Final Project Report

1.B: Analysis of Potential Impacts of Climate Change on Wildlife Habitats in the U.S.

Linda A Joyce
US Forest Service Rocky Mountain Research Station
240 West Prospect, Fort Collins, CO 80526

Curtis H Flather
US Forest Service Rocky Mountain Research Station
2150 Centre, Bldg A, Fort Collins, CO 80526

Marni Koopman
National Center for Conservation Science and Policy
84 Fourth Street, Ashland, OR 97520

I. Abstract

Resource managers face many challenges in developing management recommendations for wildlife habitat under a changing climate. Our research results offer states a more consistent and holistic approach to analyzing potential threats of climate change to terrestrial wildlife habitat. This process integrates a review of the scientific literature, the State Wildlife Action Plans (SWAPs), and analyses based on the state-of-the-art climate and ecological modeling, as well as current information on stressors to wildlife conservation.

Our review of 50 State Wildlife Actions Plans (SWAPs) indicated that states varied in their description of climate change as a potential threat and in the degree to which management recommendations for habitat or species, specific to climate change, were developed, both across states and within state plans. The scientific literature available offered few on-the-ground management recommendations to address the potential impacts of climate change to wildlife habitat.

We developed an approach to rank areas along a gradient of high to low future climate stress to terrestrial wildlife habitat. Our terrestrial climate stress index incorporated components of climate (i.e., changes in mean annual temperature and precipitation), climate-induced shifts in habitat area, and climate-induced changes in habitat quality as reflected in vegetation production. The areas of greatest stress from future climate change were associated with transitions between major biomes or in areas of high topographic relief. We calculated our climate stress index across 12 scenarios (3 global circulation models; 2 economic scenarios that affected greenhouse gas emissions; and 2 ecological assumptions that affected plant sensitivity to elevated atmospheric carbon dioxide [CO_2]). Observed variation in the climate stress index could be most ascribed to variability among the three global circulation models and less credited to the economic scenarios and ecological assumptions. We also observed that variation in the climate stress index was relatively low in high stress areas and relatively high in low stress areas. Such a pattern indicated that high stress areas were more consistently identified among the 12 scenarios than were low stress areas.

In addition to identifying areas of future stress, we assessed patterns of current stressors, including barriers to dispersal associated with urban development and agriculture, and relative proportion of species considered to be at risk of extinction. Generally, the locations where current stressors were most pronounced did not overlap with the location of high future stress associated with climate change, potentially complicating the efforts of managers to prioritize wildlife conservation actions.

We adapted our national terrestrial climate stress index to evaluate habitat-specific risk to climate change. This application sought to further inform planners and policy makers on potential priorities for management directed toward the amelioration of climate change threats. In addition to the climate shift and production components of the national index, we also included habitat-specific measures that quantified the change in total habitat area, the amount of overlap between the recent history and future footprints of the habitat type, migration resistance based on current level of intensive land use within the habitat type, and the prevalence of at-risk

species that are associated with the habitat type. We illustrated the habitat-specific version of the terrestrial stress index in three case-study states: Arizona, Minnesota, and Tennessee. These case-study states sorted into two groups: those where habitat gains (novel habitats appear over time) and habitat losses (historical habitats disappear over time) were rare events (Arizona and Minnesota), and those where habitat compositional changes dominated (Tennessee). Habitat types that ranked high on the habitat-specific stress index tended to be those associated with more xeric conditions (grassland and xeromorphic woodland habitats). The appearance of novel habitats in a state will bring new management challenges that will likely benefit from collaborative arrangements with neighboring states.

Among the three case study states, only Arizona addressed climate change in the SWAP. Arizona focused on the potential climate impacts of drought, and how to reduce those impacts, but not on other potential climate change impacts such as shifts in dominant biomes, shifts in species' ranges, and loss of high elevation habitats. Considering that our habitat-specific stress index identified xeric habitats as potential high stress areas in Arizona, their focus on drought is appropriate, although consideration of other climate change impacts is also warranted. Wildlife conservation planners in Tennessee, on the other hand, may want to consider how to best transition from its current mix of habitats to a different habitat composition without losing biodiversity, as this state is likely to experience substantial turnover in vegetation cover types. In Minnesota, a suitable management strategy would include efforts to reduce current stressors to C4 grasslands and protect areas that are expected to remain stable over the long term. All three states will need to consider how to adapt to and manage for the full suite of climate change impacts that are likely to occur.

Based on these reviews and analyses, we make the following recommendations for improving treatment of climate change in the SWAPs. Potential impacts of climate change are multiple and interacting; recommendations offered in the SWAPs to address climate change may need to be expanded to comprehensively address the diversity of potential impacts from climate change. As a result of the synergistic nature of climate change, management recommendations to conserve wildlife resources under climate change and under other threats need to be integrated. Management to address climate change impacts should also consider those currently identified species of greatest conservation concern (SGCC) that are thought to be impacted by climate change. In addition, states should broaden their criteria for identifying future SGCC to consider species sensitivity to climate change since secure populations may in fact become exposed to extinction risk under future climate change. Finally, collaboration across state boundaries will be necessary for management of many species, and such collaboration should be clearly outlined in the SWAPs. Techniques developed in this study offer a mechanism by which to explore a comprehensive suite of potential climate change threats and then to identify a suitable suite of management recommendations for terrestrial wildlife habitat under climate change.

II. Introduction

The consensus among scientists is that the global climate is now undergoing a period of rapid change. Because the wildlife management paradigm in the United States places primary responsibility of wildlife resources with individual states, state agencies are in need of spatially-explicit information on the magnitude of projected climate change impacts on wildlife habitat and tenable options for ameliorating those impacts. Our research developed that information through reviews of the climate change literature and the State Wildlife Action Plans (SWAPs), and a series of empirical studies that quantified the stress associated with climate-induced changes in terrestrial wildlife habitat. Our terrestrial climate stress index includes climate shifts (precipitation, temperature), habitat area shifts, and changes in habitat quality (vegetation production). We used information on current stresses, including barriers to dispersal associated with current land use patterns and the prevalence of terrestrial vertebrates that are at risk of extinction, to compare areas under current stress to areas under future stress from climate change. We drew upon the scientific literature, the SWAPs, and our stress index to make recommendations to modify proposed actions or identify additional management options that will help minimize climate change impacts to habitats and species.

III. Purpose

The specific purpose for this project was to develop information, methods and analyses to provide state wildlife agencies with information on the magnitude of projected climate change impacts on terrestrial wildlife habitat and tenable options for ameliorating those impacts.

IV. Summary of Results

A. Literature Review

Few on-the-ground management recommendations are offered in the scientific literature for specific regions, habitats, or species. While specific recommendations were rare, many general recommendations were prescribed in the literature. The most commonly prescribed actions for reducing the impacts of climate change on natural systems include reducing emissions (policy approaches), manipulating habitat, translocations, land conservation, and increasing the resilience of natural systems via restoration (Table 1).

Regional, biome, and taxonomic biases are associated with impact papers on wildlife habitat. Regions of the U.S. are evenly covered in the climate change literature, with the exception of Hawaii. The most common biomes investigated were forests (58 references), grasslands (26 references), and savanna (23 references). In the larger dataset (828 references, not restricted to habitat studies), birds were more often the focus of investigation than any other taxon (183 references), versus 102 for mammals, 56 for amphibians, 68 for invertebrates and 23 for reptiles. Our habitat database (73 references) encompassed 9 mammal studies, 7 bird studies, and 1 amphibian study; all other studies (60) did not specify wildlife taxa but instead focused on changes in habitat type or vegetation.

Table 1. Comparison of management recommendations made in the scientific literature and in the State Wildlife Action Plans to address the threat of climate change

	Literature		SWAPs	
Management Recommendation[1]	No.	Percent	No.	Percent
ON-THE-GROUND				
Habitat manipulation	9	12.5	3	6.0
Translocation	9	12.5	1	2.0
Land conservation	8	11.1	8	16.0
Restoration	8	11.1	10	20.0
Adaptive management	6	8.3	1	2.0
Connectivity	4	5.6	2	4.0
Biodiversity maintenance	2	2.8	0	0.0
POLICY				
Slow climate change	10	13.9	8	16.0
Other policy	4	5.6	13	26.0
COMMUNICATION/EDUCATION				
Collaboration	6	8.3	8	16.0
Inform managers	1	1.4	1	2.0
Education	0	0.0	8	16.0
RESEARCH				
Modeling	23	31.9	1	2.0
Other research and monitoring	17	23.6	15	30.0
Monitor to detect threshold	7	9.7	1	2.0
OTHER[2]	13	18.1	10	20.0
SUMMARY				
Management recommendations	31	43.1	21	42.0
No recommendations	23	31.9	25	50.0
ONLY research	18	25.0	4	8.0
TOTAL	72	100.0	50	100.0

Currently documented terrestrial wildlife response to climate change is not reflective of future projected climate stress. Documented impacts of climate change to terrestrial wildlife populations (Fig. 1) may reflect geographical and taxonomic biases in monitoring effort rather than the relative effects of climate stress already felt by wildlife or potential future effects of climate stress (Fig. 3). Taxonomic differences in their response to climate change, however, are already evident, with some high-elevation mammal populations extirpated, birds and insects expanding their ranges northward, and insects making overseas migrations to new areas. Other documented responses include changes in morphology and behavior.

1 Standardized terminology described in Appendix I
2 When a recommendation did not clearly fit into one of the other categories, we listed it as OTHER

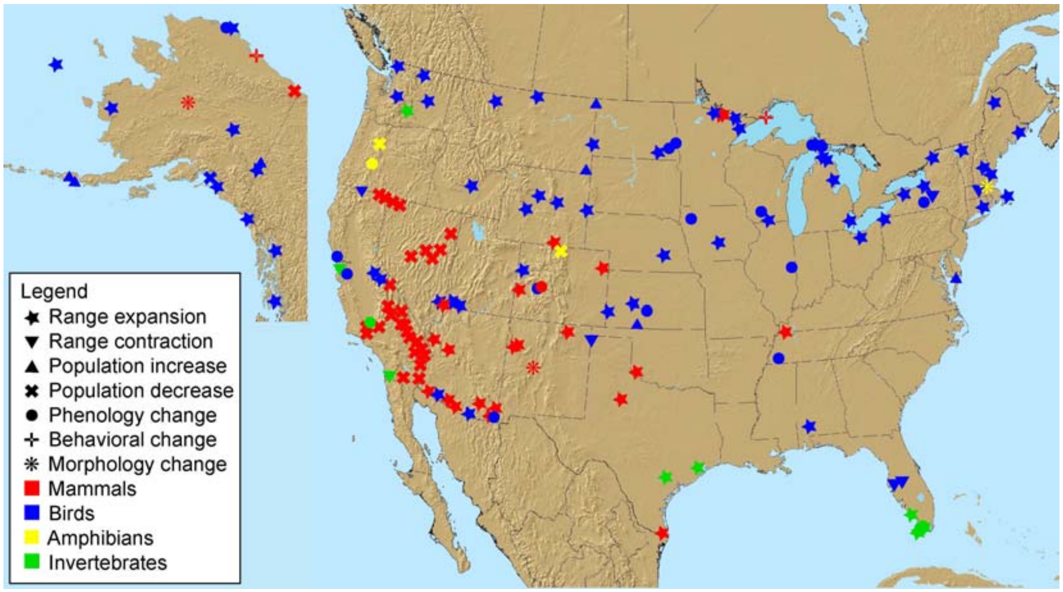


Figure 1. Documented terrestrial wildlife response to observed changes in climate, based on 189 studies within the United States. No studies included Hawaii.

