability to climate change. The index was developed to serve the needs of wildlife managers for a practical, multi-faceted, rapid assessment tool. It is designed to complement, and not duplicate, information contained in the NatureServe conservation status ranks (Master et al. 2000), and may be used to update conservation status ranks to include the additional stressor of climate change.

Using regionally-specific climate models, the index examines how the changed climate will impact a species using factors known to be associated with vulnerability to climate change, including species-specific factors as well as external stressors imposed by human actions. Downscaled climate data representing an ensemble of 16 global circulation models was downloaded from Climate Wizard (Girvetz et al. 2009) and displayed in a GIS format. Climate data was available on a 4-km grid for historic data, and a 12-km grid for predicted future data. The climate data, together with distributional and natural history information for each species to be assessed, was entered into the index calculator (an Excel workbook tool) to obtain scores for each species. Outputs were reviewed by WVDNR biologists most familiar with the species under evaluation.

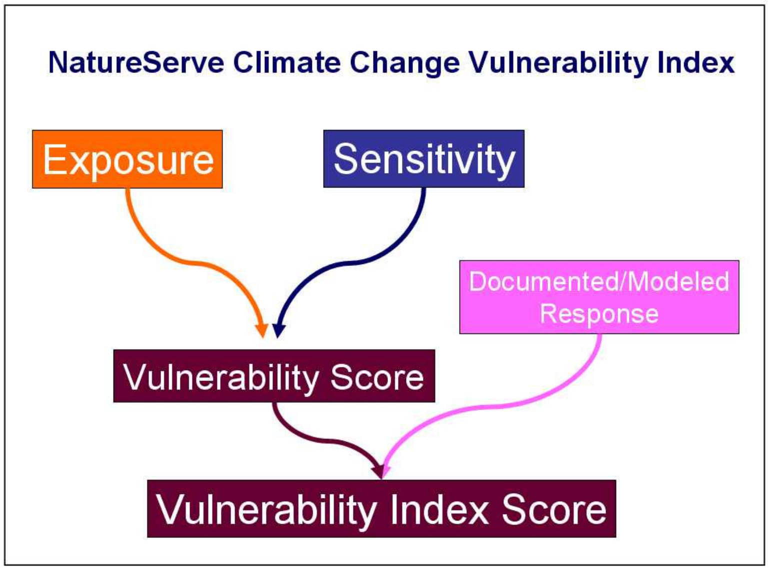

Figure 1. Components of Vulnerability Assessment

The factors considered in evaluating species response may be divided into general categories including direct exposure, indirect exposure, sensitivity, documented response, and modeled response. Complex interactions such as shifts in competitive, predator-prey, or host-parasite interactions are likely to be important as well, but they are not included in this rapid assessment because of the difficulty and unpredictability inherent in simultaneous evaluation of climate change on interacting species. Detailed information including the scientific references used to develop each factor and the limitations of the methodology are given in Young et al (2010) and Young et al (in press). Brief definitions of the factors are given below.

- Direct exposure
    - Temperature change: predicted change in annual temperature by 2050, calculated over the range of the species in West Virginia.
    - Moisture change: predicted net change in moisture based on the Hamon AET:PET Moisture Metric, calculated over the range of the species in West Virginia.

- Indirect Exposure
    - Exposure to sea level rise: not a factor in West Virginia
    - Distribution relative to natural and anthropogenic barriers: The geographical features of the landscape where a species occurs may naturally restrict it from dispersing to inhabit new areas. Similarly, dispersal may be hindered by intervening anthropogenically altered landscapes such as urban or agricultural areas for terrestrial species and dams or culverts for aquatic species.
    - Predicted impact of land use changes resulting from human responses to climate change: strategies designed to mitigate greenhouse gases, such as creating large wind farms, plowing new cropland for biofuel production, or planting trees as carbon sinks, have the potential to affect large tracts of land and the species that use these areas in both positive and negative ways.

- Sensitivity
    - Dispersal and movements: species with poor dispersal abilities may not be able to track shifting favorable climate envelopes.
    - Predicted sensitivity to temperature and moisture changes: species requiring specific moisture and temperature regimes may be less likely to find similar areas as climates change and previously-associated temperature and precipitation patterns uncouple.
        - Predicted sensitivity to changes in temperature.
            - Historic thermal niche: exposure to past variations in temperature.
            - Current physiologic thermal niche.
        - Predicted sensitivity to changes in precipitation, hydrology, or moisture regime.
            - Historical hydrological niche: exposure to past variations in precipitation.
            - Current physiologic hydrologic niche.
        - Dependence on a specific disturbance regime likely to be impacted by climate change: Species dependent on habitats such as longleaf pine forests, floodplain forests, and riparian corridors that are maintained by regular disturbances (*e.g.*, fires or flooding) are vulnerable to changes in the frequency and intensity of these disturbances caused by climate change.
        - Dependence on ice, ice-edge, or snow-cover habitats: the extent of oceanic ice sheets and mountain snow fields are decreasing as temperatures increase, imperiling species dependent on these habitats. This factor is of minor significance in West Virginia.
    - Restriction to uncommon geological features or derivatives: species requiring specific substrates, soils, or physical features such as caves, cliffs, or sand dunes may become vulnerable to climate change if their favored climate conditions shift to areas without these physical elements.
    - Reliance on interspecific interactions: because species will react idiosyncratically to climate change, those with tight relationships with other species may be threatened.
        - Dependence on other species to generate habitat.
        - Dietary versatility (animals only).
        - Pollinator versatility (plants only).
        - Dependence on other species for propagule dispersal.
        - Forms part of an interspecific interaction not covered above.
    - Genetic factors: a species' ability to evolve adaptations to environmental conditions brought about by climate change is largely dependent on its existing genetic variation.
        - Measured genetic variation.
        - Occurrence of bottlenecks in recent evolutionary history.
    - Phenological response to changing seasonal temperature and precipitation dynamics. Recent research suggests that some phylogenetic groups are declining due to lack of response to changing annual temperature dynamics (*e.g.*, earlier onset of spring, longer growing season), including some bird species that have not advanced their migration times, and some temperate zone plants that are not moving their flowering times.

- Documented or Modeled Response to Climate Change (optional, if available)
    - Documented response to recent climate change. Although conclusively linking species declines to climate change is difficult, convincing evidence relating declines to recent climate patterns has begun to accumulate in a variety of species groups. This criterion incorporates the results of these studies when available.
    - Modeled future change in range or population size. The change in area of the predicted future range relative to the current range is a useful indicator of vulnerability to climate change.
    - Overlap of modeled future range with current range. A spatially disjunct predicted future range indicates that the species will need to disperse in order to occupy the newly favored area, and geographical barriers or slow dispersal rates could prevent the species from getting there.
    - Occurrence of protected areas in modeled future distribution. For many species, future ranges may fall entirely outside of protected areas and therefore compromise their long-term viability.

- Factors not considered.—The climate change vulnerability score does not include factors that are already considered in existing conservation status assessments. These factors include population size, range size, and demographic factors. The goal is for the NatureServe Climate Change Vulnerability Index to complement NatureServe Conservation Status Ranks and not to partially duplicate factors. Ideally, Index values and Conservation Status Ranks should be used in concert.

- Confidence. A measure of confidence in species information is provided with the final score. This confidence relates specifically to the level of uncertainty indicated by the assessor based on the range of values given for each factor. Checking a range of values for particular factors tends to decrease confidence in species information.

4. Compile and analyze results: Climate Change Vulnerability Index results were compiled and analyzed in order to (a) highlight those species most (and least) vulnerable to climate change, (b) identify and rank causative factors, (c) identify geographic areas or habitat types at high risk. Statistical analysis included (a) scatterplots showing the linear regression between factors and final index scores, (b) calculating indicator values of factors for final index scores using the method of Dufrene and Legendre (1997), and (c) evaluating factor linkages through hierarchical agglomerative cluster analysis (McCune and Grace 2002).

5. Share CCVI results with partners: U.S. Fish and Wildlife Service, the Monongahela National Forest, The Nature Conservancy, NatureServe, and other partners have expressed interest in climate change vulnerability assessment results. Presentations on the project were made in 2010 to a variety of stakeholders, including a multi-agency meeting sponsored by Monongahela National Forest, a workshop with the USFWS Ecological Services staff in Elkins, two webinars for NatureServe partners, and a presentation to the West Virginia Academy of Sciences. The project report will be distributed by email to interested partners and constituents.

Results

The vulnerability index scores for 185 species in West Virginia reflect the combined effects of exposure and sensitivity in estimating the relative impacts of climate change on a species. Exposure to climate stress is based on the predicted temperature rise and potential net drying of habitats within the species' range during the next 50 years. Sensitivity is derived from 15 intrinsic species-specific factors based on the particular characteristics and life history of the species. An additional six factors consider the impacts of geography and human response to climate change. Four final factors take into account documented or modeled responses to climate change by the species. The scores should be considered in concert with NatureServe Conservation Status Ranks, which they are designed to complement, and not duplicate. Species assessment details including the global and state conservation rank, relation of the species range in West Virginia to its global range, subscores for exposure to climate change, subscores for each risk factor, and confidence in the species data for each assessment are included in the Appendices.

The results by taxonomic group are given below. Care should be exercised in interpreting the results by taxonomic group, since only a small sampling of the total species in the state were assessed. Nevertheless, the results by taxonomic group are consistent with those obtained by other states (Young et al. 2009, PNHP 2010) and may represent real differences in vulnerability of various groups. In our sample, amphibians were the taxonomic group at highest risk, followed closely by fish, mollusks, and rare plants. Highly mobile taxonomic groups including birds and mammals appear to be somewhat less vulnerable, as are common and widespread habitat foundation plants. Obligate cave invertebrates, known as troglobites, are predicted to have strong resistance to climate change impacts. Many troglobites, in fact, were able to survive the rigors of the last ice age in their buffered underground habitats.

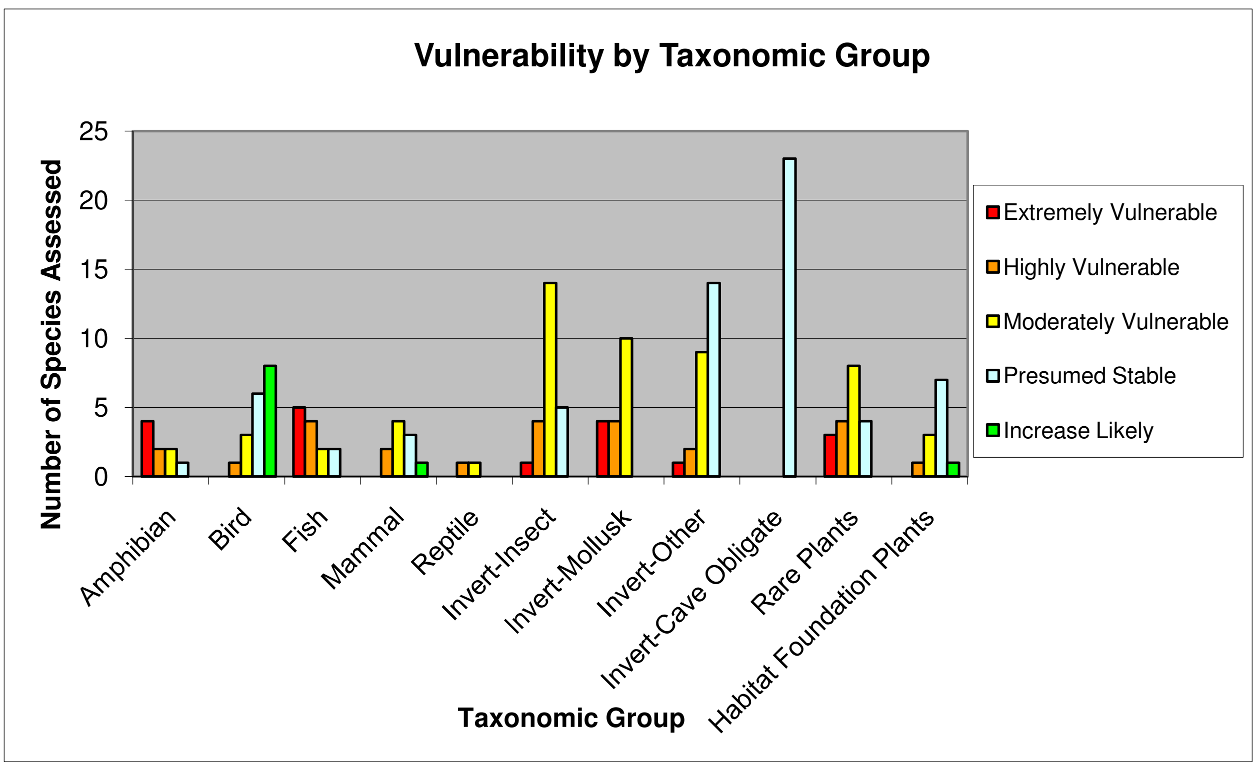

Figure 2. Vulnerability by Taxonomic Group

Amphibians

Figure 3. Cheat Mountain Salamander (*Plethodon nettingi*), photo by Craig Stihler

As a taxonomic group, amphibians are characterized by very high vulnerability to negative impacts of climate change. Nine at-risk amphibian species were assessed, eight of which appear vulnerable to climate-change related declines. Key risk factors for most amphibians include anthropogenic barriers to dispersal or movements, poor ability to disperse or move large distances, and narrow historic and physiological hydrological habitat niche. Some species, such as the extremely vulnerable Cheat Mountain Salamander, Cow Knob Salamander, and Shenandoah Mountain Salamander are also constrained by natural barriers to dispersal (mountaintop habitats), and an apparently narrow physiological thermal niche within which they are able to compete successfully against other species. Certain species with more generalized habitat requirements, such as the red-backed salamander (*Plethodon cinereus*) may benefit from climate change and expand their range to out-compete these specialist species. The West Virginia Spring Salamander, while it has many risk factors unrelated to climate change, is scored as stable since its streamside cave habitat is largely buffered from external changes in climate.

Species	Global Rank	State Rank	Index Score
Cheat Mountain Salamander (*Plethodon nettingi*)	G2	S2	Extremely vulnerable
Shenandoah Mountain Salamander (*Plethodon virginia*)	G2G3Q	S2	Extremely vulnerable
Cow Knob Salamander (*Plethodon punctatus*)	G3	S1	Extremely vulnerable
Streamside Salamander (*Ambystoma barbouri*)	G4	S1	Extremely vulnerable
Smallmouth Salamander (*Ambystoma texanum*)	G5	S1	Highly vulnerable
Eastern Spadefoot Toad (*Scaphiopus holbrookii*)	G5	S1	Highly vulnerable
Green Salamander (*Aneides aeneus*)	G3G4	S3	Moderately vulnerable
Midland Mud Salamander (*Pseudotriton montanus diastictus*)	G5T5	S1	Moderately vulnerable
WV Spring Salamander (*Gyrinophilus subterraneus*)	G1	S1	Presumed stable

Figure 4. Peregrine Falcon (*Falco peregrinus*), photo © Gary Hartley

Birds

Birds appear to be somewhat less vulnerable to climate change than other taxonomic groups, due largely to their excellent ability to disperse and move large distances, and to a lesser degree to their lack of specificity in terms of geological substrate. Those bird species that are vulnerable to climate change are likely to shift their range out of West Virginia. A variety of factors may lead to vulnerability including physiological thermal or hydrological niche, dependence on a particular disturbance regime that is likely to change with changing climates, dietary limitations, and dependence on vulnerable plants or plant communities. The USDA provides modeled responses of 150 bird species to climate change (Matthews et al. 2004). Phenological mismatches between nestling hatches and food supply have the potential to cause widespread decline in some bird species (Moller 2008), but this phenomenon is not yet well-studied in the United States.

Species	Global Rank	State Rank	Index Score
Alder Flycatcher (*Empidonax alnorum*)	G5	S3B	Highly vulnerable
Swainson's Thrush (*Catharus ustulatus*)	G5	S1B	Moderately vulnerable
Northern Saw-whet Owl (*Aegolius acadicus*) (breeding)	G5	S2B	Moderately vulnerable
Bobolink (*Dolichonyx oryzivorus*)	G5	S2B	Moderately vulnerable
Olive-sided Flycatcher (*Contopus cooperi*)	G4	S1B	Presumed stable
Peregrine Falcon (*Falco peregrinus*)	G4	S1B,S2N	Presumed stable
Swainson's Warbler (*Limnothlypis swainsonii*)	G4	S2B	Presumed stable
Northern Goshawk (*Accipiter gentilis*)	G5	S1B	Presumed stable
Prothonotary Warbler (*Protonotaria citrea*)	G5	S2B	Presumed stable
American Woodcock (*Scolopax minor*)	G5	S4B,S3N	Presumed stable
Henslow's Sparrow (*Ammodramus henslowii*)	G4	S1B	Increase likely
Golden-winged Warbler (*Vermivora chrysoptera*)	G4	S2B	Increase likely
Cerulean Warbler (*Dendroica cerulea*)	G4	S4B	Increase likely
Migrant Loggerhead Shrike (*Lanius ludovicianus migrans*)	G4T3Q	S1B	Increase likely
Barn Owl (*Tyto alba*)	G5	S1B,S1N	Increase likely
Whip-poor-will (*Caprimulgus vociferus*)	G5	S3B	Increase likely
Northern Saw-whet Owl (*Aegolius acadicus*) (wintering)	G5	S3N	Increase likely
Worm-eating Warbler (*Helmitheros vermivorus*)	G5	S5B	Increase likely

Fish

Figure 5. Candy Darter (Etheostoma osburni), WVDNR photo

Evidence is growing that higher water temperatures resulting from climate change are negatively impacting cold- and cool-water fish populations across the country (Field et al. 2007). Fish are strongly impacted by natural barriers to dispersal, particularly those species that already inhabit the upper reaches of a watershed and thus have no possibility of migrating to colder waters. Cold-water fish that inhabit small, high elevation streams that may be subject to both drying (direct habitat loss) and warming are especially sensitive. Other important risk factors for individual fish species include anthropogenic barriers to movement (*e.g.*, dams, perched culverts, chemical barriers from acid mine drainage), physical habitat specificity for certain spring-dependent species, and dependence on a disturbance regime (flood patterns) that may be disrupted by climate change.

Species	Global Rank	State Rank	Index Score
Checkered Sculpin (*Cottus cognatus*) (*C. robinsi* proposed)	G1?	S1	Extremely vulnerable
Bluestone Sculpin (*Cottus* sp1)	G2	S1	Extremely vulnerable
Redside Dace (*Clinostomus elongatus*)	G3G4	S1S2	Extremely vulnerable
Redfin Shiner (*Lythrurus umbratilis*)	G5	S3	Extremely vulnerable
Candy Darter (*Etheostoma osburni*)	G3	S1	Highly vulnerable
Kanawha Minnow (*Phenacobius teretulus*)	G3G4	S1	Highly vulnerable
Longfin Darter (*Etheostoma longimanum*)	G4	S1	Highly vulnerable
Kanawha Sculpin (*Cottus kanawhae*)	G5	S2	Highly vulnerable
Brook Trout (*Salvelinus fontinalis*)	G5	S5	Highly vulnerable
Tonguetied Minnow (*Exoglossum laurae*)	G4	S2	Moderately vulnerable
New River Shiner (*Notropis scabriceps*)	G4	S2	Moderately vulnerable
American Eel (*Anguilla rostrata*)	G4	S2	Presumed stable
Green Sunfish (*Lepomis cyanellus*)	G5	S5	Presumed stable

Mammals

Figure 6. WV Northern Flying Squirrel (*Glaucomys sabrinus fuscus*), photo by Craig Stihler

Nine at-risk mammal species and one common species were assessed for climate change vulnerability. In general, mammals tend to have good dispersal abilities, which confers some resilience to climate change, since they are sometimes able to move or disperse along with a shifting climate envelope. They vary greatly in terms of other risk factors. The Virginia Big-eared Bat and WV Northern Flying Squirrel have the highest vulnerability to climate change impacts of the mammal species assessed. Key risk factors for the WV Northern Flying Squirrel are its distribution relative to natural topographic barriers (restriction to high elevations), its dependence on a vulnerable species (red spruce) for habitat, and its low genetic variability. The Virginia Big-eared bat is ranked as vulnerable due to its narrow historic and physiological thermal habitat niche, its physical habitat specificity (cave hibernacula), and its low genetic variability. Four additional at-risk species are also vulnerable to climate change: Southern Rock Vole, Indiana Bat, Allegheny Woodrat, and Southern Water Shrew. Eastern Small-footed Bat and Hoary Bat are presumed stable under climate change stress, although their populations are still at risk due to non-climate stresses. Fisher appears resilient to climate change but is likely to shift its range and move out of West Virginia. The common North American Deermouse is likely to be a climate change winner, with populations increasing.

Species	Global Rank	State Rank	Index Score
Virginia Big-eared Bat (*Corynorhinus townsendii virginianus*)	G4T2	S2	Highly vulnerable
WV Northern Flying Squirrel (*Glaucomys sabrinus fuscus*)	G5T2	S2	Highly vulnerable

Indiana Bat (*Myotis sodalis*)	G2	S1	Moderately vulnerable
Allegheny Woodrat (*Neotoma magister*)	G3G4	S3	Moderately vulnerable
Southern Rock Vole (*Microtus chrotorrhinus carolinensis*)	G4T3	S2	Moderately vulnerable
Southern Water Shrew (*Sorex palustris puctulatus*)	G5T3	S1	Moderately vulnerable
Eastern Small-footed Bat (*Myotis leibii*)	G3	S1	Presumed stable
Hoary Bat (*Lasiurus cinereus*)	G5	S3	Presumed stable
Fisher (*Martes pennanti*)	G5	S3	Presumed stable
North American Deermouse (*Peromyscus maniculatus*)	G5	S5	Increase likely

Reptiles

Figure 7. Spotted Turtle (Clemmys guttata), WVDNR photo archive

Two at-risk reptile species were assessed and both are vulnerable to climate change. The Mountain Earthsnake has moderate risk from a number of factors, including natural barriers, anthropogenic barriers, poor dispersal, somewhat narrow physiological thermal and hydrologic niche, physical habitat specificity, and partial dependence on other species for suitable habitat (ant tunnels). The Spotted Turtle also suffers from anthropogenic barriers to movement, a narrow physiological hydrological niche, and physical habitat specificity, but it gains resilience from its good dispersal ability and generalized diet.