B. State Wildlife Action Plans

The approach of State Wildlife Actions Plans (SWAPs) towards climate change as a threat to terrestrial wildlife conservation varied greatly, both within and among SWAPs. Twenty-eight states did not address climate change as a threat, beyond a mention (< 3 in Fig. 2), while the remaining 22 states addressed it to varying degrees. States that addressed climate change focused on a varied set of potential threats associated with climate change: 42% of the states identified terrestrial wildlife range shifts; 40% identified changes in air and water temperature; 36% identified changes in precipitation; 28% of the states identified sea level rise as a threat from climate change (67% of coastal states identified this as a threat); 20% identified increases in severe storm frequency and magnitude.

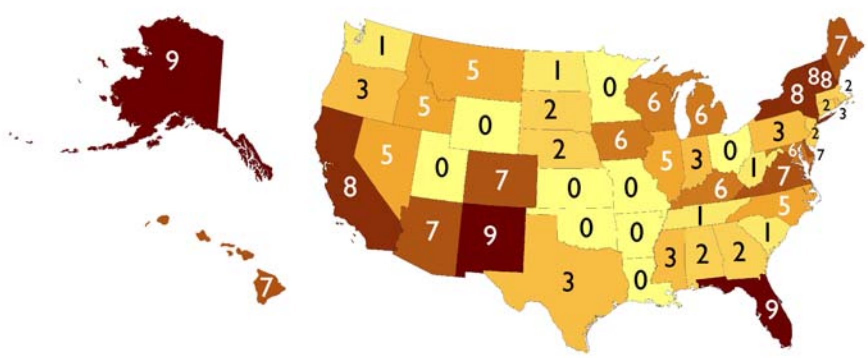


Figure 2. Level of climate change assessment in each SWAP where no mention was 0 and increasing numbers implied increasing assessment (see Table 4 for code definitions).

Potential impacts of climate change are multiple and interacting; recommendations offered in the SWAPs to address climate change need to be expanded to address the diversity of potential impacts from climate change. Many SWAPs focused only on one or a few particular aspects of climate change. For example, Arizona identified drought as the primary threat from climate change and made extensive recommendations for decreasing the impacts of drought on wildlife and wildlife habitat. Recommendations in the SWAP for species in high elevation forested habitats are also specific to drought, however, even though other climate change impacts (e.g., habitat loss) are more potent threats for this habitat. An analysis that integrates the consideration of multiple climate change threats in each habitat and area would offer states a mechanism by which to identify a suitable suite of management recommendations for wildlife habitat under climate change.

Management recommendations in the SWAPs to address non-climate change threats to terrestrial wildlife need to be integrated with those management options for climate change. The impacts of climate change may affect the success of management recommendations for other stressors. For example, a number of SWAPs included recommendations to maintain or acquire particular types of habitat, or to reintroduce extirpated populations to parts of their historical range. The potential success of such recommendations could be increased by considering long-term impacts of climate change to the area and focusing efforts in areas that might be more likely to remain stable. Similarly, maintaining connected areas that encompass a range of elevations and/or latitudes could allow species to shift their ranges over time, thereby increasing the success of management efforts in maintaining population viability.

Across all 50 states, a total of 7,696 terrestrial vertebrate taxonomic entries were identified in the SWAPs as species of greatest conservation concern (SGCC). Birds comprised 57.5% of the entries, followed by mammals (19.2 %), reptiles (14.1%), and amphibians (9.2%). Surprisingly, nearly 84% of the cumulative list of SGCC was considered to be “apparently secure” or “demonstrably widespread”. Only 17% of the entries identified species that had at least a moderate extinction risk. A total of 217 (2.8%) SGCC entries were specifically identified as being potentially impacted by climate change (see Appendix A).

C. Identifying Climate Change Stress Nationally

The terrestrial climate stress index can be used to identify areas of relatively high or low stress across the coterminous U.S. in a consistent and repeatable manner. Such information could provide managers with information on potential habitat impacts within regions and a state, including the uncertainty associated with these identified impacts, the underlying causes of that uncertainty (climate shifts, changes in habitat area, or changes in habitat quality) and the geographic range of the greatest and least stress areas. Such information can be integrated with the geographic location of current stressors such as intensive land use or with areas having large numbers of SGCC to evaluate future climate change threats with existing threats to wildlife habitat management.

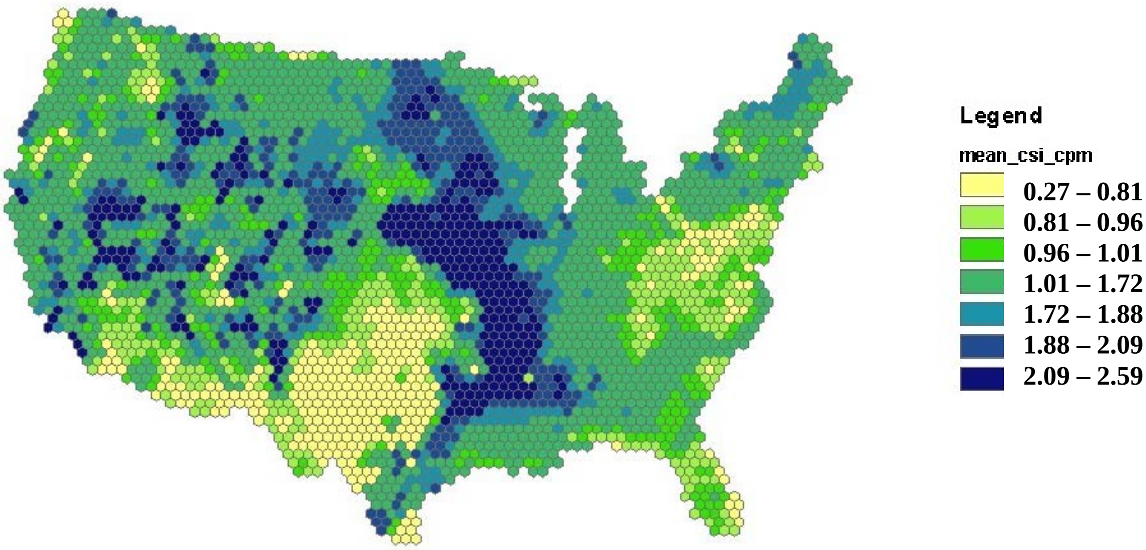


Figure 3. Composite Terrestrial Climate Stress Index. Indices from 12 different climate scenarios were averaged to produce this composite figure of hot spots of climate stress in the US. The top 10 percent stress areas (shown in dark blue) correspond to a TCSI rating of greater than 2.09.

The most sensitive terrestrial areas in the coterminous U.S. to climate change are associated with transitions between major biomes and in the areas of high topographic relief (Fig. 3). The least sensitive geographic areas on this relative scale were in the southern Great Plains, the Appalachian Mountains and the eastern coast of Florida. The states with the greatest proportional area in relatively high climate stress include Missouri and Arkansas and the least stress include the states of Texas and Oklahoma.

Variation in the terrestrial climate stress index (as a composite of the 12 scenarios) is generally low in high stress areas and high in low stress areas (Fig. 4). The 12 scenarios were derived from 3 global climate models, 2 economic scenarios that affect greenhouse gas emission levels and 2 ecological assumptions that affect plant growth sensitivity to elevated CO_2. Observed variation in the climate stress index among the 12 scenarios could be most ascribed to variability among the three climate models we examined. High climate stress areas across the coterminous United States were driven primarily by productivity/habitat shifts in the east and by all three factors (temperature/precipitation, productivity, habitat shifts) in the west.

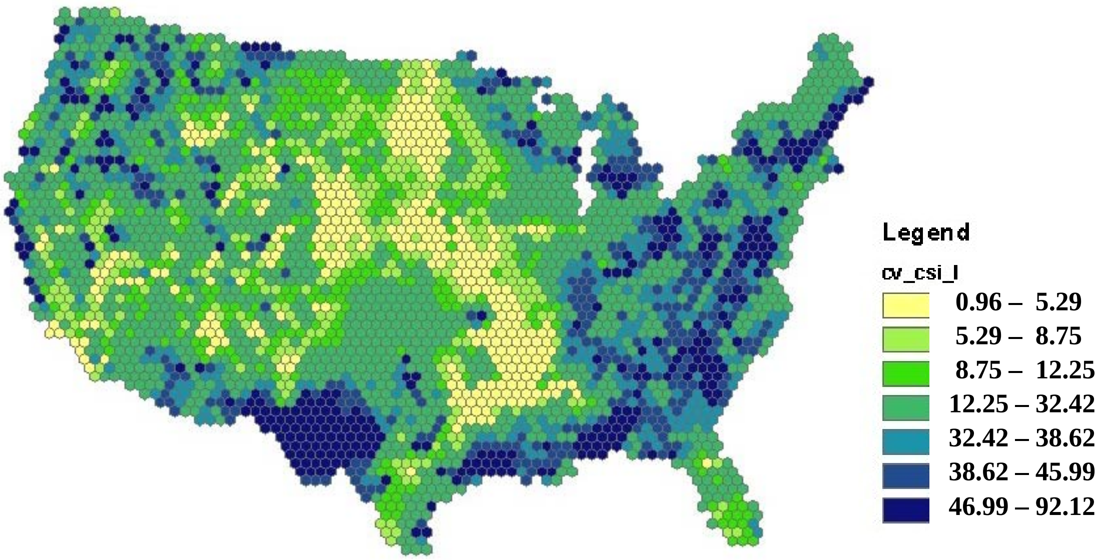


Figure 4. Coefficient of variation for the Composite Terrestrial Climate Stress Index based on 12 scenarios. Highest variation is shown in the dark blue.

D. Identifying Climate Stress on Terrestrial Wildlife Habitats within a State

The case study states sort into two groups: those where habitat losses or gains attributable to climate change were rare events (AZ, MN) and those where habitat compositional shifts dominated (TN). Across the 12 scenarios that we analyzed, Arizona and Minnesota both supported eight vegetation types while Tennessee supported two (Table 2) during the recent historical period (1950-1999). Arizona was the only state that lost a habitat type that historically occurred within its borders (Table 3).