Species	Global Rank	State Rank	Index Score
Mountain Earthsnake (*Virginia valeriae pulchra*)	G5T3T4	S2	Highly vulnerable
Spotted Turtle (*Clemmys guttata*)	G5	S1	Moderately vulnerable

Mollusks

Figure 8. Pink Mucket (*Lampsilis abrupta*), photo by Janet Clayton

Mollusks exhibit generally heightened vulnerability to the negative impacts of climate change, with the exception of cave obligates that are largely buffered from climate alterations. Lack of ability to disperse or move large distances is a key constraint. Many mussels are vulnerable in part because they rely on other species (fish) for dispersal. A variety of factors lead to increased vulnerability for mollusks, depending on the species, including strong natural and anthropogenic barriers to movement, narrow physiological thermal habitat niche, physical habitat specificity, and genetic bottlenecks.

Species	Global Rank	State Rank	Index Score
Flat-spired Three-toothed Land Snail (*Triodopsis platysayoides*)	G1	S1	Extremely vulnerable
Brook Floater (*Alasmidonta varicosa*)	G3	S1	Extremely vulnerable
Virginia Bladetooth (*Patera panselenus*)	G3	S1	Extremely vulnerable
Elktoe (*Alasmidonta marginata*)	G4	S2	Extremely vulnerable
Sidelong Supercoil (*Paravitrea ceres*)	G1	S1	Highly vulnerable
Clubshell (*Pleurobema clava*)	G1G2	S1	Highly vulnerable
Green Floater (*Lasmigona subviridis*)	G3	S2	Highly vulnerable
Spike (*Elliptio dilatata*)	G5	S2S3	Highly vulnerable
James Spiny Mussel (*Pleurobema collina*)	G1	S1	Moderately vulnerable
Buttress Threetooth (*Triodopsis rugosa*)	G1	S1	Moderately vulnerable
Fanshell (*Cyprogenia stegaria*)	G1Q	S1	Moderately vulnerable
Pink Mucket (*Lampsilis abrupta*)	G2	S1	Moderately vulnerable
Maryland Glyph (*Glyphyalinia raderi*)	G2	S2	Moderately vulnerable
Bear Creek Slitmouth Snail (*Stenotrema simile*)	G2	SNR	Moderately vulnerable
Northern Riffleshell (*Epioblasma torulosa rangiana*)	G2T2	S1	Moderately vulnerable
Round Supercoil (*Paravitrea reesei*)	G3	S1	Moderately vulnerable
Snuffbox (*Epioblasma triquetra*)	G3	S2	Moderately vulnerable
Spruce Knob Threetooth Snail (*Triodopsis picea*)	G3	S2	Moderately vulnerable
Greenbrier Cavesnail (*Fontigens turritella*)	G1	S1	Presumed stable
Organ Cavesnail (*Fontigens tartarea*)	G2	S2	Presumed stable

Crayfish

Figure 9. New River Crayfish (*Cambarus chasmodactylus*), photo by Zac Loughman

All known crayfish species in the state, including both common and rare taxa, were assessed in cooperation with Zac Loughman at West Liberty University. Half of West Virginia's crayfish species are vulnerable to climate change. The most important risk factors for this group are strong natural and anthropogenic barriers to movements and a sometimes narrow physiological hydrological niche. A few species have added vulnerability due to a narrow physiological thermal niche, dependence on a particular natural disturbance regime, physical habitat specificity, dependence on other species to create habitat, and genetic bottlenecks. The generalized diet of crayfish confers some resilience to this group.

Species	Global Rank	State Rank	Index Score
Digger Crayfish (*Fallicambarus fodiens*)	G5	S1	Extremely vulnerable
Big Sandy Crayfish (*Cambarus veteranus*)	G2G3	S1	Highly vulnerable
White River Crayfish (*Procambarus acutus*)	G5	S1	Highly vulnerable

Elk River Crayfish (*Cambarus elkensis*)	G2	S1	Moderately vulnerable
Angulated Crayfish cf. (*Cambarus angularis* cf.)	G4	S2S3	Moderately vulnerable
Atlantic Slope Crayfish (*Cambarus longulus*)	G5	S1	Moderately vulnerable
Upland Burrowing Crayfish (*Cambarus dubius* - Monroe blue)	G5	S3	Moderately vulnerable
Upland Burrowing Crayfish (*Cambarus dubius* - Teays blue)	G5	S3	Moderately vulnerable
Blue Crawfish (*Cambarus monongalensis* - plateau)	G5	S4(S3?)	Moderately vulnerable
Common Crayfish (*Cambarus bartonii*)	G5	S5	Moderately vulnerable
Blue Crawfish (*Cambarus monongalensis* - mountains)	G5(G3?)	S4(S2?)	Moderately vulnerable
Greenbrier Crayfish (*Cambarus smilax*)	GNR(G1?)	SNR(S1?)	Moderately vulnerable
Greenbrier Cave Crayfish (*Cambarus nerterius*)	G2	S1	Presumed stable
New River Crayfish (*Cambarus chasmodactylus*)	G5	S3	Presumed stable
Upland Burrowing Crayfish (*Cambarus dubius* - Halloween morph)	G5	S3	Presumed stable
Upland Burrowing Crayfish (*Cambarus dubius* - orange)	G5	S3	Presumed stable
Big River Crayfish (*Cambarus robustus*)	G5	S4	Presumed stable
Little Brown Mudbug (*Cambarus thomai*)	G5	S4	Presumed stable
Spiny Stream Crayfish (*Orconectes cristavarius*)	G5	S4	Presumed stable
Allegheny Crayfish (*Orconectes obscurus*)	G5	S4	Presumed stable
Sanborn's Crayfish (*Orconectes sanbornii*)	G5	S4	Presumed stable
Appalachian Brook Crayfish (*Cambarus bartonii cavatus*)	G5	S5	Presumed stable
Rock Crawfish (*Cambarus carinirostris*)	G5	S5	Presumed stable
Teays River Crayfish (*Cambarus sciotensis*)	G5	S5	Presumed stable
Virile Crayfish (*Orconectes virilis*)	G5	SNA	Presumed stable

Cave Invertebrates

Obligate cave invertebrates, or troglobites, while at great risk due to factors unrelated to climate such as isolation and cave pollution, are not likely to suffer significant additional stress due to climate change impacts. Troglobites experienced little or no response to the Pleistocene glacial era (Culver et al. 2003, Lamoreux 2004), and we may hope that the current era of warming will have similarly minor impacts on these unique organisms.

Figure 10. Cave Beetle (*Pseudanophthalmus* sp.), photo by Craig Stihler

Species	Global Rank	State Rank	Index Score
A Cave Beetle (*Pseudanophthalmus* sp1)	G1	S1	Presumed stable
A Cave Beetle (*Pseudanophthalmus* sp2)	G1	S1	Presumed stable
A Cave Beetle (*Pseudanophthalmus* sp3)	G1	S1	Presumed stable
A Cave Collembola (*Arrhopalites* sp3)	G1	S1	Presumed stable
A Cave Diplurian (*Litocampa* sp1)	G1	S1	Presumed stable
A Cave Oligochaete (*Haplotaxis brinkhursti*)	G1	S1	Presumed stable
A Cave Planarian (*Phagocata angusta*)	G1	S1	Presumed stable
A Cave Spider (*Islandiana* sp. 1)	G1	S1	Presumed stable

Cavern Sheet-web Spider (*Islandiana speophila*)	G1	S1	Presumed stable
Culver's Cave Amphipod (*Stygobromus culveri*)	G1	S1	Presumed stable
Culver's Planarian (*Sphalloplana culveri*)	G1	S1	Presumed stable
Dry Fork Valley Cave Beetle (*Pseudanophthalmus montanus*)	G1	S1	Presumed stable
Dry Fork Valley Cave Pseudoscorpion (*Apochthonius paucispinosus)*	G1	S1	Presumed stable
Gandy Creek Cave Springtail (*Pseudosinella certa*)	G1	S1	Presumed stable
Germany Valley Cave Millipede (*Pseudotremia lusciosa*)	G1	S1	Presumed stable
Greenbrier Cavesnail (*Fontigens turritella*)	G1	S1	Presumed stable
Lallemants Cave Beetle (*Pseudanophthalmus lallemanti*)	G1	S1	Presumed stable
Organ Cave Pseudoscorpion (*Kleptochthonius hetricki*)	G1	S1	Presumed stable
Orpheus Cave Pseudoscorpion (*Kleptochthonius orpheus*)	G1	S1	Presumed stable
Patton Cave Amphipod (*Stygobromus redactus*)	G1	S1	Presumed stable
Pocahontas Cave Amphipod (*Stygobromus nanus*)	G1	S1	Presumed stable
Proserpina Cave Pseudoscorpion (*Kleptochthonius proserpinae*)	G1	S1	Presumed stable
Seneca Cave Beetle (*Pseudanophthalmus senecae*)	G1	S1	Presumed stable
South Branch Valley Cave Millipede (*Pseudotremia princeps*)	G1	S1	Presumed stable
Timber Ridge Cave Beetle (*Pseudanophthalmus hadenoecus*)	G1	S1	Presumed stable
General Davis Cave Millipede (*Pseudotremia* sp1)	G1?	S1	Presumed stable
Cooper's Cave Amphipod (*Stygobromus cooperi*)	G1G2	S1	Presumed stable
Royal Syarinid Pseudoscorpion (*Chitrella regina*)	G1G2	S1	Presumed stable
A Cave Amphipod (*Crangonyx* sp2)	G2	S2	Presumed stable
Organ Cavesnail (*Fontigens tartarea*)	G2	S2	Presumed stable
Madison Cave Isopod (*Antrolana lira*)	G2G4	S1	Presumed stable

Odonata and Lepidoptera

Figure 11. Crimson-ringed Whiteface (Leucorrhinia glacialis), photo by www.stephencresswell.com

Twelve species of at-risk dragonflies, damselflies, butterflies, and moths were assessed for climate change vulnerability, with a wide range of resulting scores. Some of these species are mobile and already on the southern edge of their range, and are predicted to shift their populations entirely out of West Virginia due to climate change stress. Species associated with ephemeral wetlands and headwater streams tend to have the highest risk, especially where these are tied to cold-temperature habitats. Dietary specialization confers additional risk for half of the species assessed.

Species	Global Rank	State Rank	Index Score
Crimson-ringed Whiteface (*Leucorrhinia glacialis*)	G5	S1	Highly vulnerable
Black Dash (*Euphyes conspicua*)	G4	S1	Moderately vulnerable
Spatterdock Darner (*Aeshna mutata*)	G4	S1	Moderately vulnerable

Two Spotted Skipper (*Euphyes bimacula*)	G4	S1	Moderately vulnerable
Superb Jewelwing (*Calopteryx amata*)	G4	S2	Moderately vulnerable
Bog Copper (*Lycaena epixanthe*)	G4G5	S1	Moderately vulnerable
Duckweed Firetail (*Telebasis byersi*)	G5	S1	Moderately vulnerable
Pink-edged Sulpher (*Colias interior*)	G5	S1	Moderately vulnerable
Grizzled Skipper (*Pyrgus wyandot*)	G1G2Q	S1	Presumed stable
Northern Metalmark (*Calephelis borealis*)	G3G4	S2	Presumed stable
Tiger Spiketail (*Cordulegaster erronea*)	G4	S1	Presumed stable
Midland Clubtail (*Gomphus fraternus*)	G5	S1	Presumed stable

Other Insects and Spiders

Figure 12. Tiger Beetle (*Cicindela sexguttata*), WVDNR photo archive

Ten rare stonefly species, two tiger beetles, and two spider species were assessed. The life history of some of these species is poorly understood, but from the data available, these at-risk species are likely to have a wide range of vulnerabilities to climate change. Several of the stonefly species are constrained by anthropogenic barriers to movement (dams, culverts) during their larval stage. The stoneflies assessed are poor dispersers, generally moving less than 100 meters per dispersal event. The most vulnerable species have a narrow physiological hydrological niche, depending on small headwater streams with specific substrate types for habitat. Several of the stonefly species have probably experienced genetic bottlenecks in their recent evolutionary history. The two tiger beetle species have increased risk due to their physical habitat specificity and presumed genetic bottlenecks, but they gain resilience from their tolerance of varying disturbance regimes, somewhat broad temperature tolerance, and relatively good dispersal ability. The two spider species, while dissimilar in their risk profiles, do not have strong known risks and are presumed stable under climate change.

Species	Global Rank	State Rank	Index Score
Splendid Stone (*Hansonoperla hokolesqua*)	G2	S1	Extremely vulnerable
Shenandoah Needlefly (*Megaleuctra flinti*)	G2	S1	Highly vulnerable
Gaspe Sallfly (*Utaperla gaspesiana*)	G3	S1	Highly vulnerable
Spiny Salmonfly (*Pteronarcys comstocki*)	G3	S2	Highly vulnerable
Cobblestone Tiger Beetle (*Cicindela marginipennis*)	G2	S1	Moderately vulnerable
Monongahela Snowfly (*Allocapnia frumi*)	G2	S2	Moderately vulnerable
Pocahontas Sallfly (*Sweltsa pocahontas*)	G2	S2	Moderately vulnerable
Aracoma Sallfly (*Alloperla aracoma*)	G3	S1	Moderately vulnerable
Bent Forestfly (*Ostrocerca prolongata*)	G3	S1	Moderately vulnerable
Dusky Sallfly (*Alloperla biserrata*)	G3	S1	Moderately vulnerable
Hanson's Appalachian Stonefly (*Hansonoperla appalachia*)	G3	S2	Moderately vulnerable
A Spider (*Calymmaria virginica*)	G1	S1	Presumed stable
A Spider (*Chrosiothes jenningsi*)	G1	S1	Presumed stable
Appalachian Tiger Beetle (*Cicindela ancocisconensis*)	G3	S3	Presumed stable

Plants

Figure 13. Monongahela Barbara's Buttons (*Marshallia grandiflora*), photo by Elizabeth Byers

Eighteen at-risk plant species, 12 common habitat foundation tree species, and two invasive plant species were assessed. A large proportion of the at-risk plants are also vulnerable to climate change. They are vulnerable for a wide variety of reasons, including poor dispersal ability, dispersal constrained by natural and anthropogenic barriers, dependence on wetland habitats, restriction to calcareous substrates, genetic bottlenecks, and dependence of particular natural disturbance regimes that may be altered by climate change. Four of the at-risk plants, which have few known risk factors and prefer less vulnerable habitats (warm and dry slopes, larger streams, or generalized habitats), are scored as presumed stable. Seven of the 12 habitat foundation tree species assessed are presumed stable, and one species (black gum) is likely to increase, which is good news for the animal and plant species that depend on forest types where these trees are co-dominant. However, four of the foundation tree species are apparently vulnerable to climate change. Red spruce is considered highly vulnerable and may disappear entirely from West Virginia. Black cherry, sugar maple, and pin oak are moderately vulnerable. Their abundance and/or range in West Virginia will likely decrease by the middle of the century. Species that depend on red spruce forest, northern hardwood forest, or pin oak swamp will face severe stresses as regeneration in these forest types shifts to species with greater tolerance for warmer, drier conditions. The two invasive plant species assessed are, not surprisingly, expected to remained stable or increase under climate change stress.

Species	Global Rank	State Rank	Index Score
Northeastern Bulrush (*Scirpus ancistrochaetus*)	G3	S1	Extremely vulnerable
Glade Spurge (*Euphorbia purpurea*)	G3	S2	Extremely vulnerable
Shriver's Frilly Orchid (*Platanthera shriveri*)	G1	S1	Highly vulnerable
Harperella (*Ptilimnium nodosum*)	G2	S1	Highly vulnerable
Small Whorled Pogonia (*Isotria medeoloides*)	G2	S1	Highly vulnerable
Shale Barren Rock Cress (*Arabis serotina*)	G2	S2	Highly vulnerable
Kates Mountain Clover (*Trifolium virginicum*)	G3	S3	Highly vulnerable
Red Spruce (*Picea rubens*)	G5	S3	Highly vulnerable
Ammon's Tortula (*Syntrichia ammonsiana*)	G1	S1	Moderately vulnerable
Virginia Spiraea (*Spiraea virginiana*)	G2	S1	Moderately vulnerable
Canby's Mountain-lover (*Paxistima canbyi*)	G2	S2	Moderately vulnerable
Monongahela Barbara's-Buttons (*Marshallia grandiflora*)	G2	S2	Moderately vulnerable
Swordleaf Phlox (*Phlox buckleyi*)	G2	S2	Moderately vulnerable
Mountain Pimpernel (*Taenidia montana*)	G3	S3	Moderately vulnerable
Running Buffalo Clover (*Trifolium stoloniferum*)	G3	S3	Moderately vulnerable
Snow Trillium (*Trillium nivale*)	G4	S2	Moderately vulnerable
Black Cherry (*Prunus serotina*)	G5	S5	Moderately vulnerable

Pin Oak (*Quercus palustris*)	G5	S5	Moderately vulnerable
Sugar Maple (*Acer saccharum*)	G5	S5	Moderately vulnerable
Bentley's Coralroot (*Corallorhiza bentleyi*)	G1G2	S1	Presumed stable
Torrey's Mountain-mint (*Pycnanthemum torrei*)	G2	S1	Presumed stable
Tennessee Pondweed (*Potamogeton tennesseensis*)	G2	S2	Presumed stable
Lillydale Onion (*Allium oxyphilum*)	G2Q	S2	Presumed stable
Chestnut Oak (*Quercus prinus*)	G5	S5	Presumed stable
Pitch Pine (*Pinus rigida*)	G5	S5	Presumed stable
Red Maple (*Acer rubrum*)	G5	S5	Presumed stable
Red Oak (*Quercus rubra*)	G5	S5	Presumed stable
Sycamore (*Platanus occidentalis*)	G5	S5	Presumed stable
Virginia Pine (*Pinus virginiana*)	G5	S5	Presumed stable
White Oak (*Quercus alba*)	G5	S5	Presumed stable
Curly Pondweed (*Potamogeton crispus*)	GNA	SNA	Presumed stable
Blackgum (*Nyssa sylvatica*)	G5	S5	Increase likely
Garlic Mustard (*Alliaria petiolata*)	GNA	SNA	Increase likely

Discussion

Conservation Status Rank and Climate Change Vulnerability

An important result to come out of this assessment is the knowledge that we cannot predict the climate change vulnerability of a species based on its current Conservation Status Rank. In other words, rare species are not always vulnerable to climate change, and common species are not necessarily resilient. Each species behaves and responds according to its unique life history characteristics, habitat requirements, and distribution. The implications of this are important to conservation and management strategies, since our current understanding of the costs and benefits of certain strategies does not yet take into account the new landscape of risk. We need to re-examine and re-align our strategies to best conserve species and habitats with the resources available to us.

Species with high global rank (at risk throughout their range) are statistically only slightly more vulnerable to climate change than globally abundant species. Obligate cave invertebrates (troglobites) are all presumed stable under climate change regardless of their Conservation Status Rank and have been excluded from the comparison.

At the state level, Conservation Status Rank and climate change vulnerability are more closely correlated, but scores for individual species still vary widely. Critically imperiled species are more likely to be extremely vulnerable to the negative impacts of climate change than less threatened species. However, some at-risk species may actually benefit from changing climate. Most of the common species assessed are presumed stable under climate change, but some may experience declines.

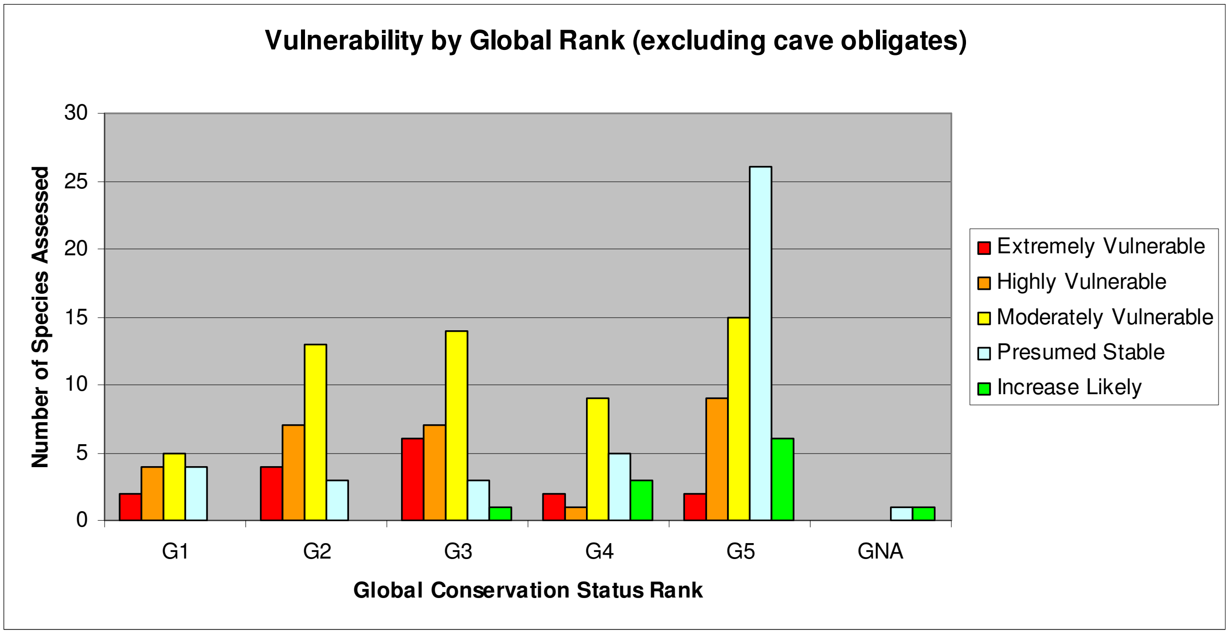

Figure 14. Vulnerability and Global Conservation Status Rank

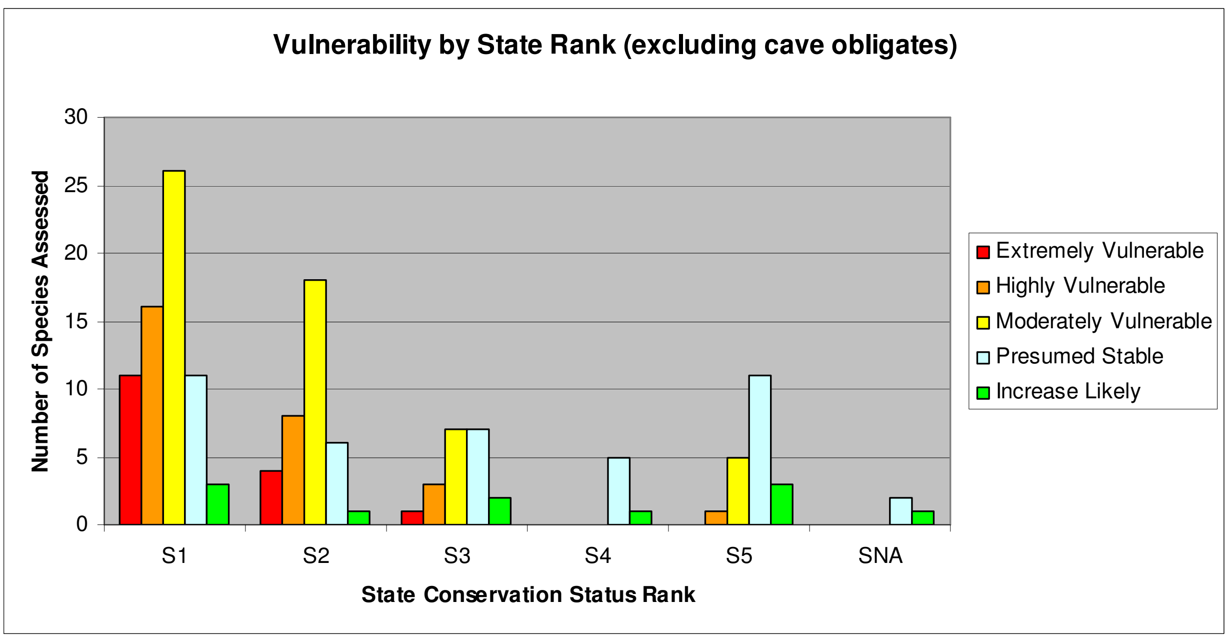

Figure 15. Vulnerability and State Conservation Status Rank

Primary Risk and Resilience Factors

Each risk factor was evaluated against vulnerability index scores for West Virginia using scatterplots and linear regression. The R^2 values of the top six factors are shown below, along with their rank (out of 23 total) in terms of highest overall risk scores, and the difference between scores of vulnerable vs. non-vulnerable species. The six factors shown rank high on all counts, and are probably representative of the most consistent risk factors across all taxonomic groups in the state. Indicator value analysis was applied to factors that were scored for most species. Factors that are significantly ($p<0.05$) associated with high vulnerability statewide are, in order of importance, natural barriers, physiological thermal niche, anthropogenic barriers, WV range relative to global range, physiological hydrological niche, historical hydrological niche, and movements/dispersal ability. Finally, hierarchical agglomerative cluster analysis was used to evaluate the factors that cluster most closely with the overall index score. This clade of important risk factors includes natural barriers, anthropogenic barriers, physiological thermal niche, and physiological hydrologic niche.