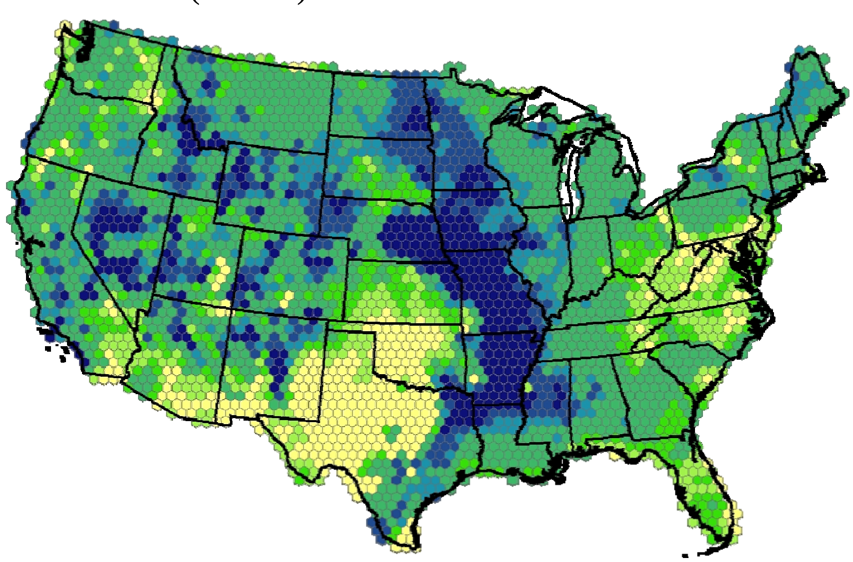


Figure 5. Composite Terrestrial Climate Stress Index as shown in Figure 3 (same legend) but with state boundaries.

Table 2. Number and fate of habitat types occurring in case-study states. Rate of habitat loss and gain represent averages across the 12 scenarios.

State	Historical Habitat Types Present	Habitat Types Lost per Scenario	Habitat Types Gained per Scenario
Arizona	8	0.58	0.75
Minnesota	8	0	1.17
Tennessee	2	0	3.92

All states gained habitat types that did not occur historically (Table 3). However, habitat gains were a much more prominent feature of Tennessee's predicted vegetation dynamics. On average, Tennessee was projected to gain nearly four habitat types by 2099 for each scenario.

Table 3. Identification of habitat types gained or lost from case study states (see Appendix B for further descriptions of the habitat types)

State	**Habitat Types Lost**	**Habitat Types Gained**
Arizona	Temperate mixed xeromorphic woodland	Continental temperate coniferous forest Tropical thorn woodland Warm temperate/subtropical mixed savanna
Minnesota		Temperate subtropical deciduous savanna Subtropical arid shrubland
Tennessee		Continental temperate coniferous forest Cool temperate mixed forest Warm temperate mixed forest Temperate mixed xeromorphic woodland Temperate conifer xeromorphic woodland Temperate subtropical deciduous savanna Warm temperate/subtropical mixed savanna Temperate conifer savanna

The state-level climate stress index can be used to identify habitats where stress, including species imperilment and land use, is high or low within the state. Adaptation of our national terrestrial climate change index to evaluate the relative stress to specific habitat types that occur within case study states will provide managers and policy analysts with information on which habitats are most at risk to the threats posed by climate change. Analysis of the contribution from each of the six terms that comprise the habitat-level stress index can also inform planners about the factors that contribute most to the stress index score.

In Arizona, the habitat type with the highest climate stress index was temperate mixed xeromorphic woodland (Appendix B, Table B-1). The high score assigned to this habitat ($TCSI_{ij}$= 4.0) is attributable to both habitat overlap (which would be expected to constrain a species' ability to move with the habitat under climate change) and climate shift. Whereas temperate mixed xeromorphic woodland is a rare habitat type in Arizona (only occurring in five of the 12 scenarios), temperate arid shrubland, the second most stressed habitat, is more prominently represented across all 12 scenarios. This habitat score ($TCSI_{ij}$= 3.5) was the result of habitat area shifts, low habitat overlap, and climate shifts.

In Minnesota, C4 grasslands had the greatest stress ($TCSI_{ij}$= 4.4) attributable to climate change (Appendix B, Table B-2). Migration resistance due to human land use intensification, habitat area, low habitat overlap, and climate shift all contribute to this types' high stress index. Interestingly, boreal coniferous forest had the lowest climate stress index ($TCSI_{ij}$= 2.0). Migration resistance, habitat overlap, and climate shifts all scored low relative to the other habitat types in the state. Although scores linked to prevalence of at-risk species and production shifts are high in boreal coniferous forest, they did not offset the low scores associated with the other factors contributing to the overall climate stress index.

Because Tennessee was dominated by gains in new habitat types, there were only two habitat types that could be evaluated by the climate stress index (Appendix B, Table B-3). C4 grassland had the highest climate stress score ($TCSI_{ij}$= 3.7) due to the contribution from migration resistance, habitat area, and habitat overlap.

Management recommendations in Arizona's SWAP (the only case study state that made recommendations) were generally congruent with our model results and similar to those in the literature. Both temperate xeromorphic mixed woodland (including juniper woodland and pinyon pine woodland) and temperate arid shrubland (including big sagebrush and desertscrub) were identified in Arizona's SWAP as habitats potentially impacted by climate change (Appendix C), in addition to rating high for climate stress under our CSI. Arizona's SWAP recommended improving land-use policies, reducing greenhouse gas emissions, and increasing monitoring efforts to detect changes. In addition, the plan recommended purchasing water rights for wildlife, maintaining watershed integrity, identifying drought-sensitive species and climate-sensitive species, and educating the public on water conservation.

There were no management recommendations in the literature, specific to the desert southwest. Many recommendations, however, were generally applicable across regions, states, and habitats. The literature recommended that managers should be flexible (Julius et al. 2008), that is to develop contingency plans and monitor for uncertain futures (Bachelet et al. 2001a). A review and revision of data collection associated with monitoring would assist in the design to detect change associated with climate as well as with other threats. Experts also recommend limiting land conversions, reducing external stressors to sensitive habitats, changing land-use policies, and managing current habitat as a reservoir until suitable habitat can be established elsewhere (Hansen et al. 2001). Many authors pointed out that reducing greenhouse gas emissions is the most effective approach to maintaining intact ecosystems and viable species (Malcolm and Markham 2000, Hansen et al. 2001).

Some non-climate motivated recommendations made in the SWAPs remain relevant under climate change scenarios. C4 grasslands were identified in our index as habitats of especially high climate stress in both Minnesota and Tennessee (Appendix D and E). No management recommendations were found in the literature specific to grasslands, but the general recommendations listed above are applicable to this biome. Quite a few recommendations made in the SWAPs, but not specific to climate change, are highly applicable to C4 grasslands in Minnesota and Tennessee, including maintaining and improving connectivity, decreasing human-induced stressors, especially land cover change, pollution, and water stress, promoting biological diversity, controlling invasive species, restoring natural fire regimes, working with private landowners, and land conservation.

Many recommendations made in the SWAPs potentially conflict with recommendations that would be made under climate change. The Minnesota, Tennessee, and Arizona SWAPs, as well as many SWAPs for other states, list management recommendations that are suitable under a stable climate, but are likely to fail or be highly risky under a changing climate. For example, Minnesota focuses conservation efforts on core areas that currently or historically supported SGCC, while peripheral populations are at risk due to a lack of conservation effort. As the climate changes, and species shift their ranges in order to find suitable habitat conditions, peripheral populations and habitat areas may increase in importance. They also suggest stabilizing and increasing SGCC, yet many species will not be viable under climate change. Similarly, Tennessee suggests reintroducing extirpated populations of SGCC to their historical range, but such reintroductions could be prone to failure if the future climate of the area is not taken into consideration. Tennessee's SWAP, similar to numerous other SWAPs, recommended an ecosystem–based approach to conservation. While an ecosystem-based approach is a valuable tool in the conservation of unique habitats, and can be adjusted to address climate change, it may fail to protect individual SGCC because species are expected to respond to different components of climate change, potentially causing the reorganization of ecological communities (Williams et al. 2007). Both Minnesota and Tennessee suggest acquiring priority tracts of habitat. While this approach is vital for near-term conservation of SGCC, it may not guarantee long-term protection. Continued species viability may depend on additional land acquisitions that allow for range shifts among SGCC. We did not see any potential conflicts in the Arizona SWAP, but numerous conflicts were apparent in the other 47 SWAPs we reviewed.

E. Communication of Findings and Applications

Communicating our project findings targeted a diverse set of audiences. We established an Advisory Board, including the liaisons, John Kostyack, and Dennis Figg (Appendix F). Members of the Advisory Board were invited from other federal agencies, state agencies, and universities. We presented various aspects of our project in 11 formal presentations to a variety of audiences including: professional scientific societies (The Wildlife Society, the American Geophysical Union, the American Ornithologists' Union); Federal and State natural resource managing agencies/organizations (Organization of State Wildlife Planners, Association of Fish and Wildlife Agencies [Midwest Region]; Federal and State Agencies in Wyoming and Colorado); and non-governmental conservation organizations (The Nature Conservancy, NatureServe). For a full list of presentations see section IV (Deliverables).

Less formal consultations and interactions also contributed to the communication of our project's findings. We interacted with three state governments (California, Minnesota, Wyoming), two federal land managing agencies (U.S. Fish and Wildlife Service, U.S. Forest Service), one international government (Uganda Wildlife Authority), four non-governmental organizations

(The Nature Conservancy, Izaak Walton League of America, NatureServe, National Center for Conservation Science and Policy), one federal government appointed advisory committee (Sporting Conservation Council), and four academic/research institutions (University of Maryland, University of Washington, National Center for Ecological Analysis and Synthesis, and the Climate Leadership Initiative of the University of Oregon), all of which increased the exposure of our project. A full list of contacts associated with this project is available in Appendix G.

Potential applications of our project have focused primarily on the question: Where should we site wildlife conservation activities to address anticipated climate change impacts on wildlife habitat? We have interacted with a number of resource managing agencies and organizations (U.S. Fish and Wildlife Service, Western Governors' Association, NatureServe, National Geographic Society, and The Nature Conservancy Wyoming Chapter) that have expressed an interest in the use of our terrestrial climate stress index to potentially inform the siting and evaluation of land management. A summary of these evolving applications is as follows:

> 1. The U.S. Fish and Wildlife Service (contact: Dr. Brian Czech, Conservation Biologist, National Wildlife Refuge System) is considering the use of our stress index to inform the Agency's Land Acquisition Program that evaluates extant and prospective additions to the Refuge System.
>
> 2. The Science Committee of the Western Governors' Association Wildlife Cooridor Initiative (contact: Mary Klein, President and CEO, NatureServe) is considering the use of our stress index to help identify where wildlife corridors are needed to accommodate climate change.
>
> 3. An alliance between NatureServe and the National Geographic Society (LandScope; contacts: Dr. Bruce Stein, Vice President and Chief Scientist, NatureServe; and Frank Biasi, Director, Conservation Projects, National Geographic Society) to advance conservation education has requested use of our coterminous U.S. map of climate stress to depict where climate change may be a particularly important threat to wildlife habitat.

Another application of our research is to prioritize regions of the U.S. for building climate change adaptation strategies. We are working closely with a number of organizations that strive to develop strategies for regional climate change adaptation. The Climate Leadership Initiative at the University of Oregon (Contact: Bob Doppelt) and the National Center for Conservation Science and Policy (Contact: Dominick DellaSala) have come together with the USFS Pacific Northwest Research Station MAPSS team (Contact: Ron Neilson) and ourselves to develop a series of workshops, called Climate Futures Forums, that are generally held at the watershed scale, and bring together experts in natural resources with economic, human, and infrastructure systems representatives to develop an integrated approach to climate change preparation (adaptation). While the workshops were developed as a pilot project in Oregon, with support from the Governor's Climate Change Commission, they are being extended to other parts of the country with our climate stress index, imperiled species assessment, and SWAP review as drivers for geographical prioritization.

F. Future Research Direction

Use of the terrestrial climate stress index to inform policy, planning, and management would benefit from increasing the resolution of the analysis; spatially and thematically.

Incorporating other stress factors (e.g., seasonality of climate, drought potential, fire potential, hydrology) would extend the applicability of the terrestrial climate stress index.

The terrestrial climate stress index could be expanded to encompass aquatic and coastal habitats and threats specific to these systems, such as water temperature, alterations in stream flow, sea level rise, as well as the potential effects of climate change on terrestrial systems impacting aquatic systems (changes in riparian habitat cover increasing stream temperatures).

Inclusion of Hawaii and Alaska in an assessment of climate risk would assist efforts to project climate impacts and develop preparation strategies in those states, both of which are likely to be especially sensitive to climate impacts.

Strong research-management partnership would enhance the management application of scientific research as well as the direction of research to address climate change and wildlife habitat management

Focused efforts are needed to evaluate the merits of specific management actions (e.g. translocation or enhancing resilience) to climate change impacts.

G. Acknowledgements

We would like to thank John Kostyack for his reviews of our on-going work, and Dennis Figg for sharing his insights into the management of wildlife at the state level. The study would not have been possible without the use of the modeling results from Ron Neilson's MAPSS team, and we would like to thank Ron Neilson and Ray Drapek especially, for facilitating access to the data and helping with its interpretation. We would also like to acknowledge the members of the Advisory Board for their review comments throughout the study, in particular Dave Theobald for his insights into equal area spatial analyses, and Dennis Figg, Dominique Bachelet, and Ron Neilson for offering comments on an earlier version of this final report. . Funding was provided by the Wildlife Habitat Research Policy Program and the USDA Forest Service.

V. Approach

A. Literature review of projected climate change impacts to wildlife habitat and of recommendations for management

We compiled two primary types of literature for the literature review; literature that explored the impact of climate change on habitats or biomes and literature that explored the impact of climate change on habitat for specific species of wildlife. Our choice of keywords ensured that we captured studies where vegetation was the primary focus of the study, as well as studies where a wildlife species was selected first and then the habitat impacts were studied. Our search included peer-reviewed journal articles, book chapters and gray literature such as government or non-governmental organization reports. Additional material was identified through the reference lists of articles in the database.

Two primary databases were developed using EndNote X.0.2[3]. The first database is a compilation of all literature, published between January 1997 and August 2008, that addresses wildlife (or wildlife habitat) and climate change, with a spatial extent that ranges from a specific region of the U.S. to the entire globe. To date, this database contains 828 references. Three hundred forty-five references are at least partially specific to the U.S and one hundred ninety-eight have a vegetation (or habitat) component.

The second database is a subset of the first and includes studies that provided projections for future distributions of biomes or habitats, as well as studies that projected future distributions or populations of species of wildlife, as long as these studies encompassed habitat variables and had a geographical range that at least partially overlapped the U.S. Climate envelope models that bypassed habitat change as the driving factor of distributional change among wildlife populations were not included in this subset, but they remained in the comprehensive database. Seventy-three studies were included in the subset database of habitat projection studies. Of these 73 papers, only 10 studies specifically addressed the potential impacts of habitat changes on wildlife populations (Cameron et al. 1997, Johnston and Schmitz 1997, Sorenson et al. 1998, Epstein et al. 2000, Cameron and Scheel 2001, Burns et al. 2003, Peterson 2003, Matthews et al. 2004, Carroll 2007, Jetz et al. 2007); a few of the 10 papers did not model the relationship between wildlife and habitat, but assessed overall changes in wildlife species diversity or alluded to potential wildlife population changes due to modeled changes in vegetation (Burns et al. 2003, Epstein et al. 2000, Jetz et al. 2007). Field names for both databases are the same, and include such components as the climate model used, specific projections for habitat and wildlife population distributions, the types of uncertainty addressed, and management recommendations, among many others. A set of 94 keywords was developed to classify each piece of literature (Appendix H). Management recommendations made in the literature were partitioned into 16 categories (Appendix I). Lists of standardized keywords and management terms were developed to facilitate searches and summarization of the contents of the databases.

[3] Use of trade names does not imply endorsement

B. Review of State Wildlife Action Plans

We examined the SWAPs for all 50 states and compiled information on climate change into a database. We ranked each SWAP based on how thoroughly it addressed climate change as a threat and provided management recommendations specific to climate change (Table 4). Many states mentioned climate change (or global warming, sea level rise, or another related term) briefly but noted that the problem was too great or complex to address in the SWAP; these states received a score of 2. No states received a score of 10, as even the most comprehensive treatment of climate change in the SWAPs still was compromised by management recommendations in other portions of the document that conflicted with climate change considerations.

Table 4. Criteria used to rank each SWAP based on their approach to climate change.

SWAP rank	Criteria
0	No mention of climate change
1	Climate change mentioned, but not as a threat
2	Mentioned as a threat to consider later or in a different venue
3	Identified as a threat to just one or two species or habitats; no management action identified
4	Mentioned as a threat to just one or two species; management recommendations
5	Addressed for multiple taxa or habitats, but considered a low threat to all
6	Identified as a threat to many species, but no or very few management recommendations specific to climate change
7	Addressed as a threat to many species, including management recommendations, but approach was inconsistent. Possibly only some climate change impacts were considered (eg. drought or sea level rise), or climate change was considered in some regions and not others.
8	Fairly thorough assessment, but some important component still missing, such as the actual species to be affected, or inadequate management recommendations
9	Fairly thorough assessment of climate change threat that is consistent across taxa and habitats, but the SWAP still included recommendations for wildlife that conflict with climate change projections
10	Thorough, consistent assessment without conflicting management recommendations

In addition to ranking the SWAPs, information was compiled on what types of species and habitat were addressed in a climate change context, and what specific management recommendations were prescribed. Additional information of interest included the SGCC addressed under climate change, management recommendations for species or habitat that may conflict with climate change projections, what scientific information was used to make climate change inferences, and whether other management recommendations made in the SWAPs might remain relevant under climate change.

C. Species of Greatest Conservation Concern Database

A systematic examination of State Wildlife Action Plans was completed to identify the cumulative list of terrestrial vertebrate wildlife species of greatest conservation concern. There were four key methodological steps in the creation of this database: species compilation, taxonomic reconciliation, determination of taxonomic level, and update of conservation rankings.

Species compilation – Species (and infraspecies) and associated attributes (Fig. 6) were manually entered into a Microsoft Access © database from 50 state SWAPs. A total of 7,696 taxonomic (species or infraspecies) entries were compiled. This count reflects the total number of entries and does not adjust for multiple entries of the same species (or infraspecies) among states.

Geography	Species Name						Taxonomic Class	Origin	NatureServe Ranks			Climate Change Identified as a Threat to this Species in SWAP (1=yes; 0=no)
State	Common Name	Genus	Species	Subspecies	Population	Taxonomic Level[1]	Bird/Mammal/Amphibian/Reptile	Native/Exotic	G-Rank	N-Rank	S-Rank	

[1]This column identifies the taxonomic level for a particular entry in the databased and distinguishes species listed at: (a) the species level; (b) the infaspecies level but considered a *de facto* species; and (c) the infraspecies level but not considered a *de facto* species. A *de facto* species identifies those infraspecies (entries below the species level, e.g., subspecies or species populations) that are effectively a species designation for a particular state. This occurs when: an infraspecies is monotypic with the state (i.e., it represents the only infraspecies that could occur in that state); infraspecies is polytypic (i.e., multiple infraspecies occur), but all infraspecific types are listed as a species of greatest conservation concern; or the infraspecies is invalid and is recongnized as a full species.

Figure 6. Initial set of data elements for the Species of Greatest Conservation Concern database.

Taxonomic reconciliation – Congress gave the states considerable flexibility in developing conservation strategies that addressed each state's unique wildlife and management context. Because of the evolving nature of species taxonomy, naming conventions did vary across states. Following our initial entry of the scientific name of each species (infraspecies) as it appeared in the SWAP, we also compared the SWAP taxonomy against NatureServe's Central Databases to ensure that all species of concern identified by the states were referenced with a common taxonomic standard (NatureServe 2008b).

Taxonomic level – States often listed subspecies (or populations) as the taxonomic entry for a "species" of greatest conservation concern. In order to compare across states we needed a process whereby references to a SGCC could be made consistent at a common taxonomic level. For example, a state that chose to identify SGCC at the subspecific level may have a greater number of entries due solely to the fact that their criteria considered the infraspecific level to be important. The entry for taxonomic level is a coding scheme that would allow queries of species counts to account for differences in taxonomic resolution. We used a number of sources to identify the taxonomic level code for infraspecific entries in the database including: NatureServe, Integrated Taxonomic Information System, museum records, and state biodiversity databases. See the data dictionary for taxonomic level code definitions in Appendix J.

Current conservation ranks – States identified SGCC using a number of criteria that varied from state to state. In order to compare the degree of conservation risk among the species identified in each state as SGCC, we needed a common assessment of conservation status. Following taxonomic reconciliation, we imported the current (as of 03 April 2008) conservation ranks based on NatureServe's criteria at the global, national, and state scales (NatureServe 2008b). The taxonomic reconciliation process and the updating to current conservation ranks expanded the data elements originally proposed (cf. Fig. 6). The expanded data elements are defined in Appendix J.

D. Analysis of Climate Stress on Terrestrial Vertebrates

We define future terrestrial climate stress associated with climate change as the degree of change between the recent history and the projected future. Wildlife habitat is influenced by climate, both temperature and precipitation. Habitat characteristics important to wildlife include the vegetation biomass or production of the habitat, as well as the habitat type. Any changes in climate, vegetation production, or the area of the habitat type will influence the suitability of habitat for associated wildlife. We define current stress on efforts to conserve biodiversity in the face of climate change as the proportion of at-risk species in the terrestrial faunal pool and the land use constraints on wildlife movement. We use both future and current stresses in our analyses.

Historical climate data and future climate scenario analysis data are from the VINCERA (Vulnerability and Impacts of North American Forests to Climate: Ecosystem Responses and Adaptation) project (http://www.fes.uwaterloo.ca/research/vincera/) (Bachelet et al 2008, Lenihan et al. 2008) and were provided by Ron Neilson[4]. The historical climate data (1901-2000) were interpolated from original climate station records from Meteorological Service of Canada and US Weather Service and summarized for 0.5 degree latitude by 0.5 degree longitude grids across the U.S (McKenney et al. 2006). Three different climate models were used: CGCM2, a product of the Canadian Centre for Climate Modelling and Analysis, CSIRO-Mk2, a product of the Australian Commonwealth Scientific and Industrial Research Organization, and HadCM3, a product of the UK Hadley Centre for Climate Prediction and Research.