Statewide, upon evaluation of all statistical methods, the top two risk factors appear to be natural and anthropogenic barriers to dispersal. Important natural barriers for the species assessed include low elevation barriers for mountaintop species in the red spruce zone and watershed barriers for aquatic species. Anthropogenic barriers of importance in the assessment include dams and improperly sized culverts for aquatic species, and roads or powerlines for some amphibians. The next two pervasive factors across species in West Virginia are no surprise: physiological thermal and hydrological niche. As temperature and moisture regimes change, those species with specific requirements for cooler and moister microhabitats will certainly suffer. Genetic variation and modeled response factors were only available for a small number of species. When these factors were available, they were very strongly correlated with the final vulnerability score.

Top Statewide Risk Factors	R^2	High Risk Rank	Difference Rank	Significant Indicator Value Rank	Cluster Association
Natural barriers	0.29	4	2	1	High
Anthropogenic barriers	0.28	9	6	3	High
Physiological thermal niche	0.24	5	3	2	High
Physiological hydrological niche	0.11	2	4	5	High
Genetic variation	0.62	6	5	n/a	n/a
Modeled response	0.54	1	1	n/a	n/a

The Geography of Vulnerability

Predicted climate warming in West Virginia over the next 40-50 years ranges from 4.5-5^{o}F in the southern part of the state to 5.0-5.6^{o}F in the northern part of the state. These estimates are based on downscaled climate data using an ensemble average of 16 global circulation models and the medium emissions (A1B) scenario (Gervitz et al. 2009). Species in the northern part of the state may experience slightly greater warming than those at the southern margin.

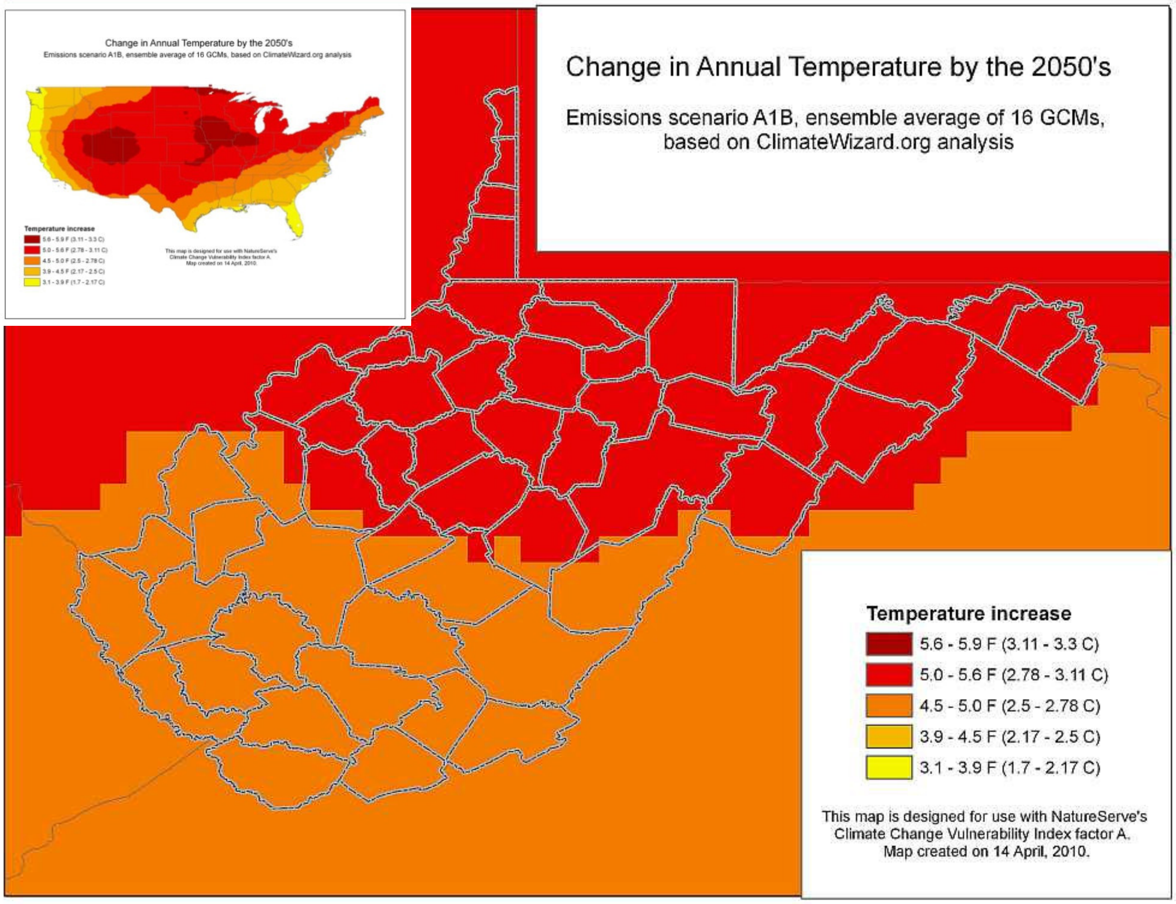

Figure 16. Predicted Change in Annual Temperature by the 2050's

Of equal importance, but fraught with greater uncertainty, are the climate predictions related to net drying or wetting of habitats. Most precipitation models show increasing precipitation for West Virginia in the next half century, but the coincident warming means that habitats are unlikely to maintain their current moisture status. Gervitz et al. (2009) and others predict net drying of habitats throughout the contiguous United States, including West Virginia. However, it should be noted that these models are significantly less consistent than the temperature models. The drying is predicted to be less severe in the portions of the state that are currently wettest, *i.e.*, at higher elevations in the Allegheny Mountains. Drying is predicted to be more severe in the already-dry eastern panhandle and in the western hills. Species dependent on moist habitats or ephemeral streams and wetlands in the eastern and western portions of the state are likely to experience greater drought stress than those in the higher-elevation Allegheny Mountains, but all habitats are likely to face increased drought stress, especially during the summer and early fall. Extreme events such as drought, severe storms, and flooding are likely to increase statewide.

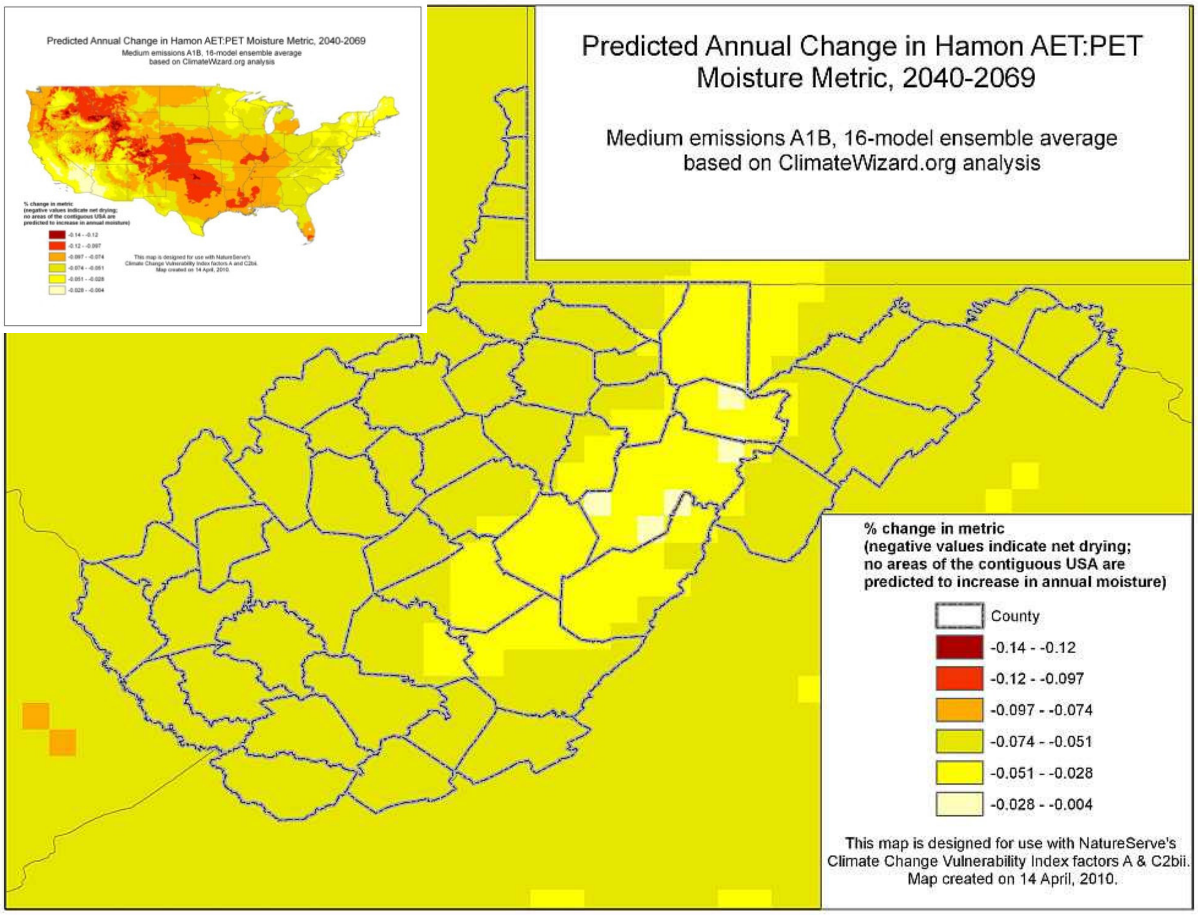

Figure 17. Predicted Change in Annual Moisture by the 2050's

Species, even rare ones, whose ranges extend beyond West Virginia in all directions, are less likely to experience range contractions within West Virginia due to the stress of climate change. The next most resilient category is species at the northernmost edge of their range in West Virginia. As the climate warms, these species may move northward from the southeastern states into West Virginia. For those species on the southern, or “trailing” edge of their range, the opposite is true. These species, if they are mobile and if suitable migration corridors exist, may move northward out of the state. Species on the east or west edge of their range, or whose entire range is restricted to West Virginia, also have relatively high vulnerability. High elevation species restricted to the cool, moist summits and plateaus of Allegheny Mountain region of the state are at increased risk because they have no possibility of migrating upward, and potential migration northward is blocked by significant low-elevation natural barriers to the north.

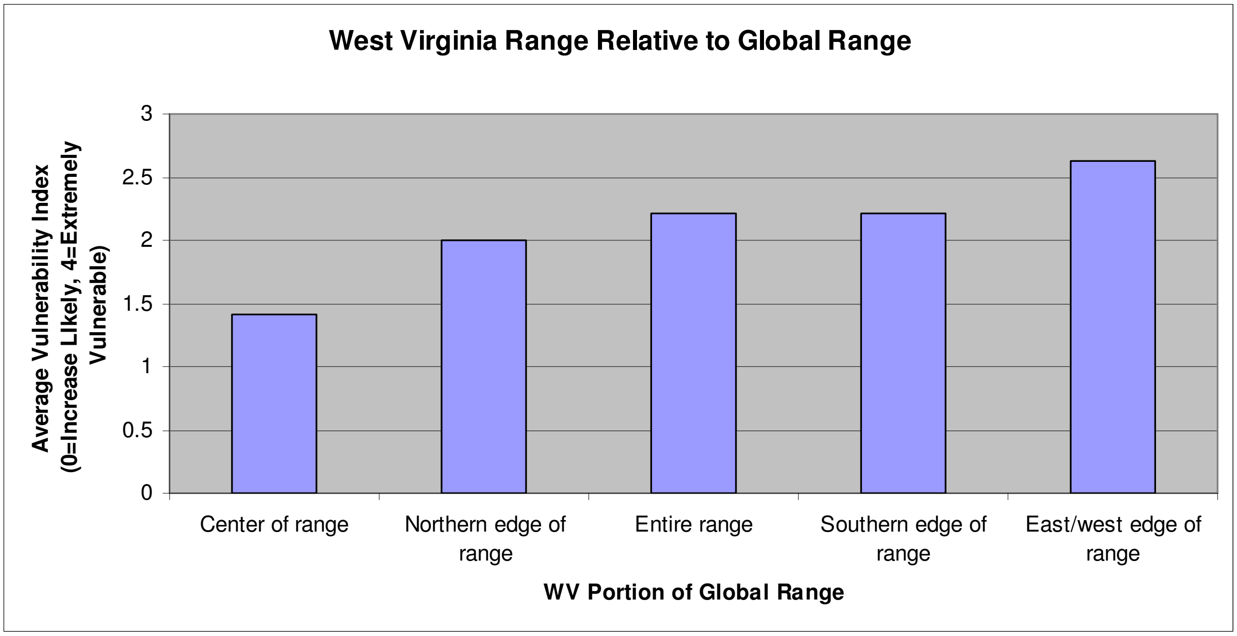

Figure 18. Species Range in West Virginia Relative to Global Range

Conclusions and Management Recommendations

Climate change is progressively impoverishing the biodiversity of our state. Species and habitats in West Virginia face significant stresses due to climate change, resulting in an on-going increase in extinctions, out-migrations, population declines, and range reductions. A few species are likely to benefit from changing climates, and some will be able to adapt to the warmer and potentially drier conditions and remain stable in the state. The majority, however, are unlikely to be able to successfully adapt to the unprecedented, rapidly changing conditions. In order to persist, species must not only adapt to climate change, but must also find a way to survive the serious "conventional" threats from extractive industries, energy development, pollution, rural sprawl, invasive species, pathogens, and other stressors.

A vulnerability assessment is only a first step toward conservation of species and ecosystems. It provides a science-based approach for differentiating between species and habitats likely to decline and those likely to thrive. Managers must then make tough choices to allocate scarce resources between the most vulnerable and the most viable conservation targets, balancing the greatest need with the highest probability of success. Economic, legal, and social factors will of necessity be part of this triage (Glick et al. 2011).

Management strategies to combat climate change are based on a combination of (a) reducing the sensitivity of species and ecosystems, (b) reducing exposure to climate change impacts, and (c) increasing adaptive capacity to deal with those impacts. Consideration of these principles should ideally be embedded into all of WVNDR's planning and decision-making processes. Most of the management strategies that effectively address conventional threats are also likely to assist in combating the negative effects of climate change. However, the risk profile of individual species and of some taxonomic groups is strongly impacted by climate change, and may require additional conservation attention. Ten management recommendations to address climate change impacts on wildlife and habitats are presented below.

1. **Increase Habitat Connectivity.** Climate change is degrading current habitats and will likely create novel habitats as species with good dispersal mechanisms redistribute themselves to track a shifting climate envelope or shifting food resources. The key to successful movements and migration is the presence of contiguous suitable habitat that species are able to colonize or at least traverse. Protecting and restoring large blocks of unfragmented habitat and using linkages and corridors to enhance connectivity between habitats will facilitate this movement. New public land acquisitions in addition to management of habitats within existing Wildlife Management Areas should reflect these priorities. In West Virginia, forested ridgetops currently provide important corridors of unfragmented habitat, but these remnant natural areas are facing rapid fragmentation from energy development. Barriers to movement need to be identified and mitigated where possible. Barriers to aquatic species are in some cases amenable to management action, for example, perched or undersized culverts can be replaced with correctly-designed culverts that allow the passage of aquatic species. Powerlines and roads that constrain the movement of certain amphibians can be narrowed or vegetated to improve habitat connectivity.

2. **Manage for Ecosystem Function and Habitat Integrity.** Healthy and biologically diverse ecosystems will be better able to withstand or recover from the impacts of climate change. Key ecological processes such as pollination, seed dispersal, nutrient cycling, natural disturbance cycles, and predator-prey relations are the glue that holds ecosystems together, and should be aggressively maintained and restored wherever possible. These processes function best in landscapes composed of large habitat blocks connected by well-placed corridors, with minimal human disturbance. Proactive management and restoration that actively facilitates the ability of species, habitats, and ecosystems to accommodate climate change are necessary. For example, in designing critical habitat buffers, more buffer area may be needed in the direction of cooler, moister habitats (*e.g.*, upstream, upslope, on cooler northerly aspects, or under denser forest cover).

3. **Protect Natural Heritage Resources.** Climate change is impacting and changing the species composition of natural habitats, but the refugia where these natural habitats occur nevertheless represent our best option for long-term biodiversity conservation. Existing natural communities are defined by unique arrays of environmental characteristics and the suite of species that interact within them. Rare species are often indicators of specialized or unique habitats. Even if some species are lost from special habitats, and some migrate in or out, the unique set of environmental characteristics will remain to provide the basis for a rich palette of opportunities for species in the future. Rare species and special habitats, such as those identified and tracked by the West Virginia Natural Heritage Program, should be a priority for conservation action.

4. **Protect Water Quality and Streamflow.** Climate change will alter the distribution, abundance, and quality of water by affecting precipitation, air and water

temperatures, and snowmelt. Riparian restoration and conservation projects can help to improve water quality by reducing stream temperatures, *e.g.*, by expanding riparian vegetation, protecting cold-water refugia, or increasing cold-water spill from existing reservoirs. Watershed restoration and reforestation initiatives provide stable base flow, reduce flood runoff, and reduce sediment to streams.

5. **Aim for Representation, Resiliency, and Redundancy.** Among the most powerful strategies for the long-term conservation of biodiversity is establishment of networks of intact habitats or conservation land that represent the full range of a region's species and ecosystems, and include multiple, robust examples of each type. These principles are at the core of many conservation planning efforts, and are increasingly important as the stresses of climate change erode existing habitats.

6. **Consider Innovative and Unconventional Strategies.** With the unprecedented scale and speed of environmental change, it may become necessary to risk new and untried management strategies. Radical management options such as assisted migration, *i.e.*, physically moving species to suitable habitat, need to at least be on the table for discussion.

7. **Reduce Existing Ecosystem Stressors.** Successful adaptation strategies for fish and wildlife will require understanding and reducing the combined effects of both climate-related and non-climate stressors. The cumulative effects of habitat loss and alteration, pollution, invasive species, and pathogens in addition to climate change may prove to be a deadly combination for many species.

8. **Monitor, Model, and Adaptively Manage**. As new conditions affect wildlife and habitats, managers need to monitor these changes and incorporate them into new action strategies. Ecological change is likely to be nonlinear and difficult to predict. As biological thresholds are reached, changes such as trophic cascades may occur with alarming rapidity, affecting many species within a habitat. Model predictions, even when handicapped by uncertainties, will help managers to understand the range of scenarios they need to plan for.

9. **Forge New Partnerships.** Success in combating the loss of significant numbers of species and habitats in West Virginia is only achievable through an unprecedented level of collaboration and cooperation between WVDNR and other agencies, organizations, scientists, and the public. Rather than working within traditional hierarchies and comfort zones, wildlife managers will need to reach out to build science-driven, landscape-scale strategies that maximize the use of scarce resources. An important element of this will be support for legislative and policy changes that support wildlife and habitats, and address climate change stresses.

10. **Mitigate:** WVDNR can work to reduce its own carbon emissions to set an example to partners, to the public and to employees. WVDNR can reduce the energy use and carbon footprint of its buildings, facilities, vehicle fleet, workforce, and operations to the maximum extent possible.

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This reference list includes sources cited in the body of this report, as well as references consulted for the individual species assessments, as listed in the Appendices.

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Appendix A. Key to codes used in tables

Vulnerability Index Scores

EV Extremely Vulnerable – Abundance and/or range extent within geographical area assessed extremely likely to substantially decrease or disappear by 2050.

HV Highly Vulnerable – Abundance and/or range extent within geographical area assessed likely to decrease significantly by 2050.

MV Moderately Vulnerable – Abundance and/or range extent within geographical area assessed likely to decrease by 2050.

PS Not Vulnerable/Presumed Stable – Available evidence does not suggest that abundance and/or range extent within the geographical area assessed will change (increase/decrease) substantially by 2050. Actual range boundaries may change.

IL Not Vulnerable/Increase Likely – Available evidence suggests that abundance and/or range extent within geographical area assessed is likely to increase by 2050.

IE Insufficient Evidence – Available information about a species' vulnerability is inadequate to calculate an Index score.