Two economic scenarios from the set of emission scenarios developed in the Special Report on Emission Scenarios (IPCC 2000) were used: A2 and B2. The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in a continuously increasing global population. Economic development is primarily regionally oriented and per capita economic growth and technological changes are more fragmented and slower than in other storylines. The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with continuously increasing global population at a rate lower than A2. While the scenario

[4] Ronald P. Neilson, Bioclimatologist, USDA Forest Service, 3200 S.W. Jefferson Way, Corvallis, Oregon 97331

is also oriented toward environmental protection and social equity, it focuses on local and regional levels. Global temperatures are warmer in the A2 scenario than the B2 scenario. Scenario data were available from 2001 to 2100 from CGCM2 and CSIRO-Mk2 and from 2001 to 2099 for the HadCM3 model.

Future projections of vegetation biomass and habitat area are from the dynamic global vegetation model MC1 (Bachelet et al. 2008, Lenihan et al. 2008), one of the models used in the VINCERA project. MC1 is a dynamic global vegetation model capable of assessing the impacts of climate change and disturbance (fire, drought) on biogeochemistry within ecosystems and on biogeographical shifts (Bachelet et al. 2001b). Biogeochemical processes (nutrient cycling) influencing vegetation production are simulated using a modified version of the CENTURY model (Bachelet et al 2001a). MC1 uses a set of physiologically based biogeography rules to determine which lifeforms (grass, forb, shrub, tree type) compete for resources and combine to project the occurrence of up to 26 vegetation types appropriate for the climate. A fire module determines if fuel loads and fuel moisture are conducive to fire, as well as the intensity, size and specific ecosystem impacts of the fire, including quantification of combustion products. Vegetation type can be modified and changed through fire and through extreme moisture stress on an ecosystem. We focused on the twenty-two vegetation classes that could potentially occur in the conterminous U.S. over time as determined by the VINCEREA project (Appendix K).

In the VINCERA project, MC1 simulated the impacts of potential climate change through the 21st century under the three climate models (CGCM2, HadCM3, CSIRO-Mk2), and two emission scenarios (SRES A2 and B2) (Bachelet et al. 2008, Lenihan et al. 2008). In addition, MC1 has the capability to explore the influence of increasing levels of atmospheric carbon dioxide concentration on plant growth. Two ecological scenarios were used: low plant response to elevated levels of atmospheric carbon dioxide and high plant response to elevated levels of atmospheric carbon dioxide. Thus, with MC1 output, 12 scenarios were available to explore the impact of climate change on terrestrial wildlife habitat (three global circulation models with two SRES emission scenarios with two ecological scenarios).

The historical climate, projected climate, and the vegetation projections are associated with a 0.5º by 0.5º latitude/longitude grid. The individual cells within this latitude and longitude grid varying in size as one moves from the equator to the poles. The unequal area of grid cells introduces a bias when counting the occurrence of vegetation types or species within the individual grid cells. All other things being equal, larger grid cells (low latitudes) will support more vegetation types or more species than smaller grid cells (high latitudes). To eliminate this area bias, we reprojected all data from geographic coordinates to an Albers Equal Area projection. We partitioned geographic space into hexagonal grids whose area approximately equaled that of a 0.5º by 0.5º latitude/longitude grid cell located at the geographic center of the coterminous U.S. Two states were not included in this analysis: Neither climate or vegetation projection data were available for Hawaii; Alaska had only incomplete current land cover data. We chose a hexagonal grid to remove the well-known distance bias associated with rectangular grids. Namely, distance among centroids of neighboring grids vary depending on direction (diagonal neighbors are further apart). Partitioning our study area into equal area hexagons thus removed both the area and directional biases that would have been present if we remained in geographic coordinates. There were a total of 3346 hexagons within the coterminous U.S. We refer to an individual hexagon cell as a hex hereafter.

The Terrestrial Climate Stress Index (TCSI) is the sum of three separate terms that reflect changes in temperature, precipitation, habitat area, and habitat quality.

The TCSI is computed for each hex accordingly:

$$TCSI_i = CS_i + P_i + A_i$$

where

> i = the individual hexagon grid, i =1 to 3346.
>
> CS_i = climate shift measured as the Mahalanobis squared distance (Manly 2005: 62-67) of the historical (1950-1999) and future (2050-2099) annual means of precipitation and temperature.
>
> P_i = production change measured as the standardized Euclidean distance of the historical (1950-1999) and future (2050-2099) monthly mean of live vegetation carbon in December.
>
> A_i = area change in habitat type based on the proportion of vegetation types in the historical period as compared to the proportions in the future using the Morisita-Horn similarity index (Magurran 2004: 174-175) which has a value of 0-1 where 1 equals identical similarity. Habitat change is represented by one minus Morisita-Horn similarity index.

Each component (*CS, P, A*) has equal weight and a range of values from 0-1, thus the TCSI index ranges from 0 to 3. Maps are displayed using the quantile approach where the hexagons are color coded representing the highest 10% TCSI, next 10%, next 10%, next 40%, next 10%, next 10% and then the lowest 10% class.

The MC1 output was used to estimate the Terrestrial Climate Stress Index (TSCI) associated with each of the 12 scenarios. We then averaged the results across the scenarios to produce a composite TCSI map with an estimate of the variability associated with each hex. In addition, we explore the sources of that underlying variability by determining which component (climate, habitat type and vegetation production, or climate model and ecological scenario) generated the greatest variability in the determination of the TCSI.

In addition to quantifying future climate stress with TCSI, we also quantified two current stressors that could affect how state wildlife agencies plan and manage wildlife resources in the face of climate change. These current stressors include the <u>prevalence of at-risk species</u> and the <u>migration resistance</u> that current land use activities may have on the ability of species to move across the landscape in response to climate change. The prevalence of at-risk species was estimated as the proportion of species considered to have a moderate to high risk of extinction according to NatureServe's Conservation Ranks (http://www.natureserve.org/explorer/ranking.htm#interpret). At-risk species are defined as those with global ranks of G1 (critically imperiled), G2 (imperiled), or G3 (vulnerable). We used NatureServe's Central Databases to enumerate potential species occurrence of terrestrial vertebrates within each hexagonal grid based range map data for each species (NatureServe 2008a). The prevalence of at-risk species was simply the proportion of the total species pool within each hexagon that was classified as at-risk. Migration resistance was estimated as the proportion of the terrestrial land base that is classified as land cover considered to be reflective of intensive human use. Estimates of migration resistance were based on the National Land Cover Data (Homer et al. 2007), a 21-class land-cover scheme derived from Landsat Thematic Mapper satellite data (30-m resolution). The proportion of land cover in intensive land uses (agriculture and developed land) within each hexagon was used as an index of how difficult it may be for a species to move across the landscape.

E. Case Study Analysis

Selection of case study states – Four criteria were considered in the selection of states for a more detailed case study analysis of climate change stress on terrestrial wildlife habitat including:

1. Geography – We selected one state from each of three geographic regions (Fig. 7).

Figure 7. Broad geographic regions for case-study state selection. Bolded state boundaries identify case-study states.

2. National terrestrial climate stress index score – Candidate states had a range (low to high) of TCSI scores within the state boundary. This would ensure that habitats within each state would likely have some variation in the habitat-level stress score.

3. Current stressors – We selected states that had either high migration resistance or a high proportion of at-risk species so that we could address important management issues that we knew were present within the habitat types occurring within the case-study states.

4. State Wildlife Action Plan – We selected states that addressed climate change to varying degrees in the SWAPs so we would have a range of management recommendations to evaluate against our literature review.

Based on those four criteria we selected Arizona, Minnesota, and Tennessee as our case-study states.

Habitat-level estimation of terrestrial climate stress – This phase of the study was comprised of a series of analyses that adapted our national TCSI in a way that allowed us to rank habitat types occurring within case-study states from low to high relative climate risk. For each habitat type within a case-study state we: (1) defined the habitat's current climate; (2) defined the habitat's future climate; (3) predicted the habitat's distributional and productivity changes induced by climate change; (4) estimated the amount of intensive land uses within each habitat type that could restrict species movement; and (5) estimated the proportion of at-risk terrestrial vertebrates (i.e., those species with a moderate to high extinction risk according to NatureServe's conservation ranks) that were determined to be affiliated with the habitats occurring in a state. The habitat types that each terrestrial vertebrate was associated with were also determined from NatureServe's Central Databases (NatureServe 2008c).

These estimated quantities for each habitat type were combined into a habitat specific terrestrial climate stress index as given by:

$$TCSI_{ij} = \sum (CS_{ij}, P_{ij}, A_{ij}, HO_{ij}, MR_{ij}, ARspp_{ij}),$$

where,

i is the i^{th} case study state and j indexes the habitat types within a state.

CS_{ij} = climate shift quantified as the Mahalanobis squared distance of the historical (1950-1999) and future (2050-2099) annual means of precipitation and temperature among those hexagons occupied by vegetation type j over the historical period.

P_{ij} = change in vegetation production quantified as the standardized Euclidean distance of the historical (1950-1999) and future (2050-2099) monthly means of vegetation carbon in December among those hexagons occupied by vegetation type j over the historical period.

A_{ij} = proportionate gain or decline in a habitat type between the historical (1950-1999) and future (2050-2099) periods, where the initial area occupied by habitat j is compared to the area occupied in the future location of habitat j.

HO_{ij} = proportionate habitat overlap between the historical (1950-1999) and future (2050-2099) footprint of vegetation type j. Overlap (*HO*) was measured as the number of shared hexagons between time periods divided by the maximum of the historical or future footprint. Because greater overlap should reduce climate risk this term was estimated as (1-*HO*).

MR_{ij} = a measure of migration resistance that may be experienced by a terrestrial vertebrate species. Because intensive human land use categories are known to affect wildlife movement across landscapes (Ricketts 2001), this term was measured as the proportion of land area within the core vegetation footprint that was classified as developed or agricultural land. The core vegetation footprint was defined as that set of hexagons where the vegetation type was most commonly (upper quartile) present from 2000-2099

$ARspp_{ij}$ = proportion of terrestrial vertebrates that are associated with vegetation type j within state i that are considered to be at-risk of extinction.

As with the national index, each term was scaled to vary between 0 and 1 and was given equal weight in the summation. The climate stress scores for each habitat type could vary from 0 to 6. Estimates for each of the twelve climate change scenarios were averaged to obtain a composite score for each term in the habitat-level climate stress index. Habitat types occurring in each state were ranked from high (large composite score) to low (small composite score) climate stress.

Evaluation of management recommendations to address climate change impacts – We returned to the literature and SWAP databases in order to determine whether management recommendations specific to (1) the states or regions of interest; (2) SGCC from the three states; or (3) climate-sensitive habitats were available in the SWAPs or in the literature. We compiled a list of all recommendations made for those states, SGCC, and habitats, in addition to general recommendations made in the literature and SWAPs for managing wildlife populations and habitat under climate change. From this, we were able to determine whether the SWAPs had sufficient support from the literature for making management recommendations, or whether additional information and guidance is needed.

F. Documented effects of climate change on wildlife populations in the U.S.

Literature review of the documented response of terrestrial wildlife to climate change. We conducted a literature search of documented impacts of climate change to wildlife in the U.S. Included in our Excel database were studies that determined a link between climate change and wildlife, and studies that were included in review papers on the effects of climate change to wildlife, for a total of 189 citations. Information collected from each paper included the taxa of interest, the documented climate change impact, where the impact occurred (geographic coordinates), and whether there was an alternative explanation for the documented change. We collected information on mammals, birds, amphibians, and invertebrates, but found no studies of reptiles or fish. The types of impacts documented included shifts in range, changes in breeding and migratory phenology, increases or declines in population size, changes in morphology, and changes in behavior. Most changes were limited to relatively small geographic areas, and were easy to plot as a point on a map (see Fig. 1). When shifts in range occurred over an extensive area, however, a point was placed approximately in the middle of the northern range expansion and another in approximately the middle of the southern range contraction.

Many documented changes to wildlife populations had alternative explanations to climate change. The alternative explanations, however, invariably worked in concert with climate change to cause changes to wildlife. For example, some species of bats are expanding their ranges northward in response to supplemental feeding from hummingbird feeders (Davis and Callahan 1992). These same species, however, are still limited by climate as they shift in response to food availability.

VI. Deliverables

The deliverables databases, bibliographic databases, and manuscripts.

1. *Databases*

Database of the terrestrial vertebrate species of greatest conservation concern. This database is an ACCESS database and will be available based on request. This will also be posted on the USFS Rocky Mountain Research Station website.

2. Bibliographic database

Bibliographic database of the effects of climate change on wildlife and wildlife habitat. This is an Endnote database available upon request. This will also be posted on the USFS Rocky Mountain Research Station website.

3. Presentations. We list presentations given based on this project, identify if the presentation was invited, and note if and where the powerpoint presentation is available through a web site:

A. Joyce, L., C. Flather, and M. Koopman. 2007. Climate change and habitats: organizing the research. 29th Annual Meeting of the Organization of Wildlife Planners. 21-25 May 2007. Virginia Tech University, Blacksburg, VA. Invited presentation. Proceedings available at: http://www.owpweb.org/OWPpubs/ConferenceProceedings.php

B. Koopman, M. E., L. A. Joyce, and C. H. Flather. 2007. A review of management recommendations for bird populations in the face of climate change, 125th stated meeting of the American Ornithologists' Union, Laramie, WY. 9-11 August 2007. University of Wyoming, Laramie, WY. Offered presentation.

C. Flather, C. H., L. A. Joyce, and M. E. Koopman. 2007. Analyzing potential impacts of climate change on terrestrial wildlife habitat. Climate Change Science Conference, The Nature Conservancy. 5-7 September 2007. Portland, OR. Invited panel participant (Panel: Extinction, Migrants, Invasives). Presentation and Audio available at: http://www.fsl.orst.edu/~bachelet/Portland%202007%20Agenda.htm

D. Joyce, L. A., C. H. Flather, and M. E. Koopman. 2007. An approach to assessing future climate change impacts on terrestrial wildlife habitats. 14th Annual Conference of The Wildlife Society. 22-26 September 2007. Tucson, AZ. Invited paper (Symposium: Ecological Responses to Rapid Climate Change within Species, Communities, and Ecoregions; Organizers: E. A. Beever and J. L. Belant).

E. Flather, C. H., L. A. Joyce, and M. E. Koopman. 2007. Assessing impacts to terrestrial wildlife from future climate change. NatureServe Conservation Conference 2007. 1-3 October 2007. Golden, CO. Offered paper. Presentation available at: http://www.natureserve.org/visitLocal/cons_conference2007.jsp

F. Joyce, L. A., C. H. Flather, M. Koopman, D. P. Coulson, and S. Knowles. 2007. Assessing the uncertainty of future climate change impacts on terrestrial wildlife habitats. American Geophysical Union, Fall Meeting 2007. 10-14 December 2007. San Francisco, CA. Offered paper. Abstract available at: http://www.agu.org/meetings/fm07/fm07-sessions/fm07_GC12A.html

G. Flather, C. H., M. E. Koopman, and L. A. Joyce. 2008. Analyzing potential impacts of climate change on terrestrial wildlife habitat. USDA, Forest Service, Rocky Mountain Region. Renewable Resources Annual Meeting. 26 February 2008. Fort Collins, CO. Invited paper (Symposium: RR on Climate Change). Presentation available at: http://fsweb.r2.fs.fed.us/rr/vegetation_ecology/presentations/index.shtml

H. Koopman, M.E., L.A. Joyce, C.H. Flather. 2008. A review of management recommendations for bird populations in the face of climate change. Invited presentation. 12 March 2008. Seminar series, University of Wyoming.

I. Koopman, M.E., L.A. Joyce, C.H. Flather. 2008. A review of management recommendations for bird populations in the face of climate change. Offered presentation. 13 March 2008. Seminar series, Rocky Mountain Research Station, Fort Collins, CO.

J. Koopman, M.E. 2008. Potential impacts of climate change on terrestrial wildlife and habitat. Climate Change Workshop. 16 June 2008. Workshop organized by State and Federal agencies in Wyoming, over 100 attendees. Presentation available at: http://gf.state.wy.us/climatechangeworkshop/index.asp

K. Flather C. H., L. A. Joyce, and M. E. Koopman. 2008. Potential impacts of climate change on terrestrial wildlife habitat. Midwest Association of Fish & Wildlife Agencies' 75th Annual Director's Meeting. 30 June 2008. Estes Park, CO

4. Manuscripts in process

Assessing climate change impacts on terrestrial biodiversity: a composite index of future and current stress. Joyce et al. Outlet: Ecological Applications

Can the scientific literature inform State Wildlife Action Plans on climate change preparation strategies? Koopman, et al. Outlet to be decided.

Habitat affinity, taxonomy, and extinction risk among species of greatest conservation need: what is being targeted by State Wildlife Action Plans? Flather et al. Outlet to be decided.

Exploring impact of climate change on habitats within states. Authors/outlet tbd

5. Additional Products:

1. Database of all literature that links climate change to observed changes in wildlife populations in the U.S. This database is an Excel database and is available on request.

2. Database of all 50 SWAPs, plus Washington D.C., detailing each state's approach to consideration of climate change as a threat to wildlife. This database is an EndNote database and is available on request.

3. LandScope America. 2008. Conservation map of the United States: open space at risk (Map). National Geographic Society, Washington DC.

VII. References

(The following references reflect citations in the final report; see also the Literature Database for additional references of value to researchers and users, Deliverable 2 and 5)

Aber, J., R. P. Neilson, S. McNulty, J. M. Lenihan, D. Bachelet, and R. J. Drapek. 2001. Forest processes and global environmental change: predicting the effects of individual and multiple stressors. Bioscience 51:735-751.

Bachelet, D., Lenihan, J., Drapek, R., Neilson, R. P. 2008. VEMAP vs VINCERA: A DGVM sensitivity to differences in climate scenarios. Global and Planetary Change.

Bachelet, D., R. P. Neilson, J. M. Lenihan, and R. J. Drapek. 2001a. Climate change effects on vegetation distribution and carbon budget in the United States. Ecosystems 4:164-185.

Bachelet, D., J. M. Lenihan, C. Daly., R. P. Neilson, D. S. Ojima, and W. J. Parton. 2001b. MC1: a dynamic vegetation model for estimating the distribution of vegetation and associated carbon, nutrients, and water—technical documentation. Version 1.0. Gen. Tech. Rep. PNW-GTR-508. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 95 p.

Bachelet, D., R. P. Neilson, T. Hickler, R. J. Drapek, J. M. Lenihan, M. T. Sykes, B. Smith, S. Sitch, and K.Thonicke. 2003. Simulating past and future dynamics of natural ecosystems in the United States. Global Biogeochemical Cycles 17(2): Art. No. 1045.

Bergengren, J. C., S. L. Thompson, D. Pollard, and R. M. Deconto. 2001. Modeling global climate-vegetation interactions in a doubled CO2 world. Climatic Change 50:31-75.

Burns, C. E., K. M. Johnston, and O. J. Schmitz. 2003. Global climate change and mammalian species diversity in U.S. national parks. Proceedings of the National Academy of Sciences of the United States of America 100:11474-11477

Cameron, G. N., and D. Scheel. 2001. Getting warmer: Effect of global climate change on distribution of rodents in Texas. Journal of Mammalogy 82:652-680.

Cameron, G. N., J. O. Seamon, and D. Scheel. 1997. Environmental change and mammalian richness: Impact on preserve design and management in east Texas. Texas Journal of Science 49:155-180.

Carroll, C. 2007. Interacting effects of climate change, landscape conversion, and harvest on carnivore populations at the range margin: Marten and Lynx in the northern Appalachians. Conservation Biology 21:1092-1104.

Davis, R. and J. R. Callahan. 1992. Post-pleistocene dispersal in the Mexican vole (*Microtus mexicanus*), and example of an apparent trend in the distribution of southwestern mammals. Great Basin Naturalist 52:262-268.

Diffenbaugh, N. S., L. C. Sloan, M. A. Snyder, J. L. Bell, J. Kaplan, S. L. Shafer, and P. J. Bartlein. 2003. Vegetation sensitivity to global anthropogenic carbon dioxide emissions in a topographically complex region. Global Biogeochemical Cycles 17:1067.

Epstein, H. E., M. D. Walker, F. S. Chapin III, and A. M. Starfield. 2000. A transient, nutrient-based model of arctic plant community response to climatic warming. Ecological Applications 10:824-841.

Hansen, A. J., R. P. Neilson, V. H. Dale, C. H. Flather, L. R. Iverson, D. J. Currie, S. Shafer, R. Cook, and P. Bartlein. 2001. Global change in forests: responses of species, communities, and biomes. BioScience 51:765-779.

Homer, C., J. Dewitz, J. Fry, M. Coan, N. Hossain, C. Larson, N. Herold, A. McKerrow, J. N. Van Driel, and J. Wickham. 2007. Completion of the 2001 National Land Cover Database for the conterminous United States. Photogrammetric Engineering and Remote Sensing 73:337-341.

IPCC, 2000. Special Report on Emissions Scenarios. N. Nakicenovic (ed.), Cambridge, Cambridge University Press.

Iverson, L. R., and A. M. Prasad. 1998. Predicting abundance of 80 tree species following climate change in the eastern United States. Ecological Monographs 68:465-485.

Iverson, L. R., A. M. Prasad, and M. W. Schwartz. 1999. Modeling potential future individual tree-species distributions in the eastern United States under a climate change scenario: a case study with *Pinus virginiana*. Ecological Modeling 115:77-93.

Iverson, L. R., M. W. Schwartz, and A. M. Prasad. 2004. Potential colonization of newly available tree-species habitat under climate change: An analysis for five eastern US species. Landscape Ecology 19: 787-799

Jetz, W., D. S. Wilcove, and A. P. Dobson. 2007. Projected impacts of climate and land-use change on the global diversity of birds. PLoS Biology 5:1211-1219.

Johnson, W. C., B. V. Millett, T. Gilmanov, R. A. Voldseth, G. R. Guntenspergen, and D. E. Naugle. 2005. Vulnerability of northern prairie wetlands to climate change. BioScience 55:863–872.

Johnston, K. M., and O. J. Schmitz. 1997. Wildlife and climate change: Assessing the sensitivity of selected species to simulated doubling of atmospheric CO2. Global Change Biology 3:531-544.