Individual Risk Factor Scores

GI Greatly Increase Vulnerability

Inc Increase Vulnerability

SI Somewhat Increase Vulnerability

N Neutral

SD Somewhat Decrease Vulnerability

Dec Decrease Vulnerability

N/A Not Applicable

U Unknown

NatureServe Conservation Status Ranks

G1 , S1 Critically Imperiled (Global or State)—At very high risk of extinction due to extreme rarity (often 5 or fewer populations), very steep declines, or other factors.

G2, S2 Imperiled (Global or State)—At high risk of extinction or elimination due to very restricted range, very few populations, steep declines, or other factors.

G3 , S3 Vulnerable (Global or State)—At moderate risk of extinction or elimination due to a restricted range, relatively few populations, recent and widespread declines, or other factors.

G4 , S4 Apparently Secure (Global or State)—Uncommon but not rare; some cause for long-term concern due to declines or other factors.

G5 , S5 Secure (Global or State)—Common; widespread and abundant.

Appendix B. Vulnerability Index Scores

Species	Grank	SRank	Index	Confi-dence	Index Notes	Assessment Sources and Notes
Accipiter gentilis (Northern Goshawk)	G5	S1B	PS	VH	Species range may shift and perhaps leave the assessment area.	NatureServe Explorer (range map); WVDNR database; Monongahela National Forest records; Dispersal ability: Wiens et. al. 2006, Squires & Kennedy 2006, Sonsthagen et. al. 2006; Genetics: Sonsthagen et. al. 2006.
Acer rubrum (Red Maple)	G5	S5	PS	Low		NatureServe Explorer, USDA Climate Change Tree Atlas, Prasad et al. 2009, Burns and Honkala 1990.
Acer saccharum (Sugar Maple)	G5	S5	MV	VH		NatureServe Explorer, USDA Climate Change Tree Atlas, Prasad et al. 2009, Burns and Honkala 1990.
Aegolius acadicus - breeding (Northern Saw-whet Owl)	G5	S2B	MV	Mod	Species range may shift and perhaps leave the assessment area.	Breeding populations assessed. Cornell Laboratory of Ornithology, WV Breeding Bird Atlas II, Buckelew and Hall 1994, NatureServe Explorer.
Aegolius acadicus - wintering (Northern Saw-whet Owl)	G5	S3N	IL	VH		Wintering (non-breeding) populations assessed. Cornell Laboratory of Ornithology, Buckelew and Hall 1994, NatureServe Explorer.
Aeshna mutata (Spatterdock Darner)	G4	S1	MV	VH	Species range may shift and perhaps leave the assessment area.	WVNHP database, NatureServe Explorer, Merritt and Cummins 1978 (dietary versatility).
Alasmidonta marginata (Elktoe)	G4	S2	EV	Mod		WVNHP database; Parmalee and Bogan 1998; Watters et al. 2009. Natural barriers: watershed change immediately to north. Habitat is small shallow rivers and creeks, cold water. Glochidia dispersed on fish hosts.
Alasmidonta varicosa (Brook Floater)	G3	S1	EV	Mod		WVNHP database; Parmalee and Bogan 1998; Watters et al. 2009; NatureServe Explorer.
Alliaria petiolata (Garlic Mustard)	GNA	SNA	IL	VH		NatureServe Explorer, WV Checklist and Atlas of Vascular Plants.
Allium oxyphilum (Lillydale Onion)	G2Q	S2	PS	Low		Norris & Sullivan 2002, WVNHP database, NatureServe Explorer (Greenbrier, Mercer, Monroe, Summers Counties), Beattie 1985 (mutualisms). Increased drought may decrease competition.

Species	Grank	SRank	Index	Confi-dence	Index Notes	Assessment Sources and Notes
Allocapnia frumi (Monongahela Snowfly)	G2	S2	MV	VH		NatureServe Explorer, WVNHP Database, Tarter and Nelson 2006, Merritt and Cummins 1978, USGS 2006.
Alloperla aracoma (Aracoma Sallfly)	G3	S1	MV	Mod		NatureServe Explorer, WVNHP Database, Tarter and Nelson 2006, Merritt and Cummins 1978, USGS 2006. Habitat is headwater streams of elevated areas (NatureServe).
Alloperla biserrata (Dusky Sallfly)	G3	S1	MV	Mod		NatureServe Explorer, WVNHP Database, Tarter and Nelson 2006, Merritt and Cummins 1978, USGS 2006. Physiological moisture scored the same as A. aracoma but with more boxes checked, in the absence of specific information.
Ambystoma barbouri (Streamside Salamander)	G4	S1	EV	Low		WVNHP database, Kraus & Petranka 1989, NatureServe Explorer; genetic variation information may be available e.g., Jones et al 1993 Syst. Biol, but assessor could not access it.
Ambystoma texanum (Smallmouth Salamander)	G5	S1	HV	High		WVNHP database, NatureServe Explorer.
Ammodramus henslowii (Henslow's Sparrow)	G4	S1B	IL	VH		Cornell Laboratory of Ornithology, WV Breeding Bird Atlas II, Buckelew and Hall 1994, USGS Upper Midwest Environmental Sciences Center (modeled distribution linked to temperature of coldest quarter), USDA Climate Change Bird Atlas.
Aneides aeneus (Green Salamander)	G3G4	S3	MV	Mod		NatureServe Explorer, WVNHP database.
Anguilla rostrata (American Eel)	G4	S2	PS	VH		NatureServe Explorer; Stauffer et al. 1995 Fishes of WV; adults most often in moderately large streams; females able to leave water on moist nights and skirt obstacles via land. Critical part of life cycle occurs outside West Virginia (in the ocean).
Antrolana lira (Madison Cave Isopod)	G2G4	S1	PS	VH		WVNHP database, NatureServe Explorer.
Apochthonius paucispinosus (Dry Fork Valley Cave Pseudoscorpion)	G1	S1	PS	VH		NatureServe Explorer, Howarth 1983.
Arabis serotina (Shale Barren Rock Cress)	G2	S2	HV	Low		Norris & Sullivan 2002, WVNHP database, NatureServe Explorer (Greenbrier, Hardy, Pendleton Counties).

Species	Grank	SRank	Index	Confi-dence	Index Notes	Assessment Sources and Notes
Arrhopalites sp3 (A Collembola)	G1	S1	PS	VH		WVNHP database, NatureServe Explorer.
Calephelis borealis (Northern Metalmark)	G3G4	S2	PS	VH		WVNHP database; NatureServe Explorer; Opler and Malekul 1998; Allen 1997.
Calopteryx amata (Superb Jewelwing)	G4	S2	MV	VH		WVNHP database; NatureServe Explorer; Dunkle 2000; Sue Olcott (pers. comm.)
Calymmaria virginica (A Spider)	G1	S1	PS	Mod		NatureServe Explorer, Heiss and Draney 2004 (distribution). Can cover relatively great distances by ballooning.
Cambarus angularis cf. (Angulated Crayfish cf.)	G4	S2S3	MV	Mod		Probably an undescribed species. Occurs in KY and WV. High elevation cobble-bottom streams. Tertiary burrower.
Cambarus bartonii (Common Crayfish)	G5	S5	MV	Low	Species range may shift and perhaps leave the assessment area.	Loughman recommends using distribution that ranges from central Virginia throughout northeast to Canada. There is a faction that feels this species extends south to Georgia.
Cambarus bartonii cavatus (Appalachian Brook Crayfish)	G5	S5	PS	VH	Species may expand range in assessment area.	This should become an accepted species within the next 10 years. Roger Thoma has worked on this species since 1983. We are waiting for his formal description. Ranges from Wetzel Co, WV through Allegheny Plateau allied with Ohio River Valley. Global range: follows southern Appalachians down to southern Georgia.
Cambarus carinirostris (Rock Crawfish)	G5	S5	PS	VH	Species range may shift and perhaps leave the assessment area.	Carinirostris has two very distinct morphs between lowlands and mountains.
Cambarus chasmodactylus (New River Crayfish)	G5	S3	PS	VH		Isolated to Greenbrier mainstem and larger tributaries. Doesn't like small streams or headwater streams.
Cambarus dubius - Halloween morph (Upland Burrowing Crayfish)	G5	S3	PS	VH		Prefers hillside seeps (open or forested). Has slightly more habitat plasticity than the blue morphs. Shows up in wetlands, seeps, ditches. Relictual populations occur in residential areas on former seeps.
Cambarus dubius - Monroe blue (Upland Burrowing Crayfish)	G5	S3	MV	VH		Prefers hillside seeps (open or forested). Known from Meadow River wetlands also. Relictual populations occur in residential areas on former seeps.

Species	Grank	SRank	Index	Confi-dence	Index Notes	Assessment Sources and Notes
Cambarus dubius - orange (Upland Burrowing Crayfish)	G5	S3	PS	VH		Wetlands, forest seeps, and roadside ditches. About 2000-3500 ft elevation. Some juveniles can stay in burrow with mother for extended period (beyond neonate phase), so less susceptible to drought in late summer. Juveniles also use wetlands in laste summer where they would be more susceptible.
Cambarus dubius - Teays blue (Upland Burrowing Crayfish)	G5	S3	MV	Mod		Isolated to upland wetlands. Not in marshes or swamps, just on hillside seeps (open or forested). Relictual populations occur in residential areas on former seeps.
Cambarus elkensis (Elk River Crayfish)	G2	S1	MV	Mod		Mainstem and larger tributaries. There may be a relationship between elevation and species range. C. elkensis is at higher elevations as compared to C. robustus, perhaps keying in on higher gradients. There could be a second low-moderate elevation species in the Elk River (not assessed here). Sutton Dam is a barrier to migration.
Cambarus longulus (Atlantic Slope Crayfish)	G5	S1	MV	Mod		Abundant in smaller streams. Potts Creek population is the smallest in the state. Sweet Springs Creek population is thriving. Species is widespread throughout the James River system, mostly in Virginia.
Cambarus monongalensis - mountains (Blue Crawfish)	G5(G3?)	S4(S2?)	MV	Low		NatureServe Explorer. Plateau population should be treated separately from Allegheny Mountain population. Mountain population is at higher elevation (above about 2800 ft) than plateau elevation. Burrower in seeps. Found in both acidic sphagnum and limestone-influenced seeps. G- and S-ranks in parentheses are suggested revisions by Z. Loughman.
Cambarus monongalensis - plateau (Blue Crawfish)	G5	S4(S3?)	MV	VH		NatureServe Explorer. Plateau population should be treated separately from Allegheny Mountain population. Potential competitive exclusion from C. dubius. Plateau population is at lower elevation (below about 2800 ft) than mountain population. Burrower in seeps. Found in both acidic sphagnum and limestone-influenced seeps. G- and S-ranks in parentheses are suggested revisions by Z. Loughman.

Species	Grank	SRank	Index	Confi-dence	Index Notes	Assessment Sources and Notes
Cambarus nerterius (Greenbrier Cave Crayfish)	G2	S1	PS	VH		NatureServe Explorer. Karstlands (caves) of Greenbrier River valley. Can live entire life cycle in deep part of cave, but occasionally found within 20 meters of cave entrance (inside or outside).
Cambarus robustus (Big River Crayfish)	G5	S4	PS	VH		NatureServe Explorer. Species complex, lumped for this assessment (populations in the Kanawha River system are likely multiple taxa, southern population is questionable). Habitat is 3-order or large mainstem, although will go into 2nd order streams. Tolerates low pH, high conductivity, high salt, but doesn't tolerate sedimentation.
Cambarus sciotensis (Teays River Crayfish)	G5	S5	PS	VH		Almost definitely a complex. New River and Ohio River sciotensis. This assessment is for New River sciotensis.
Cambarus smilax (Greenbrier Crayfish)	GNR(G1?)	SNR(S1?)	MV	High		New species, will be published by Z. Loughman in December 2010. Tributaries of Greenbrier from Marlinton south, not in mainstem. 2nd to 3rd order streams. Most abundant in cooler streams of Pocahontas County. G- and S-ranks in parentheses are proposed by Z. Loughman.
Cambarus thomai (Little Brown Mudbug)	G5	S4	PS	High		NatureServe Explorer. Primary burrower in seeps, swamps, marshes, ditches, but not sloping forested seeps. Disperses during flood events.
Cambarus veteranus (Big Sandy Crayfish)	G2G3	S1	HV	VH		NatureServe Explorer. Wyoming County (Pinnacle Creek) and Dry Fork of Tug River. 2 populations known in WV. Large streams, similar habitat to C. robustus. Often found in riffles, perhaps due to relative lack of silt in riffles. Water quality (pH and EC) spikes and siltation due to mining may be related to population reduction. Preferred habitat is silt-free slab boulders. Tertiary burrower, not adapted to deal with extreme drawdown conditions.
Caprimulgus vociferus (Whip-poor-will)	G5	S3B	IL	VH		NatureServe Explorer, Buckelew and Hall 1994, USDA Climate Change Bird Atlas; habitat is mix of forest and farmland (rare in dense forest); question about how it might be tied to oak forests; diet dependence on large moths.

Species	Grank	SRank	Index	Confi-dence	Index Notes	Assessment Sources and Notes
Catharus ustulatus (Swainson's Thrush)	G5	S1B	MV	VH	Species range may shift and perhaps leave the assessment area.	Cornell Laboratory of Ornithology, West Virginia Breeding Bird Atlas II, Buckelew and Hall 1994, NatureServe Explorer, USDA Climate Change Bird Atlas.
Chitrella regina (Royal Syarinid Pseudoscorpion)	G1G2	S1	PS	VH		NatureServe Explorer, Howarth 1983.
Chrosiothes jenningsi (A Spider)	G1	S1	PS	Mod	Species range may shift and perhaps leave the assessment area.	Piel 1994; Dispersal: most likely disperses by ballooning; Habitat and distribution: collected in pitfall trap in mixed oak-hardwood forest in Monongalia County.
Cicindela ancocisconensis (Appalachian Tiger Beetle)	G3	S3	PS	VH		NatureServe Explorer, Knisley and Schultz 1997, Pearson 1988.
Cicindela marginipennis (Cobblestone Tiger Beetle)	G2	S1	MV	Low		NatureServe Explorer (Monongalia, Pleasants, Wood Counties), WVNHP database, Knisley and Schultz 1997, Pearson 1988, Acciavatti 2001.
Clemmys guttata (Spotted Turtle)	G5	S1	MV	Low		WVNHP database, NatureServe Explorer; development creates numerous barriers; has specific wetland requirements.
Clinostomus elongatus (Redside Dace)	G3G4	S1S2	EV	VH		NatureServe Explorer; Stauffer et al. 1995 Fishes of WV. Cool water, small streams.
Colias interior (Pink-edged Sulpher)	G5	S1	MV	VH	Species range may shift and perhaps leave the assessment area.	WVNHP database; NatureServe Explorer; Allen 1997.
Contopus cooperi (Olive-sided Flycatcher)	G4	S1B	PS	High	Species range may shift and perhaps leave the assessment area.	NatureServe Explorer, Buckelew and Hall 1994, WVPIF 2006.
Corallorhiza bentleyi (Bentley's Coralroot)	G1G2	S1	PS	Low		WVNHP database, NatureServe Explorer, Bentley 2000; seed probably widely dispersed by wind; physical habitat: Bentley 2000; self-pollinated (100% cleistogamous); mycorrhizal; bottlenecks: Freudenstein 1999.
Cordulegaster erronea (Tiger Spiketail)	G4	S1	PS	VH		WVNHP database; NatureServe Explorer; Dunkle 2000.

Species	Grank	SRank	Index	Confi-dence	Index Notes	Assessment Sources and Notes
Corynorhinus townsendii virginianus (Virginia Big-eared Bat)	G4T2	S2	HV	Low	Species may expand range in assessment area.	WVNHP database, NatureServe Explorer; negative impacts from ridgetop wind turbines; Physiological thermal niche: some caves may warm beyond usable temperature range; Genetic variability is very low compared to other bat species (Piaggio et al. 2008).
Cottus cognatus (*C. robinsi* proposed) (Checkered Sculpin)	G1?	S1	EV	VH		NatureServe Explorer; Stauffer et al. 1995 Fishes of WV; restricted to cold-water springs.
Cottus kanawhae (Kanawha Sculpin)	G5	S2	HV	VH		NatureServe Explorer; Stauffer et al. 1995 Fishes of WV.
Cottus sp1 (Bluestone Sculpin)	G2	S1	EV	VH		NatureServe Explorer; restricted Bluestone drainage of WV and VA; cold-water spring habitats.
Crangonyx sp2 (An Amphipod)	G2	S2	PS	VH		WVNHP database. Treated here as a separate sp. as per Holsinger et al. 1976. Not found in NatureServe Explorer. Probably included in C. gracilis?
Cyprogenia stegaria (Fanshell)	G1Q	S1	MV	VH		WVNHP database; Parmalee and Bogan 1998; Watters et al. 2009; NatureServe Explorer.
Dendroica cerulea (Cerulean Warbler)	G4	S4B	IL	VH		Cornell Laboratory of Ornithology; Buckelew and Hall 1994; WV Breeding Bird Atlas II, USDA Climate Change Bird Atlas.
Dolichonyx oryzivorus (Bobolink)	G5	S2B	MV	Low	Species range may shift and perhaps leave the assessment area.	Cornell Laboratory of Ornithology, WV Breeding Bird Atlas II, Buckelew and Hall 1994, USGS Upper Midwest Environmental Sciences Center (modeled distribution linked to temperature of coldest quarter), USDA Climate Change Bird Atlas.
Elliptio dilatata (Spike)	G5	S2S3	HV	Mod		WVNHP database; Parmalee and Bogan 1998; Watters et al. 2009; NatureServe Explorer. Anthropogenic barriers: locks and dams.
Empidonax alnorum (Alder Flycatcher)	G5	S3B	HV	Mod	Species range may shift and perhaps leave the assessment area.	Cornell Laboratory of Ornithology, West Virginia Breeding Bird Atlas II, Buckelew and Hall 1994, NatureServe Explorer.
Epioblasma torulosa rangiana (Northern Riffleshell)	G2T2	S1	MV	VH		WVNHP database; Parmalee and Bogan 1998; Watters et al. 2009; NatureServe Explorer.
Epioblasma triquetra (Snuffbox)	G3	S2	MV	Mod		WVNHP database; Parmalee and Bogan 1998; Watters et al. 2009; NatureServe Explorer.

Species	Grank	SRank	Index	Confi-dence	Index Notes	Assessment Sources and Notes
Etheostoma longimanum (Longfin Darter)	G4	S1	HV	VH		NatureServe Explorer; Stauffer et al. 1995 Fishes of WV. James River Drainage.
Etheostoma osburni (Candy Darter)	G3	S1	HV	VH		NatureServe Explorer; Stauffer et al. 1995 Fishes of WV.
Euphorbia purpurea (Glade Spurge)	G3	S2	EV	Mod		NatureServe Explorer, WV Checklist and Atlas of Vascular Plants, WVNHP database
Euphyes bimacula (Two Spotted Skipper)	G4	S1	MV	VH		WVNHP database; NatureServe Explorer; Allen 1997.
Euphyes conspicua (Black Dash)	G4	S1	MV	VH	Species range may shift and perhaps leave the assessment area.	WVNHP database; NatureServe Explorer; Allen 1997.
Exoglossum laurae (Tonguetied Minnow)	G4	S2	MV	VH		NatureServe Explorer; Stauffer et al. 1995 Fishes of WV.
Falco peregrinus (Peregrine Falcon)	G4	S1B,S2N	PS	VH		Cornell Lab of Ornithology, NatureServe Explorer; question regarding predator-prey relationship with great horned owl - if owl populations increase under climate change, peregrine falcons may decrease. We experimented with ranking breeding (highly specific physical habitats) and non-breeding (neutral physical/geologic habitats) populations, but the overall score remained the same.
Fallicambarus fodiens (Digger Crayfish)	G5	S1	EV	VH		NatureServe Explorer. Within West Virginia, extremely disjunct distribution. Marietta River relict. Strong association with remnant swamp white oak bottomland wetlands. At Mooselodge site, Ambrosia on swamp white oak site. Four locations known in WV.
Fontigens tartarea (Organ Cavesnail)	G2	S2	PS	VH		NatureServe Explorer.
Fontigens turritella (Greenbrier Cavesnail)	G1	S1	PS	VH		NatureServe Explorer, WVNHP database.
Glaucomys sabrinus fuscus (WV Northern Flying Squirrel)	G5T2	S2	HV	Mod		WVNHP database, NatureServe Explorer, NFS Recovery Plan.

Species	Grank	SRank	Index	Confi-dence	Index Notes	Assessment Sources and Notes
Glyphyalinia raderi (Maryland Glyph)	G2	S2	MV	High		NatureServe Explorer, Hotopp and Pearce 2008, Pearce 2008 (The species appears to be both a calciphile and a burrower that lives in forest leaf litter but has been found in a city park).
Gomphus fraternus (Midland Clubtail)	G5	S1	PS	VH		WVNHP database; NatureServe Explorer; Dunkle 2000. Uses larger rivers.
Gyrinophilus subterraneus (WV Spring Salamander)	G1	S1	PS	VH		WVNHP database, AmphibiaWeb.
Hansonoperla appalachia (Hanson's Appalachian Stonefly)	G3	S2	MV	High		NatureServe Explorer, WVNHP Database, Tarter and Nelson 2006, Merritt and Cummins 1978, USGS 2006.
Hansonoperla hokolesqua (Splendid Stone)	G2	S1	EV	Mod		NatureServe Explorer, WVNHP Database, Tarter and Nelson 2006, Merritt and Cummins 1978, USGS 2006. Found in small, often intermittent streams in Kentucky (NatureServe).
Haplotaxis brinkhursti (An Oligochaete)	G1	S1	PS	VH		WVNHP database (Hillsboro quad in Pocahontas County).
Helmitheros vermivorus (Worm-eating Warbler)	G5	S5B	IL	VH		Cornell Laboratory of Ornithology, WV Breeding Bird Atlas II, Buckelew and Hall 1994, USGS Upper Midwest Environmental Sciences Center, USDA Climate Change Bird Atlas, NatureServe Explorer.
Islandiana sp. 1 (A Cave Spider)	G1	S1	PS	VH		WVNHP database (Oakvale quad in Mercer County); little data on this species - categories were scored based on Sam Norris assessment of Islandiana speophila, but with more boxes checked to indicate uncertainty.
Islandiana speophila (Cavern Sheet-web Spider)	G1	S1	PS	VH		WVNHP database (Sugar Grove quad in Pendleton County), Ivie 1965; Dispersal: presumably no ballooning.
Isotria medeoloides (Small Whorled Pogonia)	G2	S1	HV	VH		WVNHP database (distribution), NatureServe Explorer, Small Whorled Pogonia Recovery Plan; primarily self-pollinated (Recovery Plan); Genetic variation (Stone 2006).
Kleptochthonius hetricki (Organ Cave Pseudoscorpion)	G1	S1	PS	VH		NatureServe Explorer, Howarth 1983.

Species	Grank	SRank	Index	Confi-dence	Index Notes	Assessment Sources and Notes
Kleptochthonius orpheus (Orpheus Cave Pseudoscorpion)	G1	S1	PS	VH		NatureServe Explorer, Howarth 1983.
Kleptochthonius proserpinae (Proserpina Cave Pseudoscorpion)	G1	S1	PS	VH		NatureServe Explorer, Howarth 1983.
Lampsilis abrupta (Pink Mucket)	G2	S1	MV	High		WVNHP database; Parmalee and Bogan 1998; Watters et al. 2009; NatureServe Explorer.
Lanius ludovicianus migrans (Migrant Loggerhead Shrike)	G4T3Q	S1B	IL	VH	Species may expand range in assessment area.	Cornell Laboratory of Ornithology, WV Breeding Bird Atlas II, Buckelew and Hall 1994, USDA Climate Change Bird Atlas (model not used since it shows great increase in shrike abundance that seems inconsistent with continued forest cover in the state), NatureServe Explorer.
Lasiurus cinereus (Hoary Bat)	G5	S3	PS	VH		NatureServe Explorer, Bat Conservation International Species Profile. USGS Fort Collins Science Center, Bat Fatalities at Wind Turbines: Investigating the Causes and Consequences: "USGS scientists recently pioneered the application of stable hydrogen isotope analysis to the study of migration in terrestrial mammals and proved the efficacy of the technique for studying the continental movements of bats. Coincidentally, this groundbreaking research focused on the very same species of bat (the hoary bat, Lasiurus cinereus) that is killed most frequently at wind turbine sites across North America."
Lasmigona subviridis (Green Floater)	G3	S2	HV	Mod		WVNHP database; Parmalee and Bogan 1998; Watters et al. 2009; NatureServe Explorer.
Lepomis cyanellus (Green Sunfish)	G5	S5	PS	VH		NatureServe Explorer; Stauffer et al. 1995 Fishes of WV. Common species.
Leucorrhinia glacialis (Crimson-ringed Whiteface)	G5	S1	HV	Low	Species range may shift and perhaps leave the assessment area.	WVNHP database; NatureServe Explorer; Dunkle 2000; Sue Olcott (pers. comm.) for dispersal distance. High elevation species.
Limnothlypis swainsonii (Swainson's Warbler)	G4	S2B	PS	VH		Cornell Laboratory of Ornithology; Buckelew and Hall 1994; WV Breeding Bird Atlas II, NatureServe Explorer, Hall 1983.

Species	Grank	SRank	Index	Confi-dence	Index Notes	Assessment Sources and Notes
Litocampa sp1 (A Diplurian)	G1	S1	PS	VH		WVNHP database, NatureServe Explorer, Neville 2007 (dietary versatility).
Lycaena epixanthe (Bog Copper)	G4G5	S1	MV	VH	Species range may shift and perhaps leave the assessment area.	WVNHP database; NatureServe Explorer; Allen 1997.
Lythrurus umbratilis (Redfin Shiner)	G5	S3	EV	VH		NatureServe Explorer; Stauffer et al. 1995 Fishes of WV. Midwestern species.
Marshallia grandiflora (Monongahela Barbara's-Buttons)	G2	S2	MV	VH		NatureServe Explorer, WV Checklist and Atlas of Vascular Plants, WVNHP database.
Martes pennanti (Fisher)	G5	S3	PS	Mod	Species range may shift and perhaps leave the assessment area.	NatureServe Explorer; Rich Rogers (WVDNR) pers. comm; Williams 1999. Prefers closed canopy/dense foliage. Typically found in large, heavily wooded areas consisting of spruce or mixed hardwood trees, also inhabits forested peatlands and swamps. Rare or extirpated in WV by 1912, successfully reintroduced in 1969. Known from 28 counties with about half the records from higher elevations in the Alleghenies. Increased fire could remove older, cavity-bearing trees needed for denning.
Megaleuctra flinti (Shenandoah Needlefly)	G2	S1	HV	Mod		NatureServe Explorer, WVNHP Database, Tarter and Nelson 2006, USGS 2006. Generally restricted to springs and small rheocrenes (springs that immediately flow into streams) (NatureServe).
Microtus chrotorrhinus carolinensis (Southern Rock Vole)	G4T3	S2	MV	Mod		NatureServe Explorer, WVNHP database.
Myotis leibii (Eastern Small-footed Bat)	G3	S1	PS	VH		WVNHP database, NatureServe Explorer; negative impacts from ridgetop wind turbines; Physiological thermal niche: some caves may warm beyond usable temperature range; Genetic variability not well known (C. Stihler pers. comm., Trujillo and Amelon 2009).
Myotis sodalis (Indiana Bat)	G2	S1	MV	Mod		WVNHP database, NatureServe Explorer; negative impacts from ridgetop wind turbines; Physiological thermal niche: some caves may warm beyond usable temperature range; Genetic variability not well known (C. Stihler pers. comm., Trujillo and Amelon 2009).

Species	Grank	SRank	Index	Confi-dence	Index Notes	Assessment Sources and Notes
Neotoma magister (Allegheny Woodrat)	G3G4	S3	MV	VH		NatureServe Explorer; WVDNR database; Monongahela National Forest records. Barriers include wide highways with heavy traffic or continuous solid barriers that prevent rodent passage and major water bodies (NatureServe 3/2010). Because the species generally occurs at higher elevations, wind farm development could impact habitats directly or indirectly by disrupting travel corridors; however, the vast majority of suitable habitat is not necessarily located in such areas in WV (CJ). Dispersal ability. Genetic analysis indicates that dispersal is limited among subpops > 3 km apart (or less) (Castleberry et al (2002a). Foraging movements may extend up to 160 meters from the den site; den shifts tend be less than 100 meters, and woodrats, particularly females, often live their entire lives in the same outcrop (NatureServe 3/2010), but some reports of large unidirectional movements of displaced woodrats (e.g., 1- 4 km) and naturally dispersing individuals (0.3-1 km) - (McGowan 1993). Tend to be in cooler micro-sites (shaded rocky outcrops); Manjerovic et al (2009) also note that warmer temperatures appear to negatively affect populations based on capture rates. Specialized habitat- rock outcrops, caves and talus slopes. Fairly flexible diet -Castleberry et al (2002b, c), Castleberry et al. 2006. Genetics: Castleberry et al (2002a), Ford et al 2006, Hayes and Harrison 1992.
Notropis scabriceps (New River Shiner)	G4	S2	MV	VH		NatureServe Explorer; Stauffer et al. 1995 Fishes of WV. Restricted to New River drainage upstream of Kanawha Falls.
Nyssa sylvatica (Blackgum)	G5	S5	IL	VH		NatureServe Explorer, USDA Climate Change Tree Atlas, Prasad et al. 2009, Burns and Honkala 1990.
Orconectes cristavarius (Spiny Stream Crayfish)	G5	S4	PS	VH		NatureServe Explorer. Coal fields area. Lots of inter-state movement by fisherman. Habitat is 3-order or large mainstem, although will go into 2nd order streams. Tolerates low pH, high conductivity, high salt, but doesn't tolerate sedimentation.

Species	Grank	SRank	Index	Confi-dence	Index Notes	Assessment Sources and Notes
Orconectes obscurus (Allegheny Crayfish)	G5	S4	PS	VH	Species may expand range in assessment area.	NatureServe Explorer. Habitat is 3-order or large mainstem, although will go into 2nd order streams. Tolerates low pH, high conductivity, high salt, but doesn't tolerate sedimentation.
Orconectes sanbornii (Sanborn's Crayfish)	G5	S4	PS	VH	Species may expand range in assessment area.	NatureServe Explorer. Habitat is 3-order or large mainstem, although will go into 2nd order streams. Tolerates low pH, high conductivity, high salt, but doesn't tolerate sedimentation.
Orconectes virilis (Virile Crayfish)	G5	SNA	PS	VH	Species may expand range in assessment area.	NatureServe Explorer. Habitat is 3-order or large mainstem, although will go into 2nd order streams. Tolerates low pH, high conductivity, high salt, but doesn't tolerate sedimentation.
Ostrocerca prolongata (Bent Forestfly)	G3	S1	MV	High		NatureServe Explorer, WVNHP Database, Tarter and Nelson 2006, Merritt and Cummins 1978, USGS 2006. Restricted to seeps, springs and rheocrenes (springs that immediately form streams) (NatureServe).
Paravitrea ceres (Sidelong Supercoil)	G1	S1	HV	Mod		Hotopp and Pearce 2008 (known only from Pocahontas County).
Paravitrea reesei (Round Supercoil)	G3	S1	MV	Mod		Hubricht 1985, Hotopp and Pearce 2008, Pilsbry 1939-1948.
Patera panselenus (Virginia Bladetooth)	G3	S1	EV	Mod		WVNHP database; Hotopp et al. 2008; NatureServe Explorer. Any major highway would be a barrier.
Paxistima canbyi (Canby's Mountain-lover)	G2	S2	MV	Mod		WVNHP database; NatureServe Explorer; Dispersal: seed is very rare and there's no mechanism for dispersal of vegetative propagules. Physiological thermal niche: prefers northern aspects (NatureServe Explorer). Pollination: unimportant (seed is very rare). Genetics: no data, although genetic variation is probably low, considering population = often clone? (NatureServe Explorer).
Peromyscus maniculatus (North American Deermouse)	G5	S5	IL	Mod		NatureServe Explorer.
Phagocata angusta (A Planarian)	G1	S1	PS	VH		WVNHP database (Mozark Mtn quad in Tucker County), Holsinger et al. 1976.
Phenacobius teretulus (Kanawha Minnow)	G3G4	S1	HV	VH		NatureServe Explorer; Stauffer et al. 1995 Fishes of WV.

Species	Grank	SRank	Index	Confi-dence	Index Notes	Assessment Sources and Notes
Phlox buckleyi (Swordleaf Phlox)	G2	S2	MV	High		Norris & Sullivan 2002, WVNHP database, NatureServe Explorer (Greenbrier, Pocahontas, Summers Counties); Dispersal: seeds of other Phlox spp. forcibly expelled, probably less than 4 m (SN). Bottlenecks: population has probably increased with anthropogenic disturbance (SN). Sensitivity to moisture: increased drought may decrease competition.
Picea rubens (Red Spruce)	G5	S3	HV	VH	Species range may shift and perhaps leave the assessment area.	NatureServe Explorer, WV Checklist and Atlas of Vascular Plants, WVNHP database.
Pinus rigida (Pitch Pine)	G5	S5	PS	Mod		NatureServe Explorer, USDA Climate Change Tree Atlas, Prasad et al. 2009, Burns and Honkala 1990.
Pinus virginiana (Virginia Pine)	G5	S5	PS	Mod	Species may expand range in assessment area.	NatureServe Explorer, USDA Climate Change Tree Atlas, Prasad et al. 2009, Burns and Honkala 1990.
Platanthera shriveri (Shriver's Frilly Orchid)	G1	S1	HV	VH		Brown et al. 2008 (distribution, hydrologic niche, geologic features); mycorrhizal; phenological response of Platanthera genus may not keep up with climate change (Willis et al. 2008).
Platanus occidentalis (Sycamore)	G5	S5	PS	Low		NatureServe Explorer, USDA Climate Change Tree Atlas, Prasad et al. 2009, Burns and Honkala 1990.
Plethodon nettingi (Cheat Mountain Salamander)	G2	S2	EV	VH		WVNHP database, AmphibiaWeb.
Plethodon punctatus (Cow Knob Salamander)	G3	S1	EV	Low		WVNHP database, NatureServe Explorer, Virginia NHP CCVI draft assessment of this species.
Plethodon virginia (Shenandoah Mountain Salamander)	G2G3Q	S2	EV	VH		WVNHP database, NatureServe Explorer, AmphibiaWeb.
Pleurobema clava (Clubshell)	G1G2	S1	HV	Low		WVNHP database; Parmalee and Bogan 1998; Watters et al. 2009; NatureServe Explorer. Anthropogenic barriers: locks and dams.
Pleurobema collina (James Spiny Mussel)	G1	S1	MV	High		WVNHP database; Parmalee and Bogan 1998; Watters et al. 2009; NatureServe Explorer.
Potamogeton crispus (Curly Pondweed)	GNA	SNA	PS	VH		NatureServe Explorer, WV Checklist and Atlas of Vascular Plants.

Species	Grank	SRank	Index	Confi-dence	Index Notes	Assessment Sources and Notes
Potamogeton tennesseensis (Tennessee Pondweed)	G2	S2	PS	VH		WVNHP database; NatureServe Explorer; Probably dispersed by river currents within watersheds and by waterfowl between watersheds; Pollination (Hellquist and Pike 2003).
Procambarus acutus (White River Crayfish)	G5	S1	HV	Mod		NatureServe Explorer. Within West Virginia, extremely disjunct distribution. Marietta River relict. Marsh specialist, associated with Juncus, Carex, Cornus amomum, Quercus bicolor. Also ephemeral wetland bottomlands. Not associated with river backwater wetlands nor with large swamps. Winfield is the farthest east, also at Mooselodge site, Ambrosia swamp white oak site. C. thomai seems to outcompete in more disturbed environments, e.g., north side of Winfield.
Protonotaria citrea (Prothonotary Warbler)	G5	S2B	PS	VH	Species may expand range in assessment area.	Cornell Laboratory of Ornithology, West Virginia Breeding Bird Atlas II, Buckelew and Hall 1994, NatureServe Explorer, USDA Climate Change Bird Atlas (model not used since it shows increase in range to the entire state of WV, even where there is no suitable habitat, e.g., rivers or swamps).
Prunus serotina (Black Cherry)	G5	S5	MV	VH	Species range may shift and perhaps leave the assessment area.	NatureServe Explorer, USDA Climate Change Tree Atlas, Prasad et al. 2009, Burns and Honkala 1990.
Pseudanophthalmus hadenoecus (Timber Ridge Cave Beetle)	G1	S1	PS	VH		WVNHP database, NatureServe Explorer, Kane and Ryan 1983 (dietary versatility).
Pseudanophthalmus lallemanti (Lallemants Cave Beetle)	G1	S1	PS	VH		WVNHP database, NatureServe Explorer, Kane and Ryan 1983 (dietary versatility).
Pseudanophthalmus montanus (Dry Fork Valley Cave Beetle)	G1	S1	PS	VH		WVNHP database, NatureServe Explorer, Kane and Ryan 1983 (dietary versatility).
Pseudanophthalmus senecae (Seneca Cave Beetle)	G1	S1	PS	VH		WVNHP database, NatureServe Explorer, Kane and Ryan 1983 (dietary versatility).
Pseudanophthalmus sp1 (A Cave Beetle)	G1	S1	PS	VH		WVNHP database, NatureServe Explorer, Kane and Ryan 1983 (dietary versatility).

Species	Grank	SRank	Index	Confi-dence	Index Notes	Assessment Sources and Notes
Pseudanophthalmus sp2 (A Cave Beetle)	G1	S1	PS	VH		WVNHP database, NatureServe Explorer, Kane and Ryan 1983 (dietary versatility).
Pseudanophthalmus sp3 (A Cave Beetle)	G1	S1	PS	VH		WVNHP database, NatureServe Explorer, Kane and Ryan 1983 (dietary versatility).
Pseudosinella certa (Gandy Creek Cave Springtail)	G1	S1	PS	VH		WVNHP database, NatureServe Explorer, Frost 1959 and SLIME 2007 (dietary versatility).
Pseudotremia lusciosa (Germany Valley Cave Millipede)	G1	S1	PS	VH		WVNHP database, NatureServe Explorer, Levi and Levi 1968 (dietary versatility).
Pseudotremia princeps (South Branch Valley Cave Millipede)	G1	S1	PS	VH		WVNHP database, NatureServe Explorer, Levi and Levi 1968 (dietary versatility).
Pseudotremia sp1 (General Davis Cave Millipede)	G1?	S1	PS	VH		WVNHP database, NatureServe Explorer, Levi and Levi 1968 (dietary versatility).
Pseudotriton montanus diastictus (Midland Mud Salamander)	G5T5	S1	MV	Mod		NatureServe Explorer.
Pteronarcys comstocki (Spiny Salmonfly)	G3	S2	HV	Mod		NatureServe Explorer, WVNHP Database, Tarter and Nelson 2006, Merritt and Cummins 1978, USGS 2006.
Ptilimnium nodosum (Harperella)	G2	S1	HV	Mod		WVNHP database; NatureServe Explorer; urbanization is a barrier in developed eastern panhandle; disturbance regime: depends on flooding, but climate change impacts are difficult to specify; pollinator versatility from USFWS.
Pycnanthemum torrei (Torrey's Mountain-mint)	G2	S1	PS	Low		WVNHP database; NatureServe Explorer; Dispersal score based on seed morphology and population descriptions. Pollinator versatility based on the Pynanthemum spp.
Pyrgus wyandot (Grizzled Skipper)	G1G2Q	S1	PS	VH		WVNHP database; NatureServe Explorer; Allen 1997.
Quercus alba (White Oak)	G5	S5	PS	VH		NatureServe Explorer, USDA Climate Change Tree Atlas, Prasad et al. 2009, Burns and Honkala 1990.
Quercus palustris (Pin Oak)	G5	S5	MV	VH		NatureServe Explorer, USDA Climate Change Tree Atlas, Prasad et al. 2009, Burns and Honkala 1990.
Quercus prinus (Chestnut Oak)	G5	S5	PS	VH		NatureServe Explorer, USDA Climate Change Tree Atlas, Prasad et al. 2009, Burns and Honkala 1990.
Quercus rubra (Red Oak)	G5	S5	PS	VH		NatureServe Explorer, USDA Climate Change Tree Atlas, Prasad et al. 2009, Burns and Honkala 1990.

Species	Grank	SRank	Index	Confi-dence	Index Notes	Assessment Sources and Notes
Salvelinus fontinalis (Brook Trout)	G5	S5	HV	VH		NatureServe Explorer; Stauffer et al. 1995 Fishes of WV. Both natural and anthropogenic barriers are important for this species, including watershed boundaries, culverts, chemical (acid mine drainage) barriers, temperature barriers. Streams with brook trout generally occur at elevations above 2000 ft. A small amount of stream restoration and re-stocking is done on a project basis, as funding permits. Flebbe at al. 2006 modeled 92% reductions in the southern Appalachians at +4.5F temperature rise and note "present-day distributions are already fragmented and restricted to higher elevations. Habitat area and stream length suitable for trout will shrink and become much more fragmented as climate becomes increasingly warm, until only small refuges in headwater streams at the highest elevations will remain. Populations in these small fragments are unlikely to remain viable." Trumbo et al. 2010 found that small-scale refugia might be more common than predicted by large-scale models such as Flebbe et al. 2006.
Scaphiopus holbrookii (Eastern Spadefoot Toad)	G5	S1	HV	VH		WVNHP database, NatureServe Explorer, Green & Pauley 1987.
Scirpus ancistrochaetus (Northeastern Bulrush)	G3	S1	EV	Mod		WVNHP database; NatureServe Explorer; Urban/subdivision development is a barrier; Wind turbine projects could destroy habitat. Seed morphology suggests dispersal by animals. Disturbance regime: seems associated with fluctuating water levels. Known only from black ponds (rare sandstone sinkhole feature) in WV. Pollination presumably by wind.
Scolopax minor (American Woodcock)	G5	S4B,S3N	PS	VH		Cornell Laboratory of Ornithology; Buckelew and Hall 1994; WV Breeding Bird Atlas II, NatureServe Explorer, Hall 1983.
Sorex palustris puctulatus (Southern Water Shrew)	G5T3	S1	MV	Mod		NatureServe Explorer; WVDNR database; Monongahela National Forest records.

Species	Grank	SRank	Index	Confi-dence	Index Notes	Assessment Sources and Notes
Sphalloplana culveri (Culver's Planarian)	G1	S1	PS	VH		WVNHP database (Mozark Mtn quad in Tucker County), Holsinger et al. 1976.
Spiraea virginiana (Virginia Spiraea)	G2	S1	MV	VH		NatureServe Explorer, WV Checklist and Atlas of Vascular Plants, WVNHP database.
Stenotrema simile (Bear Creek Slitmouth Snail)	G2	SNR	MV	Mod		Hotopp and Pearce 2008, Hubricht 1985.
Stygobromus cooperi (Cooper's Cave Amphipod)	G1G2	S1	PS	VH		WVNHP database, NatureServe Explorer, Burton & Burton 1969 (dietary versatility score based on diet of other amphipods).
Stygobromus culveri (Culver's Cave Amphipod)	G1	S1	PS	VH		WVNHP database, NatureServe Explorer, Burton & Burton 1969 (dietary versatility score based on diet of other amphipods).
Stygobromus nanus (Pocahontas Cave Amphipod)	G1	S1	PS	VH		WVNHP database, NatureServe Explorer, Burton & Burton 1969 (dietary versatility score based on diet of other amphipods).
Stygobromus redactus (Patton Cave Amphipod)	G1	S1	PS	VH		WVNHP database, NatureServe Explorer, Burton & Burton 1969 (dietary versatility score based on diet of other amphipods).
Sweltsa pocahontas (Pocahontas Sallfly)	G2	S2	MV	High		NatureServe Explorer, WVNHP Database, Tarter and Nelson 2006, Merritt and Cummins 1978. Upper drainages of Pocahontas, Braxton, Greenbrier Counties.
Syntrichia ammonsiana (Ammon's Tortula)	G1	S1	MV	Low		NatureServe Explorer, WVNHP database.
Taenidia montana (Mountain Pimpernel)	G3	S3	MV	Mod		Norris & Sullivan 2002, WVNHP database, NatureServe Explorer (Grant, Greenbrier, Hampshire, Hardy, Mercer, Mineral, Monroe, Morgan, Pendleton, Tucker Counties), Keener 1983 (dispersal and dependence on other species for propagule dispersal); increased drought may decrease competition; numerous possible pollinators.
Telebasis byersi (Duckweed Firetail)	G5	S1	MV	Mod		WVNHP database; NatureServe Explorer; Dunkle 2000; always associated with Lemna mats (Beaton 2007).
Trifolium stoloniferum (Running Buffalo Clover)	G3	S3	MV	Mod		NatureServe Explorer, WV Checklist and Atlas of Vascular Plants, WVNHP database, USFWS species profile.