Kirilenko, A. P. and A. M. Solomon. 1998. Modeling dynamic vegetation response to rapid climate change using bioclimatic classification. Climatic Change 38:15-49.

Kupfer, J. A., J. Balmat, and J. L. Smith. 2005. Shifts in the potential distribution of Sky Island plant communities in response to climate change. USDA Forest Service Proceedings RMRS-P-36:485-490.

Leemans, R. and B. Eikhout. 2004. Another reason for concern: regional and global impacts on ecosystems for different levels of climate change. Global Environmental Change 14:219-228.

Lenihan, J. M., D. Bachelet, R. P. Neilson, R. J. Drapek. 2008. Simulated response conterminous United States ecosystems to climate change at different levels of fire suppression, CO2, and growth response to CO2. Global and Planetary Change.

Lucht, W., S. Schaphoff, T. Erbrecht, U. Heyder, and W. Cramer. 2006. Terrestrial vegetation redistribution and carbon balance under climate change. Carbon Balance and Management 1:6.

Magurran, A. E. 2004. Measuring biological diversity. Blackwell Science Ltd. Malden, MA. 256 p

Malcolm, J. R. and A. Markham. 2000. Global warming and terrestrial diversity decline. World Wildlife Fund International, Gland, Switzerland. 35pp.

Manly, B. F. J. 2005. Multivariate statistical methods: a primer. 3rd ed. Chapman & Hall/CRC. Boca Raton, FL. 214 p.

Matthews, S., R. O'Connor, L. R. Iverson, and A. M. Prasad. 2004. Atlas of climate change effects in 150 bird species of the Eastern United States. USDA Forest Service General Technical Report NE-318. 340pp.

McKenney, D., D. Price, P. Papadapol, M. Siltanen, and K. Lawrence. 2006. High-resolution climate change scenarios for North America. Frontline. Technical Note 107. Canadian Forestry Service, Sault Ste. Marie, Ontario, Canada.

McKenzie, D., Z. Gedalof, D. L. Peterson, and P. Mote. 2004. Climatic change, wildfire, and conservation. Conservation Biology 18:890-902.

NatureServe. 2008a. NatureServe Central Databases – 28 August 2008. NatureServe, Arlington, VA.

NatureServe. 2008b. NatureServe Central Databases – 03 April 2008. NatureServe, Arlington, VA.

NatureServe. 2008c. NatureServe Central Databases – 25 June 2008. NatureServe, Arlington, VA.

Neilson, R. P. and J. Chaney. 1997. Potential changes in the vegetation distribution in the U.S. Pages 66-80 in U. S. Forest Service Global Change Program Highlights 1991-1995. Birdsey, R., R. Mickler, and D. Sandberg et al. Editors. USDA Forest Service General Technical Report NE-237.

Neilson, R. P. and R. J. Drapek. 1998. Potentially complex biosphere responses to transient global warming. Global Change Biology 4:505-521.

Notaro, M., S. Vavrus, and Z. Liu. 2007. Global vegetation and climate change due to future increases in CO2 as projected by a fully coupled model with dynamic vegetation. Journal of Climate 20:70-90.

Peterson, A. T. 2003. Projected climate change effects on Rocky Mountain and Great Plains birds: generalities of biodiversity consequences. Global Change Biology 9:647-655.

Rehfeldt, G. E., N. L. Crookston, M. V. Warwell, and J. S. Evans. 2006. Empirical analyses of plant-climate relationships for the Western United States. International Journal of Plant Sciences 167:1123-1150.

Ricketts, T. R. 2001. The matrix matters: effective isolation in fragmented landscapes. American Naturalist 158:87-99.

Sala, O. E., F. S. Chapin III, Juan J. Armesto, Eric Berlow, Janine Bloomfield, Rodolfo Dirzo, Elisabeth Huber-Sanwald, Laura F. Huenneke, Robert B. Jackson, Ann Kinzig, Rik Leemans, David M. Lodge, Harold A. Mooney, Martín Oesterheld, N. LeRoy Poff, Martin T. Sykes, Brian H. Walker, Marilyn Walker, and Diana H. Wall. 2000. Global biodiversity scenarios for the year 2100. Science 287:1770-1774.

Schmitz, O. J., E. Post, C. E. Burns, and K. M. Johnston. 2003. Ecosystem responses to global climate change: moving beyond color mapping. Bioscience 53:1199-1205.

Shafer, S. L., P. J. Bartlein, and R. S. Thompson. 2001. Potential changes in the distributions of western North America tree and shrub taxa under future climate scenarios. Ecosystems 4:200-215.

Sorenson, L. G., R. Goldberg, T. L. Root, and M. G. Anderson. 1998. Potential effects of global warming on waterfowl populations breeding in the Northern Great Plains. Climatic Change 40:343-369.

Thompson, R. S., S. W. Hostetler, P. J. Bartlein, and K. H. Anderson. 1998. A strategy for assessing future changes in climate, hydrology, and vegetation in the western United States. USGS Circular Report 1153. Washington D. C. 21pp.

Walker, K. V., M. B. Davis, and S. Sugita. 2002. Climate change and shifts in potential tree species range limits in the Great Lakes region. Journal of Great Lakes Research 28:555-567.

Williams, J.W, S.T. Jackson, J.E. Kutzbach. 2007. Projected distributions of novel and disappearing climates by 2100. Proceedings of the National Academies of Sciences 104: 5738-5742.

APPENDICES:

Appendix A. Number of terrestrial Species of Greatest Conservation Concern that were explicitly identified as potentially impacted by climate change in each state.

STATE	Number of Taxonomic Entries for SGCC
AZ	78
CO	3
CT	9
HI	3
ID	1
IL	14
MD	45
ME	18
MI	10
NH	4
NM	3
VA	5
VT	11
WI	13
Total	217

Appendix B. Habitat-level terrestrial climate stress index scores for case study states.

Table B-1. Habitat-level terrestrial climate stress index scores for Arizona.

Vegetation Type (AZ)	*N*[1]	*Status*[2]	CS_j	P_j	A_j	HO_j	MR_j (core)	$ARspp_j$	$TCSI_j$
Continental temperate coniferous forest		Gained							
Temperate mixed xeromorphic woodland	5	Lost	0.769	0.548	0.584	0.936	0.552	0.612	4.001
Temperate conifer xeromorphic woodland	12	Retained	0.728	0.728	0.33	0.46	0.164	0.782	3.192
Tropical thorn woodland		Gained							
Temperate subtropical deciduous savanna	12	Retained	0.13	0.465	0.538	0.71	0.033	0	1.876
Warm temperate/subtropical mixed savanna		Gained							
Temperate conifer savanna	12	Retained	0.658	0.672	0.828	0.921	0.121	0.017	3.217
C3 grasslands	12	Retained	0.771	0.58	0.838	0.785	0.073	0.191	3.238
C4 grasslands	12	Retained	0.381	0.469	0.172	0.186	0.225	1	2.433
Temperate arid shrubland	12	Retained	0.742	0.613	0.982	0.941	0.064	0.122	3.464
Subtropical arid shrubland	12	Retained	0.452	0.275	0.042	0.002	0.985	0.864	2.62

[1]N = number of scenarios where present

[2]Status = defines whether a vegetation type was: **Lost** from the mix of habitat types by 2099; **Retained** as a vegetation type in both the historical and future periods; or **Gained** in the future as a new vegetation type with no historical record of occurrence in the state.

Table B-2. Habitat-level terrestrial climate stress index scores for Minnesota.

Vegetation Type (MN)	N^1	*Status*[2]	CS_j	P_j	A_j	HO_j	MR_j (core)	$ARspp_j$	$TCSI_j$
Boreal coniferous forest	12	Retained	0.198	0.707	0.347	0	0	0.731	1.983
Continental temperate coniferous forest	12	Retained	0.593	0.695	0.119	0.802	0.517	1	3.726
Cool temperate mixed forest	12	Retained	0.673	0.444	0.698	0.617	0.742	0	3.174
Temperate conifer xeromorphic woodland	12	Retained	0.568	0.434	0.996	0.983	0.899	0.107	3.987
Temperate subtropical deciduous savanna		Gained							
Temperate conifer savanna	12	Retained	0.187	0.787	0.245	0.468	0.931	0.869	3.487
C3 grasslands	12	Retained	0.22	0.579	0.253	0.943	0.699	0.394	3.088
C4 grasslands	12	Retained	0.733	0.608	1	0.981	0.994	0.119	4.435
Temperate arid shrubland	12	Retained	0.205	0.598	0.2	0.94	0.699	0.372	3.014
Subtropical arid shrubland		Gained							

[1]N = number of scenarios where present

[2]Status = defines whether a vegetation type was: **Lost** from the mix of habitat types by 2099; **Retained** as a vegetation type in both the historical and future periods; or **Gained** in the future as a new vegetation type with no historical record of occurrence in the state.

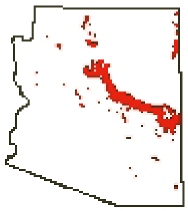
Table B-3. Habitat-level terrestrial climate stress index scores for Tennessee.

Vegetation Type (TN)	N[1]	*Status*[2]	CS_j	P_j	A_j	HO_j	MR_j (core)	$ARspp_j$	$TCSI_j$
Continental temperate coniferous forest		Gained							
Cool temperate mixed forest		Gained							
Warm temperate mixed forest		Gained							
Temperate deciduous forest	12	Retained	0.833	0.25	0.083	0.083	0.083	1	2.332
Temperate mixed xeromorphic woodland		Gained							
Temperate conifer xeromorphic woodland		Gained							
Temperate subtropical deciduous savanna		Gained							
Warm temperate/subtropical mixed savanna		Gained							
Temperate conifer savanna		Gained							
C4 grasslands	12	Retained	0.167	0.75	0.917	0.917	0.917	0	3.668

[1]N = number of scenarios where present

[2]Status = defines whether a vegetation type was: **Lost** from the mix of habitat types by 2099; **Retained** as a vegetation type in both the historical and future periods; or **Gained** in the future as a new vegetation type with no historical record of occurrence in the state.

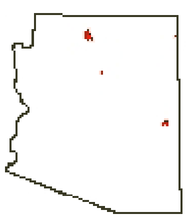
Appendix C. Arizona Literature and SWAP review



Habitat: Montane conifer (ponderosa pine, Douglas fir, Gambel oak, aspen)

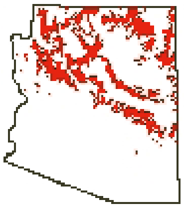
Projections:
Shafer et al. (2001) project upslope retreat of Douglas fir, increase in Ponderosa pine.
Thompson et al. (1998) project complete loss of Douglas fir, contraction of ponderosa pine in middle of state, and extension in NE corner. Almost complete loss of Gambel oak.
Neilson and Cheney (1998) project that Douglas fir will be replaced by oaks in much of the west.
Bachelet et al. (2001a) project that woodlands and forest could disappear completely
Kupfer et al. (2005) project a potential increase in desert scrub at the expense of montane conifer forest; unless precipitation increases in which case montane conifer forest increases 500%. Percent changes in desert scrub and montane conifer forest were more extreme due to their placement on steep mountain slopes and their small amount of total areal extent. Declines of conifer forest would not be offset anywhere else. Most likely scenario = large declines OR substantial gains. Some scenarios saw very little change in areal extent of vegetation types because of the balancing limitations of moisture and temperature stress.
Rehfeldt et al. (2006) - Ponderosa, Douglas fir, Engelmann spruce all decline by 2090
McKenzie et al. (2004) project that the length of fire season, based on drought indices, temperature, degree days and fire-weather indices, will be longer, with more fires occurring earlier and later than is currently typical, and increases in the total area burned in some regions.
Notaro et al. (2007) projects that the physiological effect increases forest cover in dry areas, like the western U.S., and a decrease in % trees burned.
Malcolm and Markham (2000) project high rates of habitat loss due to migration rates that are unable to keep up with climate shifts.
Neilson and Drapek (1998) project that forests will decline and release CO_2.