Species	Grank	SRank	Index	Confi-dence	Index Notes	Assessment Sources and Notes
Trifolium virginicum (Kates Mountain Clover)	G3	S3	HV	Low		Norris & Sullivan 2002, WVNHP database, NatureServe Explorer (Berkeley, Grant, Greenbrier, Hampshire, Hardy, Mineral, Monroe, Morgan, Pendleton Counties). Increased drought may decrease competition.
Trillium nivale (Snow Trillium)	G4	S2	MV	High		NatureServe Explorer, WV Checklist and Atlas of Vascular Plants, WVNHP database.
Triodopsis picea (Spruce Knob Threetooth Snail)	G3	S2	MV	Mod		Hotopp and Pearce 2008, Hubricht 1985.
Triodopsis platysayoides (Flat-spired three-toothed land snail)	G1	S1	EV	Mod		WVNHP database, Wikipedia, NatureServe Explorer, Dourson 2010, Hotopp and Pearce 2008 (distribution limited to Monongalia & Preston Counties).
Triodopsis rugosa (Buttress Threetooth)	G1	S1	MV	Mod		NatureServe Explorer, Hotopp and Pearce 2008 (Pocahontas, Gilmer, Calhoun, Jackson, Putnam, Logan Counties); spotty distribution over relatively wide range.
Tyto alba (Barn Owl)	G5	S1B,S1N	IL	VH		Cornell Laboratory of Ornithology, WV Breeding Bird Atlas II, Owling.com website.
Utaperla gaspesiana (Gaspe Sallfly)	G3	S1	HV	Low		NatureServe Explorer (occurs in medium to large freshwater rivers), WVNHP Database, Tarter and Nelson 2006, Merritt and Cummins 1978. Lack precision in distribution data. Nearctic relict. Pocahontas County.
Vermivora chrysoptera (Golden-winged Warbler)	G4	S2B	IL	VH		NatureServe Explorer (range map); Buehler et. al. 2007 (disturbance regime); Genetics: Problem is hybridization rather than inbreeding…doesn't appear to be a way to account for that within the model (CJ); Marra et. al. 2005 (phenological response); Matthews et al online (modeled Climate Change Bird Atlas).
Virginia valeriae pulchra (Mountain Earthsnake)	G5T3T4	S2	HV	Low	Species range may shift and perhaps leave the assessment area.	NatureServe Explorer, Green and Pauley 1987, WVDNR Wildlife Action Plan, PA Herp Atlas 2009, VA Dept. of Game and Inland Fisheries, Ware 2008. Uses abandoned ant tunnels under rocks for habitat. Roads are a partial barrier to movement.

Appendix C. Intrinsic and Modeled Risk Factor Scores

Species	Dispersal / Movement	historical thermal niche	physiological thermal niche	historical hydrol niche	physiological hydrol. niche	Disturbance	Ice/snow	Physical habitat	Other spp for habitat	Diet	Pollinators	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenologic response	Doc response	Modeled change	Modeled overlap	Protected Areas
Accipiter gentilis (Northern Goshawk)	Dec	N	SI-N	N	SI	N	N	N	N	N	N/A	N	N	N	N/A	U	U	U	U	U
Acer rubrum (Red Maple)	SI-N	N	N	N	N	N	N	N	N	N/A	N	N	N	U	N	U	U	Inc-SI	N	U
Acer saccharum (Sugar Maple)	SI-N	N	N	N	SI	N	N	N	N	N/A	N	N	N	U	N	U	U	Inc	N	U
Aegolius acadicus - breeding (Northern Saw-whet Owl)	Dec	N	GI-Inc	SI	N	N	N	N-SD	Inc-SI	N	N/A	N	N	U	U	U	U	U	U	U
Aegolius acadicus - wintering (Northern Saw-whet Owl)	Dec	N	N	N	N	N	N	SD	N	N	N/A	N	N	U	U	U	U	U	U	U
Aeshna mutata (Spatterdock Darner)	N	N	Inc	N	GI	N	N	N	N	N	N/A	N	N	U	U	U	U	U	U	U
Alasmidonta marginata (Elktoe)	SI-N	N	GI	N	Inc-SI-N	N	N	N	N	N	N/A	Inc-SI	N	U	N	U	U	U	U	U
Alasmidonta varicosa (Brook Floater)	SI-N	N	Inc-SI	SI	SI-N	N	N	N	N	N	N/A	SI	N	U	N	U	U	U	U	U
Alliaria petiolata (Garlic Mustard)	SD	N	N	SD	N	SD	N	SD	N	N/A	N	N	N	U	U	SD	U	U	U	U
Allium oxyphilum (Lillydale Onion)	GI-Inc	N	SD	Inc-SI	SD	N	N	SI	N	N/A	N	N	N	U	N	U	U	U	U	U
Allocapnia frumi (Monongahela Snowfly)	Inc-SI	N	N	N	Inc-SI	N	N	SI	N	N	N/A	N	N	U	U	U	U	U	U	U
Alloperla aracoma (Aracoma Sallfly)	Inc-SI	N	N	N	Inc-SI	N	N	SI	N	N	N/A	N	N	U	Inc-SI	U	U	U	U	U
Alloperla biserrata (Dusky Sallfly)	Inc-SI	N	N	N	Inc-SI-N	N	N	SI	N	N	N/A	N	N	U	Inc-SI	U	U	U	U	U
Ambystoma barbouri (Streamside Salamander)	SI-N	N	SI-N	GI	GI-Inc	N	N	N	N	N	N/A	N	N	U	SI	U	U	U	U	U
Ambystoma texanum (Smallmouth Salamander)	SI-N	N	SI-N	Inc	GI-Inc	N	N	N	N	N	N/A	N	N	U	SI-N	U	U	U	U	U
Ammodramus henslowii	Dec	N	N	SI	N	N	N	SD	N	N	N/A	N	N	U	U	U	U	U	U	U

Species	Dispersal / Movement	historical thermal niche	physiological thermal niche	historical hydrol niche	physiological hydrol. niche	Disturbance	Ice/snow	Physical habitat	Other spp for habitat	Diet	Pollinators	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenologic response	Doc response	Modeled change	Modeled overlap	Protected Areas
(Henslow's Sparrow)																				
Aneides aeneus (Green Salamander)	SI	N	SI	N	Inc-SI	N	N	N	N	N	N/A	N	N	U	N	U	U	U	U	U
Anguilla rostrata (American Eel)	Dec	N	N	SI	N	N	N	N	N	N	N/A	U	N	U	N	U	U	U	U	U
Antrolana lira (Madison Cave Isopod)	GI	N	N	Inc	N	N	N	Inc	N	SD	N/A	N	N	U	U	U	U	U	U	U
Apochthonius paucispinosus (Dry Fork Valley Cave Pseudoscorpion)	Inc	GI	N	N	SI-N	N	N	Inc	N	N	N/A	SI-N	N	U	U	U	U	U	U	U
Arabis serotina (Shale Barren Rock Cress)	Inc	N	SD	SI	SD	SI-N-SD	N	Inc	N	N/A	N	N	N	U	Inc-SI	U	U	U	U	U
Arrhopalites sp3 (A Collembola)	GI-Inc	N	N	GI	N	N	N	Inc	N	N	N/A	N	N	U	U	U	U	U	U	U
Calephelis borealis (Northern Metalmark)	N	N	N	SD	N	N	N	N	N	Inc	N/A	N	N	U	N	U	U	U	U	U
Calopteryx amata (Superb Jewelwing)	N	N	GI-Inc	N	GI	N	N	N	N	N	N/A	N	N	U	N	U	U	U	U	U
Calymmaria virginica (A Spider)	N	N	Inc-SI	SI	Inc-SI	N	N	N	N	N	N/A	N	N	U	U	U	U	U	U	U
Cambarus angularis cf. (Angulated Crayfish cf.)	N	N	N	Inc	SI-N	N	N	N	N	SD	N/A	N	N	N	N/A	N	U	U	U	U
Cambarus bartonii (Common Crayfish)	N	N	Inc	SI	Inc-SI	N	N	N	N	SD	N/A	N	N	N	N/A	N	U	U	U	U
Cambarus bartonii cavatus (Appalachian Brook Crayfish)	N	N	SI-N	SI	Inc-SI	N	N	N	N	SD	N/A	N	N	N	N/A	N	U	U	U	U
Cambarus carinirostris (Rock Crawfish)	N	N	SI-N	SI	Inc-SI	N	N	N	N	SD	N/A	N	N	N	N/A	N	U	U	U	U
Cambarus chasmodactylus (New River Crayfish)	N	N	N	SI	N	N	N	N	N	SD	N/A	N	N	N	N/A	N	U	U	U	U
Cambarus dubius - Halloween morph (Upland Burrowing Crayfish)	N	N	N	SI	Inc-SI	N	N	N	N	SD	N/A	N	N	N	N/A	N	U	U	U	U

Species	Dispersal / Movement	historical thermal niche	physiological thermal niche	historical hydrol niche	physiological hydrol. niche	Disturbance	Ice/snow	Physical habitat	Other spp for habitat	Diet	Pollinators	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenologic response	Doc response	Modeled change	Modeled overlap	Protected Areas
Cambarus dubius - Monroe blue (Upland Burrowing Crayfish)	N	N	N	Inc-SI	Inc	N	N	N	N	SD	N/A	N	N	N	N/A	N	U	U	U	U
Cambarus dubius - orange (Upland Burrowing Crayfish)	N	N	N	SI-N	Inc-SI-N	N	N	N	N	SD	N/A	N	N	N	N/A	N	U	U	U	U
Cambarus dubius - Teays blue (Upland Burrowing Crayfish)	N	N	N	Inc	GI-Inc	N	N	N	N	SD	N/A	N	N	N	N/A	N	U	U	U	U
Cambarus elkensis (Elk River Crayfish)	N	N	SI-N	SI	SI-N	N	N	N	N	SD	N/A	N	N	N	N/A	N	U	U	U	U
Cambarus longulus (Atlantic Slope Crayfish)	N	N	N	Inc-SI	SI-N	N	N	N	N	SD	N/A	N	N	N	N/A	N	U	U	U	U
Cambarus monongalensis - mountains (Blue Crawfish)	N	N	N	SI	GI-Inc	N	N	N	N	SD	N/A	N	N	U	U	U	U	U	U	U
Cambarus monongalensis - plateau (Blue Crawfish)	N	N	N	SI	GI-Inc	N	N	N	N	SD	N/A	N	N	U	U	U	U	U	U	U
Cambarus nerterius (Greenbrier Cave Crayfish)	N	N	N	SI	GI	N	N	Inc	N	SD	N/A	N	N	U	U	U	U	U	U	U
Cambarus robustus (Big River Crayfish)	N	N	N	SI	N	SI-N	N	N	N	SD	N/A	N	N	U	U	U	U	U	U	U
Cambarus sciotensis (Teays River Crayfish)	N	N	N	N	N	SI-N	N	N	N	SD	N/A	N	N	N	N/A	N	U	U	U	U
Cambarus smilax (Greenbrier Crayfish)	N	N	Inc-SI	SI	N	SI-N	N	N	N	SD	N/A	N	N	U	U	U	U	U	U	U
Cambarus thomai (Little Brown Mudbug)	N	N	N	SI	Inc	SI-N-SD	N	N	N	SD	N/A	N	N	U	U	U	U	U	U	U
Cambarus veteranus (Big Sandy Crayfish)	N	N	N	Inc	N	SI	N	N	N	SD	N/A	N	N	U	Inc	U	U	U	U	U
Caprimulgus vociferus (Whip-poor-will)	Dec	N	N	SI	N	N	N	SD	N	SI-N	N/A	N	N	U	N	U	U	Dec	N	U
Catharus ustulatus (Swainson's Thrush)	Dec	N	Inc	Inc	N	N	N	N	Inc	N	N/A	N	N	U	U	U	U	GI	U	U
Chitrella regina (Royal Syarinid Pseudoscorpion)	Inc	GI	N	N	SI-N	N	N	Inc	N	N	N/A	SI-N	N	U	U	U	U	U	U	U

Species	Dispersal / Movement	historical thermal niche	physiological thermal niche	historical hydrol niche	physiological hydrol. niche	Disturbance	Ice/snow	Physical habitat	Other spp for habitat	Diet	Pollinators	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenologic response	Doc response	Modeled change	Modeled overlap	Protected Areas
Chrosiothes jenningsi (A Spider)	N-SD-Dec	N	N-SD	GI	N	N	N	N	N	N	N/A	N	N	U	U	U	U	U	U	U
Cicindela ancocisconensis (Appalachian Tiger Beetle)	N-SD	N	N-SD	N	N	N-SD	N	Inc-SI	N	N	N/A	N	N	U	SI	U	U	U	U	U
Cicindela marginipennis (Cobblestone Tiger Beetle)	N-SD	N	N-SD	GI	N	N-SD-Dec	N	Inc	N	N	N/A	N	N	U	Inc	U	U	U	U	U
Clemmys guttata (Spotted Turtle)	SD	N	N	GI	GI	N	N	SI-N	N	SD	N/A	N	N	U	N	U	U	U	U	U
Clinostomus elongatus (Redside Dace)	SD	N	GI	Inc	Inc	N	N	N	N	N	N/A	N	N	U	U	U	U	U	U	U
Colias interior (Pink-edged Sulpher)	N-SD	N	Inc	Inc	N	N	N	N	N	SI	N/A	N	N	U	N	U	U	U	U	U
Contopus cooperi (Olive-sided Flycatcher)	Dec	N	Inc	N	Inc-SI	N	N	N	Inc-SI-N	N	N/A	N	N	U	U	U	U	U	U	U
Corallorhiza bentleyi (Bentley's Coralroot)	N	N	N	Inc	SI-N	N	N	N	N	N/A	N	N	Inc	U	N	U	U	U	U	U
Cordulegaster erronea (Tiger Spiketail)	SD	N	N	SI-N	GI	N	N	N	N	N	N/A	N	N	U	N	U	U	U	U	U
Corynorhinus townsendii virginianus (Virginia Big-eared Bat)	SD-Dec	SI	GI-Inc-SI	N	N	N	N	Inc	N	N	N/A	N	N	Inc	N/A	U	U	U	U	U
Cottus cognatus (*C. robinsi* proposed) (Checkered Sculpin)	SI	N	GI-Inc-SI	Inc-SI	N	N	N	Inc	N	N	N/A	N	N	U	U	U	U	U	U	U
Cottus kanawhae (Kanawha Sculpin)	SI	N	Inc	SI	N	N	N	N	N	N	N/A	N	N	U	U	U	U	U	U	U
Cottus sp1 (Bluestone Sculpin)	SI	SI	GI-Inc-SI	Inc	N	N	N	Inc	N	N	N/A	N	N	U	U	U	U	U	U	U

Species	Dispersal / Movement	historical thermal niche	physiological thermal niche	historical hydrol niche	physiological hydrol. niche	Disturbance	Ice/snow	Physical habitat	Other spp for habitat	Diet	Pollinators	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenologic response	Doc response	Modeled change	Modeled overlap	Protected Areas
Crangonyx sp2 (An Amphipod)	GI-Inc	N	N	Inc	N	N	N	Inc	N	N-SD	N/A	N	N	U	U	U	U	U	U	U
Cyprogenia stegaria (Fanshell)	SI-N	N	N	SI	N	N	N	N	N	N	N/A	Inc-SI	N	U	N	U	U	U	U	U
Dendroica cerulea (Cerulean Warbler)	Dec	N	N	N	N	N	N	SD	N	N	N/A	N	N	U	N	U	U	SI	N	U
Dolichonyx oryzivorus (Bobolink)	Dec	N	Inc-SI	N	N	N	N	SD	N	N	N/A	N	N	U	U	U	U	GI	U	U
Elliptio dilatata (Spike)	SI-N	N	N	SI	N	N	N	N	N	N	N/A	Inc-SI	N	U	N	U	U	U	U	U
Empidonax alnorum (Alder Flycatcher)	Dec	N	Inc	N	Inc	Inc-SI-N	N	SI	Inc	N	N/A	N	N	U	U	U	U	U	U	U
Epioblasma torulosa rangiana (Northern Riffleshell)	SI-N	N	N	GI	N	N	N	N	N	N	N/A	Inc-SI	N	U	N	U	U	U	U	U
Epioblasma triquetra (Snuffbox)	SI-N	N	N	SI	N	N	N	N	N	N	N/A	Inc-SI	N	U	N	U	U	U	U	U
Etheostoma longimanum (Longfin Darter)	N	N	SI	Inc	N	SI	N	N	N	N	N/A	N	N	U	U	U	U	U	U	U
Etheostoma osburni (Candy Darter)	SI	N	Inc	SI	N	N	N	N	N	N	N/A	N	N	U	U	U	U	U	U	U
Euphorbia purpurea (Glade Spurge)	Inc	N	Inc-SI	SI	SI	N	N	SI	N	N/A	N	N	N	U	U	U	U	U	U	U
Euphyes bimacula (Two Spotted Skipper)	N	N	SI-N	N	GI	N	N	N	N	SI	N/A	N	N	U	N	U	U	U	U	U
Euphyes conspicua (Black Dash)	N	N	SI-N	GI	GI	N	N	N	N	SI	N/A	N	N	U	N	U	U	U	U	U
Exoglossum laurae (Tonguetied Minnow)	Dec	N	N	SI	N	SI	N	N	N	N	N/A	N	N	U	U	U	U	U	U	U
Falco peregrinus (Peregrine Falcon)	Dec	N	N	SI	N	N	N	Inc-SI-N	N	N	N/A	N	SI-N	U	U	U	U	U	U	U
Fallicambarus fodiens (Digger Crayfish)	N	N	N	Inc	GI	SI-N-	N	SI-N	Inc-SI	SD	N/A	N	N	U	Inc	U	U	U	U	U

Species	Dispersal / Movement	historical thermal niche	physiological thermal niche	historical hydrol niche	physiological hydrol. niche	Disturbance	Ice/snow	Physical habitat	Other spp for habitat	Diet	Pollinators	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenologic response	Doc response	Modeled change	Modeled overlap	Protected Areas
						SD														
Fontigens tartarea (Organ Cavesnail)	GI	GI	N	N	SI-N	N	N	Inc	N	N	N/A	N	N	U	U	U	U	U	U	U
Fontigens turritella (Greenbrier Cavesnail)	GI	GI	N	N	SI-N	N	N	Inc	N	N	N/A	N	N	U	U	U	U	U	U	U
Glaucomys sabrinus fuscus (WV Northern Flying Squirrel)	N	N	N	N	N	N	N	N	SI	SI-N	N/A	N	N	Inc-SI	N/A	U	U	U	U	U
Glyphyalinia raderi (Maryland Glyph)	GI	N	SI	N	N	N	N	SI-N	N	N-SD	N/A	N	N	U	SI-N	U	U	U	U	U
Gomphus fraternus (Midland Clubtail)	SD	N	N	SI	N	N	N	N	N	N	N/A	N	N	U	N	U	U	U	U	U
Gyrinophilus subterraneus (WV Spring Salamander)	SI	N	N	Inc	Inc-SI-N	N	N	Inc	N	N	N/A	N	N	U	U	U	U	U	U	U
Hansonoperla appalachia (Hanson's Appalachian Stonefly)	Inc-SI	N	N	SI	SI-N	N	N	SI	N	N	N/A	N	N	U	Inc-SI	U	U	U	U	U
Hansonoperla hokolesqua (Splendid Stone)	Inc-SI	N	N	GI	Inc-SI	N	N	SI	N	N	N/A	N	N	U	Inc-SI	U	U	U	U	U
Haplotaxis brinkhursti (An Oligochaete)	GI	N	N	GI	SI-N-SD	N	N	Inc	N	SI-N	N/A	N	N	U	Inc	U	U	U	U	U
Helmitheros vermivorus (Worm-eating Warbler)	Dec	N	N	SI	N	N	N	SD	N	N	N/A	N	N	U	U	U	U	N	N	U
Islandiana sp. 1 (A Cave Spider)	GI-Inc	N	SI-N-SD	GI	SI-N-SD	N	N	Inc	N	N	N/A	N	N	U	U	U	U	U	U	U
Islandiana speophila (Cavern Sheet-web Spider)	GI-Inc	N	N	GI	N	N	N	Inc	N	N	N/A	N	N	U	Inc	U	U	U	U	U
Isotria medeoloides (Small Whorled Pogonia)	N	N	N	GI	N	N	N	N	N	N/A	N	N	Inc	Inc	N/A	U	U	U	U	U
Kleptochthonius hetricki (Organ Cave Pseudoscorpion)	Inc	GI	N	N	SI-N	N	N	Inc	N	N	N/A	SI-N	N	U	U	U	U	U	U	U

Species	Dispersal / Movement	historical thermal niche	physiological thermal niche	historical hydrol niche	physiological hydrol. niche	Disturbance	Ice/snow	Physical habitat	Other spp for habitat	Diet	Pollinators	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenologic response	Doc response	Modeled change	Modeled overlap	Protected Areas
Kleptochthonius orpheus (Orpheus Cave Pseudoscorpion)	Inc	GI	N	N	SI-N	N	N	Inc	N	N	N/A	SI-N	N	U	U	U	U	U	U	U
Kleptochthonius proserpinae (Proserpina Cave Pseudoscorpion)	Inc	GI	N	N	SI-N	N	N	Inc	N	N	N/A	SI-N	N	U	U	U	U	U	U	U
Lampsilis abrupta (Pink Mucket)	SI-N	N	N	SI	N	N	N	N	N	N	N/A	Inc-SI	N	U	N	U	U	U	U	U
Lanius ludovicianus migrans (Migrant Loggerhead Shrike)	Dec	N	N	SI	N	N	N	SD	N	N	N/A	N	N	U	U	U	U	U	U	U
Lasiurus cinereus (Hoary Bat)	Dec	N	N	N	N	N	N	N-SD	SI-N	SI	N/A	N	N	U	U	U	U	U	U	U
Lasmigona subviridis (Green Floater)	SI-N	N	GI	N	SI-N	N	N	N	N	N	N/A	Inc-SI	N	U	N	U	U	U	U	U
Lepomis cyanellus (Green Sunfish)	Dec	N	N	SI	N	N	N	N	N	N	N/A	N	N	U	N	U	U	U	U	U
Leucorrhinia glacialis (Crimson-ringed Whiteface)	N	N	Inc-SI	Inc	GI	N	N	N	N	N	N/A	N	N	U	N	U	U	U	U	U
Limnothlypis swainsonii (Swainson's Warbler)	Dec	N	SD	SI	Inc-SI	N	N	SI	SI-N	N	N/A	N	N	U	U	U	U	U	U	U
Litocampa sp1 (A Diplurian)	GI	SI-N	N	GI	N	N	N	Inc	N	SD	N/A	N	N	U	U	U	U	U	U	U
Lycaena epixanthe (Bog Copper)	N	N	SI-N	GI	GI	N	N	N	N	SI	N/A	N	N	U	N	U	U	U	U	U
Lythrurus umbratilis (Redfin Shiner)	N	N	SI	SI	Inc	SI	N	N	SI	N	N/A	N	N	U	U	U	U	U	U	U
Marshallia grandiflora (Monongahela Barbara's-Buttons)	SI	N	SI	SI	SI	SI	N	SI-N	N	N/A	N	N	N	U	U	U	U	U	U	U
Martes pennanti (Fisher)	SD	N	Inc-SI	N	SI	SI-N	N	N	N	N	N/A	N	N	U	N	U	U	U	U	U
Megaleuctra flinti (Shenandoah Needlefly)	Inc-SI	N	N	N	Inc-SI	N	N	Inc	N	N	N/A	N	N	U	Inc-SI	U	U	U	U	U
Microtus chrotorrhinus carolinensis (Southern Rock	N	N	Inc-SI	N	SI	N	N	N	N	N	N/A	N	N	U	U	U	U	U	U	U

Species	Dispersal / Movement	historical thermal niche	physiological thermal niche	historical hydrol niche	physiological hydrol. niche	Disturbance	Ice/snow	Physical habitat	Other spp for habitat	Diet	Pollinators	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenologic response	Doc response	Modeled change	Modeled overlap	Protected Areas
Vole)																				
Myotis leibii (Eastern Small-footed Bat)	Dec	SI-N	Inc-SI	N	N	N	N	SI	N	N	N/A	N	N	U	U	U	U	U	U	U
Myotis sodalis (Indiana Bat)	Dec	SI-N	GI-Inc	N	N	N	N	Inc	N	N	N/A	N	N	U	U	U	U	U	U	U
Neotoma magister (Allegheny Woodrat)	N	N	SI	N	N	N	N	SI	N	N	N/A	N	N	SI	N/A	U	U	U	U	U
Notropis scabriceps (New River Shiner)	N	N	SI	SI	N	N	N	N	N	N	N/A	N	N	U	U	U	U	U	U	U
Nyssa sylvatica (Blackgum)	N	N	N	SI	N	N	N	N	N	N/A	N	N	N	U	N	U	U	Dec	N	U
Orconectes cristavarius (Spiny Stream Crayfish)	N	N	N	SI	N	SI-N	N	N	N	SD	N/A	N	N	U	U	U	U	U	U	U
Orconectes obscurus (Allegheny Crayfish)	N	N	N	N	N	SI	N	N	N	SD	N/A	N	N	U	U	U	U	U	U	U
Orconectes sanbornii (Sanborn's Crayfish)	N	N	N	SI	N	SI	N	N	N	SD	N/A	N	N	U	U	U	U	U	U	U
Orconectes virilis (Virile Crayfish)	N	N	N	SI	N	SI	N	N	N	SD	N/A	N	N	U	U	U	U	U	U	U
Ostrocerca prolongata (Bent Forestfly)	Inc-SI	N	N	N	Inc-SI	N	N	Inc	N	N	N/A	N	N	U	SI	U	U	U	U	U
Paravitrea ceres (Sidelong Supercoil)	GI	N	SI	GI	SI	N	N	N	N	N-SD	N/A	N	N	U	Inc-SI	U	U	U	U	U
Paravitrea reesei (Round Supercoil)	GI	N	SI	SI	SI-N	N	N	N	N	N-SD	N/A	N	N	U	U	U	U	U	U	U
Patera panselenus (Virginia Bladetooth)	SI	SI-N	GI-Inc	N	SI	N	N	SI	N	N	N/A	N	N	U	N	U	U	U	U	U
Paxistima canbyi (Canby's Mountain-lover)	GI	N	Inc-SI-N	N	SD	N	N	Inc-SI	N	N/A	N	N	N	U	SI-N	U	U	U	U	U
Peromyscus maniculatus (North American Deermouse)	N	N	N	N	N-SD	N	N	SD-Dec	N	SD	N/A	N	N	U	U	U	U	U	U	U
Phagocata angusta (A Planarian)	GI-Inc	N	N	GI	SI-N-SD	N	N	Inc	N	SI-N	N/A	N	N	U	Inc	U	U	U	U	U

Species	Dispersal / Movement	historical thermal niche	physiological thermal niche	historical hydrol niche	physiological hydrol. niche	Disturbance	Ice/snow	Physical habitat	Other spp for habitat	Diet	Pollinators	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenologic response	Doc response	Modeled change	Modeled overlap	Protected Areas
Phenacobius teretulus (Kanawha Minnow)	N-SD	N	Inc	SI	Inc	SI	N	U	N	N	N/A	N	N	U	U	U	U	U	U	U
Phlox buckleyi (Swordleaf Phlox)	GI-Inc	N	N	Inc-SI	N-SD	N	N	SI	N	N/A	N	N	N	U	N	U	U	U	U	U
Picea rubens (Red Spruce)	Inc	N	Inc	SI	SI	N	N	N	N	N/A	N	N	N	U	U	U	U	GI	U	U
Pinus rigida (Pitch Pine)	SI-N-SD	N	N	N	SD	SD	N	SI	N	N/A	N	N	N	U	N	U	U	N	N	U
Pinus virginiana (Virginia Pine)	SI-N-SD	N	N	SI	SD	SD	N	N	N	N/A	N	N	N	U	N	U	U	N	SI	U
Platanthera shriveri (Shriver's Frilly Orchid)	N	N	Inc	SI	Inc	N	N	SD	N	N/A	N	N	Inc	U	Inc	SI-N	U	U	U	U
Platanus occidentalis (Sycamore)	SD	N	N	N	N	N-SD	N	N	N	N/A	N	N	N	U	N	U	U	SD	N	U
Plethodon nettingi (Cheat Mountain Salamander)	GI	N	Inc	SI	SI	N	N	N	Inc-SI	N	N/A	N	N	U	U	U	U	U	U	U
Plethodon punctatus (Cow Knob Salamander)	Inc-SI	N	Inc-SI-N	Inc-SI	SI-N	N	N	N-SD	N	N	N/A	N	N	U	U	U	U	U	U	U
Plethodon virginia (Shenandoah Mountain Salamander)	Inc	N	Inc-SI	Inc-SI	SI-N	N	N	N-SD	N	N	N/A	N	N	U	U	U	U	U	U	U
Pleurobema clava (Clubshell)	SI-N	N	N	Inc	N	N	N	N	N	N	N/A	Inc-SI	N	U	N	U	U	U	U	U
Pleurobema collina (James Spiny Mussel)	SI-N	N	N	SI	N	N	N	N	N	N	N/A	Inc-SI	N	U	N	U	U	U	U	U
Potamogeton crispus (Curly Pondweed)	SD-Dec	N	N	Inc-SI-N	SI-N	N	N	N	N	N/A	N	N	N	U	U	U	U	U	U	U
Potamogeton tennesseensis (Tennessee Pondweed)	SD-Dec	N	N	N	GI-Inc	N	N	N	N	N/A	N	N	N	U	U	U	U	U	U	U
Procambarus acutus (White River Crayfish)	N	N	N	Inc	GI	SI-N-SD	N	SI-N	N	SD	N/A	N	N	U	U	U	U	U	U	U
Protonotaria citrea	Dec	N	SD	N	Inc	N	N	N	SI	N	N/A	N	N	U	U	U	U	U	U	U

Species	Dispersal / Movement	historical thermal niche	physiological thermal niche	historical hydrol niche	physiological hydrol. niche	Disturbance	Ice/snow	Physical habitat	Other spp for habitat	Diet	Pollinators	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenologic response	Doc response	Modeled change	Modeled overlap	Protected Areas
(Prothonotary Warbler)																				
Prunus serotina (Black Cherry)	SD	N	SI	N	N	N	N	N	N	N/A	N	N	N	U	N	U	U	GI	U	U
Pseudanophthalmus hadenoecus (Timber Ridge Cave Beetle)	GI-Inc	N	N	GI-Inc	N	N	N	Inc	N	N	N/A	N	N	U	U	U	U	U	U	U
Pseudanophthalmus lallemanti (Lallemants Cave Beetle)	GI-Inc	N	N	GI	N	N	N	Inc	N	N	N/A	N	N	U	U	U	U	U	U	U
Pseudanophthalmus montanus (Dry Fork Valley Cave Beetle)	GI-Inc	N	N	GI	N	N	N	Inc	N	N	N/A	N	N	U	U	U	U	U	U	U
Pseudanophthalmus senecae (Seneca Cave Beetle)	GI-Inc	N	N	GI-Inc	N	N	N	Inc	N	N	N/A	N	N	U	U	U	U	U	U	U
Pseudanophthalmus sp1 (A Cave Beetle)	GI-Inc	N	N	GI-Inc	N	N	N	Inc	N	N	N/A	N	N	U	U	U	U	U	U	U
Pseudanophthalmus sp2 (A Cave Beetle)	GI-Inc	N	N	GI-Inc	N	N	N	Inc	N	N	N/A	N	N	U	U	U	U	U	U	U
Pseudanophthalmus sp3 (A Cave Beetle)	GI	N	N	GI-Inc	N	N	N	Inc	N	N	N/A	N	N	U	U	U	U	U	U	U
Pseudosinella certa (Gandy Creek Cave Springtail)	GI	N	N	GI	N	N	N	Inc	N	N	N/A	N	N	U	U	U	U	U	U	U
Pseudotremia lusciosa (Germany Valley Cave Millipede)	GI	N	N	GI	N	N	N	Inc	N	N	N/A	N	N	U	U	U	U	U	U	U
Pseudotremia princeps (South Branch Valley Cave Millipede)	GI	N	N	SI	N	N	N	Inc	N	N	N/A	N	N	U	U	U	U	U	U	U
Pseudotremia sp1 (General Davis Cave Millipede)	GI	N	N	Inc	N	N	N	Inc	N	N	N/A	N	N	U	U	U	U	U	U	U
Pseudotriton montanus diastictus (Midland Mud Salamander)	SI	N	SI-N	SI	GI-Inc	N	N	N	N	N	N/A	N	N	U	N	U	U	U	U	U
Pteronarcys comstocki (Spiny Salmonfly)	Inc-SI	N	N	N	SI	N	N	SI	N	N	N/A	N	N	U	Inc	U	U	U	U	U
Ptilimnium nodosum (Harperella)	Inc-SI	N	N	Inc	Inc	Inc-SI-N	N	N	N	N/A	N	N	N	U	U	U	U	U	U	U

Species	Dispersal / Movement	historical thermal niche	physiological thermal niche	historical hydrol niche	physiological hydrol. niche	Disturbance	Ice/snow	Physical habitat	Other spp for habitat	Diet	Pollinators	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenologic response	Doc response	Modeled change	Modeled overlap	Protected Areas
Pycnanthemum torrei (Torrey's Mountain-mint)	GI-Inc	N	N	GI-Inc	SD	N	N	N-SD	N	N/A	N	N	N	U	U	U	U	U	U	U
Pyrgus wyandot (Grizzled Skipper)	N	N	N-SD	SI	SD	N	N	SI-N	N	SI	N/A	N	N	U	N	U	U	U	U	U
Quercus alba (White Oak)	SI	N	N	N	N	N	N	N	N	N/A	N	N	N	U	N	U	U	SD	N	U
Quercus palustris (Pin Oak)	SI	N	N	SI	Inc	N	N	N	N	N/A	N	N	N	U	N	U	U	N	N	U
Quercus prinus (Chestnut Oak)	SI	N	N	N	N	N	N	N	N	N/A	N	N	N	U	N	U	U	SI	N	U
Quercus rubra (Red Oak)	SI	N	N	N	N	N	N	N	N	N/A	N	N	N	U	N	U	U	N	N	U
Salvelinus fontinalis (Brook Trout)	Dec	N	GI-Inc	SI	SI	SI	N	N	N	N	N/A	N	N	U	N	U	U	Inc	N	N
Scaphiopus holbrookii (Eastern Spadefoot Toad)	SI	N	SI-N	SI	GI	N	N	SI	N	N	N/A	N	N	U	N	U	U	U	U	U
Scirpus ancistrochaetus (Northeastern Bulrush)	N	N	N	Inc	GI	SI-N	N	Inc	N	N/A	N	SI-N	N	U	U	U	U	U	U	U
Scolopax minor (American Woodcock)	Dec	N	N	N	GI-Inc-SI	N	N	N	N	SI-N	N/A	N	N	U	U	U	U	U	U	U
Sorex palustris puctulatus (Southern Water Shrew)	N	N	SI	N	GI-Inc	N	N	N	N	N	N/A	N	SI-N	U	U	U	U	U	U	U
Sphalloplana culveri (Culver's Planarian)	GI-Inc	N	N	GI	SI-N-SD	N	N	Inc	N	SI-N	N/A	N	N	U	Inc	U	U	U	U	U
Spiraea virginiana (Virginia Spiraea)	Inc	N	N	N	SI	SI	N	N	N	N/A	N	N	N	U	Inc	U	U	U	U	U
Stenotrema simile (Bear Creek Slitmouth Snail)	Inc-SI	N	Inc-SI	N	SI-N	N	N	N	N	N-SD	N/A	N	N	U	U	U	U	U	U	U
Stygobromus cooperi (Cooper's Cave Amphipod)	GI	N	N	GI	N	N	N	Inc	N	N-SD	N/A	N	N	U	U	U	U	U	U	U
Stygobromus culveri (Culver's Cave Amphipod)	GI	N	N	GI-Inc	N	N	N	Inc	N	N-SD	N/A	N	N	U	U	U	U	U	U	U
Stygobromus nanus (Pocahontas Cave Amphipod)	GI	N	N	GI-Inc	N	N	N	Inc	N	N-SD	N/A	N	N	U	U	U	U	U	U	U

Species	Dispersal / Movement	historical thermal niche	physiological thermal niche	historical hydrol niche	physiological hydrol. niche	Disturbance	Ice/snow	Physical habitat	Other spp for habitat	Diet	Pollinators	Other spp disp	Other spp interaction	Genetic var	Gen bottleneck	Phenologic response	Doc response	Modeled change	Modeled overlap	Protected Areas
Stygobromus redactus (Patton Cave Amphipod)	GI	N	N	GI-Inc	N	N	N	Inc	N	N-SD	N/A	N	N	U	U	U	U	U	U	U
Sweltsa pocahontas (Pocahontas Sallfly)	Inc-SI	N	N	N	Inc-SI-N	N	N	SI	N	N	N/A	N	N	U	Inc-SI	U	U	U	U	U
Syntrichia ammonsiana (Ammon's Tortula)	GI-Inc	N	SI-N-SD	GI-Inc	SI-N-SD	SI-N	N	Inc	N	N/A	U	N	U	U	U	U	U	U	U	U
Taenidia montana (Mountain Pimpernel)	GI	N	N-SD	N	N-SD	N	N	SI	N	N/A	N	N	N	U	U	U	U	U	U	U
Telebasis byersi (Duckweed Firetail)	SI	N	N-SD	GI-Inc	GI	N	N	N	N	N	N/A	N	N	U	N	U	U	U	U	U
Trifolium stoloniferum (Running Buffalo Clover)	SI	N	N	SI	N	N	N	SI	SI-N	N/A	U	U	N	SI	N/A	U	U	U	U	U
Trifolium virginicum (Kates Mountain Clover)	GI-Inc	N	N-SD	N	N-SD	N	N	Inc-SI	N	N/A	N	N	N	U	U	U	U	U	U	U
Trillium nivale (Snow Trillium)	Inc	N	N	N	N	N	N	SI	N	N/A	SI-N	SI-N	N	U	U	U	U	U	U	U
Triodopsis picea (Spruce Knob Threetooth Snail)	Inc-SI	N	Inc-SI	N	SI-N	N	N	N	N	N-SD	N/A	N	U	U	U	U	U	U	U	U
Triodopsis platysayoides (Flat-spired three-toothed land snail)	Inc-SI	N	Inc-SI	GI	SI-N	N	N	Inc	N	SD	N/A	N	N	U	SI-N	U	U	U	U	U
Triodopsis rugosa (Buttress Threetooth)	GI	N	SI	N	SI-N	N	N	N	N	N	N/A	N	N	U	Inc-SI-N	U	U	U	U	U
Tyto alba (Barn Owl)	Dec	N	N	SI	N	N	N	SD	N	SI-N	N/A	N	N	U	N	SD	U	U	U	U
Utaperla gaspesiana (Gaspe Sallfly)	Inc-SI	N	N	Inc-SI-N	SI-N	N	N	SI-N	N	N	N/A	N	N	U	Inc	U	U	U	U	U
Vermivora chrysoptera (Golden-winged Warbler)	Dec	N	SI	N	N	N-SD	N	SD	N	N	N/A	N	N	U	N	N	U	N	N	U
Virginia valeriae pulchra (Mountain Earthsnake)	SI-N	N	Inc-SI	N	SI-N	SI	N	SI-N	SI-N	N	N/A	N	N	U	U	U	U	U	U	U

Appendix D. Exposure and Geography Risk Factor Scores

Species	WV Range Relative to Global Range	Temp 5.0 F	Temp 4.5 F	Most drying	Mod drying	Least drying	Cave	Sea level	Natl barriers	Anth barriers	CC mitigation
Accipiter gentilis (Northern Goshawk)	Southern edge of range	80	20		100			N	N	N	SI
Acer rubrum (Red Maple)	Center of range	50	50	80	15	5		N	N	N	N
Acer saccharum (Sugar Maple)	Center of range	50	50	80	15	5		N	N	N	N
Aegolius acadicus - breeding (Northern Saw-whet Owl)	Southern edge of range	100		5	95			N	N	N	SI
Aegolius acadicus - wintering (Northern Saw-whet Owl)	Center of range	60	40	35	60	5		N	N	N	N
Aeshna mutata (Spatterdock Darner)	Southern edge of range	55	45	5	90	5		N	N	N	N
Alasmidonta marginata (Elktoe)	East/west edge of range	20	80	38	59	3		N	GI	N	N
Alasmidonta varicosa (Brook Floater)	East/west edge of range	100		100				N	GI-Inc	SI	N
Alliaria petiolata (Garlic Mustard)	Center of range	50	50	75	20	5		N	N	N	N
Allium oxyphilum (Lillydale Onion)	Entire range		100	95	5			N	N	SI-N	N
Allocapnia frumi (Monongahela Snowfly)	East/west edge of range		100	50	50			N	N	SI	N
Alloperla aracoma (Aracoma Sallfly)	Southern edge of range		100	100				N	N	SI-N	N
Alloperla biserrata (Dusky Sallfly)	East/west edge of range	50	50	60	40			N	N	SI-N	N
Ambystoma barbouri (Streamside Salamander)	East/west edge of range		100	100				N	N	Inc	N
Ambystoma texanum (Smallmouth Salamander)	East/west edge of range	34	66	100				N	N	Inc	N
Ammodramus henslowii (Henslow's Sparrow)	East/west edge of range	50	50	70	30			N	N	N	N
Aneides aeneus (Green Salamander)	Center of range	40	60	80	15	5		N	N	SI-N	N
Anguilla rostrata (American Eel)	Center of range	90	10	100				N	N	N	N
Antrolana lira (Madison Cave Isopod)	Northern edge of range	100		100			X	N	N	N	N
Apochthonius paucispinosus (Dry Fork Valley Cave Pseudoscorpion)	Entire range	100			100		X	N	N	N	N
Arabis serotina (Shale Barren Rock Cress)	East/west edge of range	67	33	95	5			N	GI-Inc	N	N
Arrhopalites sp3 (A Collembola)	Entire range		100	100			X	N	N	N	N
Calephelis borealis (Northern Metalmark)	Center of range	60	40	55	40	5		N	N	N	N
Calopteryx amata (Superb Jewelwing)	East/west edge of range	70	30	10	85	5		N	N	N	N
Calymmaria virginica (A Spider)	Entire range		100		100			N	N	N	N
Cambarus angularis cf. (Angulated Crayfish cf.)	Northern edge of range		100	100				N	Inc	SI-N	N
Cambarus bartonii (Common Crayfish)	Southern edge of range	100		100				N	N	N	N

Species	WV Range Relative to Global Range	Temp 5.0 F	Temp 4.5 F	Most drying	Mod drying	Least drying	Cave	Sea level	Natl barriers	Anth barriers	CC mitigation
Cambarus bartonii cavatus (Appalachian Brook Crayfish)	Northern edge of range	50	50	100				N	N	N	N
Cambarus carinirostris (Rock Crawfish)	Southern edge of range	50	50	80	20			N	N	N	N
Cambarus chasmodactylus (New River Crayfish)	Northern edge of range	10	90	40	55	5		N	N	N	N
Cambarus dubius - Halloween morph (Upland Burrowing Crayfish)	Entire range		100	90	10			N	N	SI-N	N
Cambarus dubius - Monroe blue (Upland Burrowing Crayfish)	Northern edge of range		100	100				N	Inc	SI-N	N
Cambarus dubius - orange (Upland Burrowing Crayfish)	Center of range	100		10	90			N	SI-N	N	N
Cambarus dubius - Teays blue (Upland Burrowing Crayfish)	Entire range		100	100				N	Inc	SI-N	N
Cambarus elkensis (Elk River Crayfish)	Entire range	95	5		100			N	Inc	Inc	N
Cambarus longulus (Atlantic Slope Crayfish)	East/west edge of range		100	100				N	GI	N	N
Cambarus monongalensis - mountains (Blue Crawfish)	Entire range	70	30		95	5		N	Inc	SI-N	N
Cambarus monongalensis - plateau (Blue Crawfish)	Entire range	80	20	100				N	Inc	SI-N	N
Cambarus nerterius (Greenbrier Cave Crayfish)	Entire range		100	90	10		X	N	GI	N	N
Cambarus robustus (Big River Crayfish)	Center of range	50	50	100				N	N	SI-N	N
Cambarus sciotensis (Teays River Crayfish)	Northern edge of range		100	70	30			N	N	SI-N	N
Cambarus smilax (Greenbrier Crayfish)	Entire range	5	95	60	40			N	GI-Inc	N	N
Cambarus thomai (Little Brown Mudbug)	Center of range	60	40	100				N	SI-N	N	N
Cambarus veteranus (Big Sandy Crayfish)	Northern edge of range		100	100				N	SI	GI	N
Caprimulgus vociferus (Whip-poor-will)	Center of range	50	50	95	5			N	N	N	N
Catharus ustulatus (Swainson's Thrush)	Southern edge of range	90	10		90	10		N	N	N	N
Chitrella regina (Royal Syarinid Pseudoscorpion)	Entire range	100			100		X	N	N	N	N
Chrosiothes jenningsi (A Spider)	Entire range	100		100				N	N	Inc-SI	N
Cicindela ancocisconensis (Appalachian Tiger Beetle)	Center of range	60	40	60	40			N	N	N	N
Cicindela marginipennis (Cobblestone Tiger Beetle)	Center of range	100		100				N	N	SI-N	N
Clemmys guttata (Spotted Turtle)	Center of range	100		100				N	N	Inc	N
Clinostomus elongatus (Redside Dace)	Southern edge of range	70	30	100				N	Inc	SI	N
Colias interior (Pink-edged Sulpher)	Southern edge of range	90	10	30	65	5		N	N	N	N
Contopus cooperi (Olive-sided Flycatcher)	Southern edge of range	80	20		90	10		N	N	N	N
Corallorhiza bentleyi (Bentley's Coralroot)	East/west edge of range		100		100			N	N	N	N

Species	WV Range Relative to Global Range	Temp 5.0 F	Temp 4.5 F	Most drying	Mod drying	Least drying	Cave	Sea level	Natl barriers	Anth barriers	CC mitigation
Cordulegaster erronea (Tiger Spiketail)	Center of range	60	40	60	35	5		N	N	N	N
Corynorhinus townsendii virginianus (Virginia Big-eared Bat)	Northern edge of range	80	20	20	75	5		N	N	N	SI
Cottus cognatus (*C. robinsi* proposed) (Checkered Sculpin)	Southern edge of range	100		100				N	GI	SI	N
Cottus kanawhae (Kanawha Sculpin)	Northern edge of range		100	80	20			N	GI	SI	N
Cottus sp1 (Bluestone Sculpin)	Northern edge of range		100	100				N	GI	SI	N
Crangonyx sp2 (An Amphipod)	Entire range		100	100			X	N	N	N	N
Cyprogenia stegaria (Fanshell)	East/west edge of range	50	50	100				N	N	Inc	N
Dendroica cerulea (Cerulean Warbler)	Center of range	50	50	90	10			N	N	N	N
Dolichonyx oryzivorus (Bobolink)	Southern edge of range	70	30	5	90	5		N	N	N	N
Elliptio dilatata (Spike)	East/west edge of range	95	5	100				N	SI-N	GI	N
Empidonax alnorum (Alder Flycatcher)	Southern edge of range	95	5	5	90	5		N	N	N	N
Epioblasma torulosa rangiana (Northern Riffleshell)	East/west edge of range		100	100				N	N	N	N
Epioblasma triquetra (Snuffbox)	East/west edge of range	85	15	100				N	N	SI	N
Etheostoma longimanum (Longfin Darter)	East/west edge of range		100	100				N	GI	SI	N
Etheostoma osburni (Candy Darter)	Entire range	10	90	40	60			N	GI	SI	N
Euphorbia purpurea (Glade Spurge)	Center of range	100			90	10		N	GI-Inc	N	N
Euphyes bimacula (Two Spotted Skipper)	Center of range	85	15	55	40	5		N	N	N	N
Euphyes conspicua (Black Dash)	Southern edge of range	100			100			N	N	N	N
Exoglossum laurae (Tonguetied Minnow)	Center of range		100	80	20			N	GI	SI	N
Falco peregrinus (Peregrine Falcon)	Center of range	70	30	95	5			N	N	N	N
Fallicambarus fodiens (Digger Crayfish)	Center of range		100	100				N	GI-Inc	Inc-SI	N
Fontigens tartarea (Organ Cavesnail)	Entire range	50	50	35	60	5	X	N	N	SI-N	N
Fontigens turritella (Greenbrier Cavesnail)	Entire range		100	100			X	N	N	N	N
Glaucomys sabrinus fuscus (WV Northern Flying Squirrel)	Center of range	70	30	25	70	5		N	Inc	N	SI
Glyphyalinia raderi (Maryland Glyph)	East/west edge of range	33	67	85	15			N	N	SI-N	N
Gomphus fraternus (Midland Clubtail)	Center of range	90	10	60	35	5		N	N	N	N
Gyrinophilus subterraneus (WV Spring Salamander)	Entire range		100	100			X	N	Inc	SI	N
Hansonoperla appalachia (Hanson's Appalachian Stonefly)	East/west edge of range		100	50	50			N	N	N	N
Hansonoperla hokolesqua (Splendid Stone)	Northern edge of range		100	100				N	N	Inc-	N

Species	WV Range Relative to Global Range	Temp 5.0 F	Temp 4.5 F	Most drying	Mod drying	Least drying	Cave	Sea level	Natl barriers	Anth barriers	CC mitigation
										SI	
Haplotaxis brinkhursti (An Oligochaete)	Entire range		100		100		X	N	N	N	N
Helmitheros vermivorus (Worm-eating Warbler)	Center of range	40	60	95	5			N	N	N	N
Islandiana sp. 1 (A Cave Spider)	Entire range		100	100			X	N	N	N	N
Islandiana speophila (Cavern Sheet-web Spider)	Entire range	100		100			X	N	N	N	N
Isotria medeoloides (Small Whorled Pogonia)	Center of range		100	100				N	N	SI	N
Kleptochthonius hetricki (Organ Cave Pseudoscorpion)	Entire range	100			100		X	N	N	N	N
Kleptochthonius orpheus (Orpheus Cave Pseudoscorpion)	Entire range	100			100		X	N	N	N	N
Kleptochthonius proserpinae (Proserpina Cave Pseudoscorpion)	Entire range	100			100		X	N	N	N	N
Lampsilis abrupta (Pink Mucket)	East/west edge of range	20	80	100				N	N	Inc-SI	N
Lanius ludovicianus migrans (Migrant Loggerhead Shrike)	Northern edge of range	50	50	95	5			N	N	N	N
Lasiurus cinereus (Hoary Bat)	Center of range	50	50	85	15			N	N	N	Inc
Lasmigona subviridis (Green Floater)	East/west edge of range	10	90	60	40			N	GI-Inc	N	N
Lepomis cyanellus (Green Sunfish)	Center of range	50	50	90	10			N	N	N	N
Leucorrhinia glacialis (Crimson-ringed Whiteface)	Southern edge of range	100		90	10			N	N	N	N
Limnothlypis swainsonii (Swainson's Warbler)	Northern edge of range	15	85	90	10			N	N	N	N
Litocampa sp1 (A Diplurian)	Northern edge of range		100	100			X	N	N	N	N
Lycaena epixanthe (Bog Copper)	Southern edge of range	100			100			N	N	N	N
Lythrurus umbratilis (Redfin Shiner)	East/west edge of range	70	30	100				N	SI	SI	N
Marshallia grandiflora (Monongahela Barbara's-Buttons)	Center of range	85	15	30	65	5		N	N	N	N
Martes pennanti (Fisher)	Southern edge of range	60	40	60	35	5		N	N	N	N
Megaleuctra flinti (Shenandoah Needlefly)	East/west edge of range	40	60	35	60	5		N	N	SI-N	N
Microtus chrotorrhinus carolinensis (Southern Rock Vole)	Center of range	80	20	25	70	5		N	Inc-SI	N	N
Myotis leibii (Eastern Small-footed Bat)	Center of range	50	50	60	35	5		N	N	N	SI
Myotis sodalis (Indiana Bat)	Center of range	50	50	45	50	5		N	N	N	SI
Neotoma magister (Allegheny Woodrat)	Center of range	90	10	5	90	5		N	N	N	SI
Notropis scabriceps (New River Shiner)	Northern edge of range	10	90	30	70			N	GI	SI	N
Nyssa sylvatica (Blackgum)	Center of range	50	50	95	5			N	N	N	N

Species	WV Range Relative to Global Range	Temp 5.0 F	Temp 4.5 F	Most drying	Mod drying	Least drying	Cave	Sea level	Natl barriers	Anth barriers	CC mitigation
Orconectes cristavarius (Spiny Stream Crayfish)	Northern edge of range		100		100			N	N	SI-N	N
Orconectes obscurus (Allegheny Crayfish)	Northern edge of range	95	5	70	25	5		N	N	SI-N	N
Orconectes sanbornii (Sanborn's Crayfish)	Northern edge of range	50	50	95	5			N	N	SI-N	N
Orconectes virilis (Virile Crayfish)	Northern edge of range	70	30	100				N	N	SI-N	N
Ostrocerca prolongata (Bent Forestfly)	Southern edge of range	50	50		95	5		N	N	SI-N	N
Paravitrea ceres (Sidelong Supercoil)	Entire range		100	100				N	N	N	N
Paravitrea reesei (Round Supercoil)	Northern edge of range	5	95	95	5			N	N	SI	N
Patera panselenus (Virginia Bladetooth)	Northern edge of range	10	90	90	10			N	N	GI	N
Paxistima canbyi (Canby's Mountain-lover)	Center of range	40	60	85	15			N	N	N	N
Peromyscus maniculatus (North American Deermouse)	Center of range	50	50	80	18	2		N	N	N	N
Phagocata angusta (A Planarian)	Entire range	100			100		X	N	N	N	N
Phenacobius teretulus (Kanawha Minnow)	Northern edge of range		100	30	70			N	N	SI	N
Phlox buckleyi (Swordleaf Phlox)	East/west edge of range		100	60	40			N	N	SI-N	N
Picea rubens (Red Spruce)	Southern edge of range	80	20	5	90	5		N	GI-Inc	N	SI-N-SD
Pinus rigida (Pitch Pine)	Center of range	75	25	90	10			N	N	N	N
Pinus virginiana (Virginia Pine)	Northern edge of range	75	25	100				N	N	N	N
Platanthera shriveri (Shriver's Frilly Orchid)	Center of range	50	50	15	85			N	N	SI-N	N
Platanus occidentalis (Sycamore)	Center of range	50	50	95	5			N	N	N	N
Plethodon nettingi (Cheat Mountain Salamander)	Entire range	80	20		90	10		N	GI-Inc	Inc	N
Plethodon punctatus (Cow Knob Salamander)	East/west edge of range	100		100				N	GI-Inc	SI-N	SI
Plethodon virginia (Shenandoah Mountain Salamander)	East/west edge of range	100		100				N	GI	SI	SI-N
Pleurobema clava (Clubshell)	East/west edge of range	95	5	100				N	SI-N	GI	N
Pleurobema collina (James Spiny Mussel)	East/west edge of range		100	100				N	GI-Inc	N	N
Potamogeton crispus (Curly Pondweed)	Center of range	50	50	100				N	N	N	N
Potamogeton tennesseensis (Tennessee Pondweed)	Center of range	50	50	50	45	5		N	N	N	N
Procambarus acutus (White River Crayfish)	Center of range		100	100				N	GI-Inc	Inc-SI	N
Protonotaria citrea (Prothonotary Warbler)	Northern edge of range	50	50	100				N	N	N	N

Species	WV Range Relative to Global Range	Temp 5.0 F	Temp 4.5 F	Most drying	Mod drying	Least drying	Cave	Sea level	Natl barriers	Anth barriers	CC mitigation
Prunus serotina (Black Cherry)	Southern edge of range	50	50	60	35	5		N	N	N	N
Pseudanophthalmus hadenoecus (Timber Ridge Cave Beetle)	Entire range	100		100			X	N	N	N	N
Pseudanophthalmus lallemanti (Lallemants Cave Beetle)	Entire range	100		100			X	N	N	N	N
Pseudanophthalmus montanus (Dry Fork Valley Cave Beetle)	Entire range	100			100		X	N	N	N	N
Pseudanophthalmus senecae (Seneca Cave Beetle)	Entire range	100		100			X	N	N	N	N
Pseudanophthalmus sp1 (A Cave Beetle)	Entire range		100	100			X	N	N	N	N
Pseudanophthalmus sp2 (A Cave Beetle)	Entire range	100			100		X	N	N	N	N
Pseudanophthalmus sp3 (A Cave Beetle)	Entire range		100	100			X	N	N	N	N
Pseudosinella certa (Gandy Creek Cave Springtail)	Entire range	100			100		X	N	N	N	N
Pseudotremia lusciosa (Germany Valley Cave Millipede)	Entire range	100		100			X	N	N	N	N
Pseudotremia princeps (South Branch Valley Cave Millipede)	Northern edge of range	95	5	100			X	N	N	N	N
Pseudotremia sp1 (General Davis Cave Millipede)	Entire range		100	100			X	N	N	N	N
Pseudotriton montanus diastictus (Midland Mud Salamander)	Northern edge of range	5	95	85	15			N	N	SI	N
Pteronarcys comstocki (Spiny Salmonfly)	East/west edge of range	90	10	50	50			N	N	SI-N	N
Ptilimnium nodosum (Harperella)	Northern edge of range	100		100				N	N	SI	N
Pycnanthemum torrei (Torrey's Mountain-mint)	Center of range	50	50	100				N	N	N	N
Pyrgus wyandot (Grizzled Skipper)	Center of range	95	5	100				N	N	N	N
Quercus alba (White Oak)	Center of range	50	50	80	20			N	N	N	N
Quercus palustris (Pin Oak)	Center of range	50	50	100				N	SI	N	N
Quercus prinus (Chestnut Oak)	Center of range	50	50	80	20			N	N	N	N
Quercus rubra (Red Oak)	Center of range	50	50	80	20			N	N	N	N
Salvelinus fontinalis (Brook Trout)	Center of range	75	25	40	60			N	GI-Inc	SI	N
Scaphiopus holbrookii (Eastern Spadefoot Toad)	Northern edge of range	15	85	100				N	N	SI	N
Scirpus ancistrochaetus (Northeastern Bulrush)	East/west edge of range	100		100				N	N	SI-N	SI-N
Scolopax minor (American Woodcock)	Center of range	50	50	80	20			N	N	N	N
Sorex palustris puctulatus (Southern Water Shrew)	Center of range	80	20	10	85	5		N	N	N	SI-N
Sphalloplana culveri (Culver's Planarian)	Entire range	100			100		X	N	N	N	N
Spiraea virginiana (Virginia Spiraea)	Northern edge of range	10	90	90	10			N	N	N	N

Species	WV Range Relative to Global Range	Temp 5.0 F	Temp 4.5 F	Most drying	Mod drying	Least drying	Cave	Sea level	Natl barriers	Anth barriers	CC mitigation
Stenotrema simile (Bear Creek Slitmouth Snail)	Center of range	70	30		100			N	SI	N	N
Stygobromus cooperi (Cooper's Cave Amphipod)	Entire range	100		100			X	N	N	N	N
Stygobromus culveri (Culver's Cave Amphipod)	Entire range	100			70	30	X	N	N	N	N
Stygobromus nanus (Pocahontas Cave Amphipod)	Entire range		100		100		X	N	N	N	N
Stygobromus redactus (Patton Cave Amphipod)	Entire range		100	100			X	N	N	N	N
Sweltsa pocahontas (Pocahontas Sallfly)	Southern edge of range		100		100			N	N	N	N
Syntrichia ammonsiana (Ammon's Tortula)	Northern edge of range		100		100			N	N	N	N
Taenidia montana (Mountain Pimpernel)	East/west edge of range	60	40	85	15			N	SI-N	SI-N	N
Telebasis byersi (Duckweed Firetail)	Northern edge of range		100	100				N	N	N	N
Trifolium stoloniferum (Running Buffalo Clover)	East/west edge of range	90	10	10	85	5		N	N	N	SI-N
Trifolium virginicum (Kates Mountain Clover)	East/west edge of range	75	25	100				N	GI-Inc-SI	SI-N	N
Trillium nivale (Snow Trillium)	Center of range	80	20	60	40			N	N	N	SI-N
Triodopsis picea (Spruce Knob Threetooth Snail)	Center of range	70	30		100			N	SI	N	N
Triodopsis platysayoides (Flat-spired three-toothed land snail)	Entire range	100		50	50			N	U	SI-N	N
Triodopsis rugosa (Buttress Threetooth)	Northern edge of range	30	70	80	20			N	N	SI-N	N
Tyto alba (Barn Owl)	Center of range	60	40	100				N	N	N	N
Utaperla gaspesiana (Gaspe Sallfly)	Southern edge of range	100		100				N	N	N	N
Vermivora chrysoptera (Golden-winged Warbler)	Center of range	50	50	80	15	5		N	N	N	N
Virginia valeriae pulchra (Mountain Earthsnake)	Southern edge of range	50	50	30	70			N	Inc-SI	SI	

Appendix E. Sample Vulnerability Assessment Form

The NatureServe Climate Change Vulnerability Index

Release 2.01 *10 May 2010; Bruce Young, Elizabeth Byers, Kelly Gravuer, Kim Hall, Geoff Hammerson, Alan Redder*

With input from: *Jay Cordeiro, Kristin Szabo*

Funding for Release 2.0 generously provided by the Duke Energy Corporation.

NatureServe

** = Required field*

Clear Form

Geographic Area Assessed:	West Virginia *
Assessor:	Sam Norris
Species Scientific Name:	*Alasmidonta marginata* *
English Name:	Elktoe
Major Taxonomic Group:	Invert-Mollusk *
Relation of Species' Range to Assessment Area:	East/west edge of range *
G-Rank:	G4
S-Rank:	S2
Check if species is an obligate of caves or groundwater aquatic systems:	*(Must be marked with an "X" for accurate scoring of these species.)*

Assessment Notes (to document special methods and data sources)

WVNHP database; Parmalee and Bogan 1998; Watters et al. 2009. Natural barriers: watershed change immediately to north. Habitat is small shallow rivers and creeks, cold water. Glochidia dispersed on fish hosts.

Section A: Exposure to Local Climate Change *(Calculate for species' range within assessment area)*

Temperature *

Severity	**Scope** (percent of range)
>5.5° F (3.1° C) warmer	
5.1-5.5° F (2.8-3.1° C) warmer	20
4.5-5.0° F (2.5-2.7° C) warmer	80
3.9-4.4° F (2.2-2.4° C) warmer	
< 3.9° F (2.2° C) warmer	
Total:	100 *(Must sum to 100)*

Hamon AET:PET Moisture Metric *

Severity	**Scope** (percent of range)
< -0.119	
-0.097 - -0.119	
-0.074 - -0.096	
-0.051 - -0.073	38
-0.028 - -0.050	59
>-0.028	3
Total:	100 *(Must sum to 100)*

Section B: Indirect Exposure to Climate Change *(Evaluate for specific geographical area under consideration)*

Mark an "X" in all boxes that apply.

Greatly increase	Increase	Somewhat increase	Neutral	Somewhat decrease	Decrease	Unknown	**Factors that influence vulnerability** *(* at least three required)*
			x				1) Exposure to **sea level rise**
							2) Distribution relative to **barriers**
x							a) **Natural barriers**
			x				b) **Anthropogenic barriers**
			x				3) Predicted **impact of land use changes resulting from human responses** to climate change

Section C: Sensitivity

Mark an "X" in all boxes that apply.

Greatly increase	Increase	Somewhat increase	Neutral	Somewhat decrease	Decrease	Unknown	**Factors that influence vulnerability** *(* at least 10 required)*
		x	x				1) **Dispersal and movements**
							2) Predicted **sensitivity to temperature** and **moisture changes**
							a) Predicted **sensitivity to changes in temperature**
			x				i) **historical thermal niche**
x							ii) **physiological thermal niche**
							b) Predicted **sensitivity to changes in precipitation, hydrology, or moisture regime**
			x				i) **historical hydrological niche**
	x	x	x				ii) **physiological hydrological niche**
			x				c) Dependence on a **specific disturbance regime** likely to be impacted by climate change
			x				d) Dependence on **ice, ice-edge, or snow-cover habitats**
			x				3) **Restriction to uncommon geological features or derivatives**
							4) **Reliance on interspecific interactions**
			x				a) Dependence on **other species to generate habitat**
			x				b) **Dietary versatility** (animals only)
						X	c) **Pollinator versatility** (plants only)
	x	x					d) Dependence on **other species for propagule dispersal**
			x				e) Forms part of an **interspecific interaction** not covered by 4a-d
							5) **Genetic factors**
						X	a) Measured **genetic variation**
			x				b) Occurrence of **bottlenecks** in recent evolutionary history *(use only if 5a is "unknown")*
						X	6) **Phenological response** to changing seasonal temperature and precipitation dynamics

Section D: Documented or Modeled Response to Climate Change *(Optional; May apply across the range of a species)*

Mark an "X" in all boxes that apply.

Effect on Vulnerability

Greatly increase	Increase	Somewhat increase	Neutral	Somewhat decrease	Decrease	Unknown	(Optional)
						X	1) **Documented response** to recent climate change
						X	2) Modeled **future (2050) change in population** or **range size**
						X	3) **Overlap** of modeled future (2050) range with current range
						X	4) Occurrence of **protected areas in modeled future (2050) distribution**

Climate Change Vulnerability Index

for Alasmidonta marginata in West Virginia

Extremely Vulnerable

Notes:

Copy Data to Results Table

Confidence in Species Information

Moderate

* Histogram below

Definitions of Index Values

Extremely Vulnerable (EV): Abundance and/or range extent within geographical area assessed extremely likely to substantially decrease or disappear by 2050.

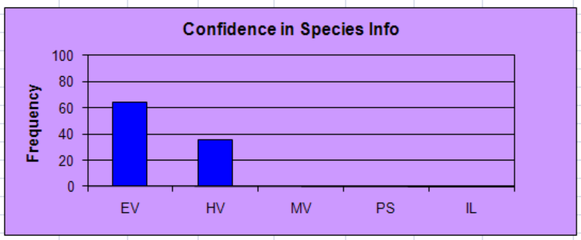
Highly Vulnerable (HV): Abundance and/or range extent within geographical area assessed likely to decrease significantly by 2050.

Moderately Vulnerable (MV): Abundance and/or range extent within geographical area assessed likely to decrease by 2050.

Not Vulnerable/Presumed Stable (PS): Available evidence does not suggest that abundance and/or range extent within the geographical area assessed will change (increase/decrease) substantially by 2050. Actual range boundaries may change.

Not Vulnerable/Increase Likely (IL): Available evidence suggests that abundance and/or range extent within geographical area assessed is likely to increase by 2050.

Insufficient Evidence (IE): Available information about a species' vulnerability is inadequate to calculate an Index score.



Results of a Monte Carlo simulation (1000 runs) of the data entered in the Index.