SWAP: Climate change is a threat to this habitat



Habitat: Alpine conifer forest (Engelmann spruce, Blue spruce, Doug fir, Limber pine, etc.)

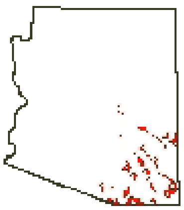
Projections:
Rehfeldt et al. (2006) project that Engelmann spruce declines by 2090
McKenzie et al. (2004) project that sky-island species are at risk due to advance of lower elevation forests and increased fire frequency.
Length of fire season, based on drought indices, temperature, degree days and fire-weather indices, will be longer, with more fires occurring earlier and later than is currently typical, and increases in the total area burned in some regions.
Neilson and Drapek (1998) project that temperate mixed forest, boreal conifer forest, and temperate evergreen forest are the most sensitive to change.
SWAP: Climate change is a threat to this habitat



Habitat: Great Basin conifer (pinyon pine and juniper)

Projections:
Thompson et al. (1998) project an almost complete loss of pinyon pine.
Aber et al. (2001) project that increased rainfall balances out temperature rise for stability
Bachelet et al. (2001a) shows that some scenarios show all grassland while others have shrub and woodland.
Rehfeldt et al. (2006) demonstrate that pinyon pine and juniper are expected to disappear almost completely.

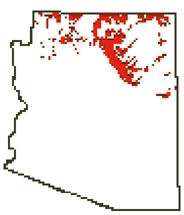
SWAP: Climate change is a threat to this habitat



Habitat: Madrean evergreen woodlands (evergreen oaks and juniper)

Projections:
Bachelet et al. (2001a) project all grassland with some scenarios but some shrub and woodland with others
Kupfer et el. (2005) demonstrated that for most scenarios, percent change in areal extent of desert savanna grassland and Madrean evergreen woodland forest did not change so much because of the greater range to start with and more room for movement upslope or downslope. But Madrean evergreen woodland forest still declined in all scenarios.

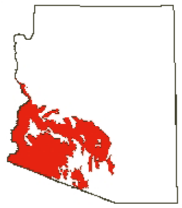
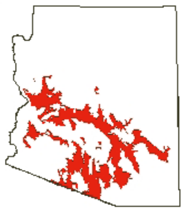
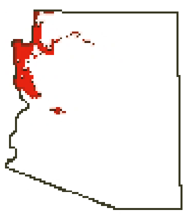
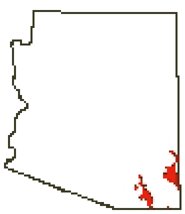
SWAP: Climate change is a threat to this habitat



Habitat: Great Basin desertscrub (big sagebrush and shadscale)

Projections:
Shafer et al. (2001) project a complete loss of big sagebrush, and they predict that the mean monthly winter temperatures in northern AZ will go from below freezing to above freezing.
Thompson et al. (1998) project a range shift for big sagebrush
Bachelet et al. (2001a) show some scenarios with all grassland and no shrubland.
Kupfer et al. (2005) show that with an increase in temperature (alone) they saw an increase in desert scrub at the expense of montane conifer forest. Some scenarios saw very little change in areal extent of vegetation types because of the balancing limitations of moisture and temperature stress.
McKenzie et al. (2004) suggest that sage obligate species would be at risk due to susceptibility of sage to fire and the invasion of annual species.

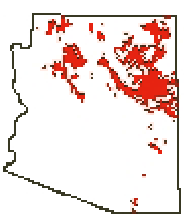
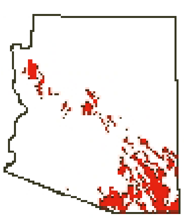
SWAP: Climate change is a threat to this habitat

Habitat: Lowland and upland Sonoran, Mohave, and Chihuahuan desertscrub (creosotebush, cacti, Joshua tree, yucca, giant saguaro, etc.)

Projections:
Shafer et al. (2001) project range shifts for saguaro and creosote bush, loss of Joshua tree in current range, but potentially suitable climate in NE AZ.
Thompson et al. (1998) also project that saguaro will completely die off in its present range, and its future range is disjunct. They project that Joshua tree is expected to expand eastward, and increase its coverage substantially
Diffenbaugh et al. (2003) project conversion to forest
Bachelet et al. (2003) project that by 2095, desert areas of the southwest become greatly reduced, and are replaced by grasslands.
Bachelet et al. (2001a) show some scenarios with all grassland and no shrubland. Desert disappears completely.
Kupfer et al. (2005) show that with an increase in temperature (alone) they saw an increase in desert scrub at the expense of montane conifer forest. Some scenarios saw very little change in areal extent of vegetation types because of the balancing limitations of moisture and temperature stress.
Aber et al. (2001) show that the southwest is stable due to the balance between increased temperatures and increased rainfall.
Hansen et al. (2001) project a loss of desert and increase in grasslands
Rehfeldt et al. (2006) project that saguaro disappears almost completely
Sala et al. (2000) project that deserts and northern temperate forests are expected to see the least change.
Leemans and Eikhout (2004) project a shift from desert to grasslands.

SWAP: All 4 habitat types are threatened by climate change.

Habitat: Plains and Great Basin, Semidesert grasslands

Projections: Bachelet et al. (2001a) show all grassland in some scenarios while others have shrub and woodland
Hansen et al. (2001) again show a loss of desert and increase in grasslands.
Kupfer et al. (2005) show that for most scenarios, percent change in areal extent of desert savanna grassland and Madrean evergreen woodland forest did not change so much because of the greater range to start with and more room for movement upslope or downslope. Desert grassland savanna showed moderate increases or small decreases
Sala et al. (2000) show that freshwater ecosystems, grasslands, Mediterranean ecosystems, and savannas are expected to see the greatest change in biodiversity due to substantial influences by all stressors.
Leemans and Eikhout (2004) project a shift from desert to grasslands.

SWAP: This habitat type is threatened by climate change

Other types: These were not mentioned in the literature but are delineated in the SWAPs and identified in the state as threatened by climate change: chaparral, subalpine grassland, tundra, lakes and reservoirs (not searched for in the literature), streams and rivers (not searched for in the literature), riparian/aquatic (not searched for in the literature).

Where do management recommendations agree, and where can the literature inform the SWAP?

Agree:

1) Improve forest management policy to increase biodiversity and resilience
2) Reduce human-induced stressors to natural systems
3) Implement better land-use planning and land use regulations
4) Reduce greenhouse gas emissions
5) Reestablish and restore native species in suitable areas
6) Develop monitoring techniques to identify alternative conditions
7) Individual species/habitat models to identify species at risk from climate change

Literature can inform SWAP:

1) Develop contingency plans for uncertain futures
2) Monitor for CO_2-induced water-use efficiency in order to identify appropriate models
3) Do not degrade intact native systems for climate change mitigation purposes
4) Active management of current communities may be necessary until those communities are established elsewhere
5) Manage to encourage change
6) Seedbanks and captive breeding will be necessary at times
7) Collaborate internationally and across land ownership boundaries
8) Translocate
9) Increase and retain connectivity

Which recommendations made in the SWAP potentially conflict with climate change recommendations?

None

Which recommendations made in the SWAP, NOT specific to climate change, might be appropriate under a climate change scenario?

Maintaining and improving connectivity
Decreasing human-induced stressors, especially land cover change, pollution, and water stress
Promoting biological diversity
Controlling invasive species
Restoring natural fire regimes
Working with private landowners
Land conservation

Synopsis
Arizona cited a few climate change studies, including IPCC, and gave a general overview of the types of changes that are expected to occur in the state. These changes included shifts in habitat type, increasingly variable weather patterns, drought, etc. When discussing the threats to species and habitats, in addition to making actual recommendations, however, they limited their discussion almost completely to drought. For example, pine grosbeaks and American three-toed woodpeckers are found in high elevation forested habitats, but management recommendations for dealing with climate change are specific to drought, not loss of habitat. This seems to be the major shortcoming in their approach to climate change. There are <u>many</u> seemingly inappropriate recommendations, such as the recommendation for maintaining proper functioning riparian systems for a non-riparian species that depends on pine seed crops.

Continue to the next page to see specific management recommendations….

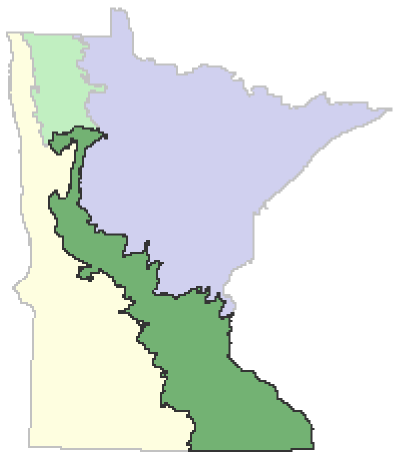
Appendix C. Table 1. Comparison of management recommendations made in the literature to those made in Arizona's SWAP. Because the other case study states did not address climate change in their SWAPs, equivalent tables for those states are not provided. Underlined recommendations reflect recommendations to be found in the literature and in the SWAP; these recommendations can be found in both columns.

Literature	SWAP
Aber et al. 2001 Need better data for validating model predictions and develop baselines for calculations Better understanding of CO_2 fertilization effect **Bachelet et al. 2001** Managers should develop contingency plans for uncertain futures Monitoring should be configured to identify alternative conditions as they occur Monitor for increased CO_2-induced water-use efficiency to assess whether predicted increases are accurate or whether the models need to be adjusted **Diffenbaugh et al. 2003** More modeling **Hansen et al. 2001** Reduce atmospheric concentration of greenhouse gasses by reduced use of fossil fuels and less harvesting of large trees for short-turnover products and by establishing new locations and means of carbon storage If carbon storage by fast growing vegetation is used as a tool, this vegetation should not replace intact native vegetation with weed or invasive species Reduce human-induced disturbances Reduce land-cover changes Manage human population growth, implement better land-use planning,	**On-the-ground** Use riparian and aquatic habitats as buffers against drought Design better forest and woodland harvest strategies Design forest-woodland harvest management strategies that promote wildlife diversity and connectivity Manage watersheds to maintain vegetation to prevent drought Adjust livestock use during drought Maintain hydrological integrity in watersheds Survey for areas to reestablish native species Develop plans to conserve species Maintain hydrological integrity and incorporate wildlife values **Policy** Protecting instream flow by better planning or purchasing water rights Establish laws that protect instream flows for wildlife Limit or prevent development in watersheds Work with city and county planners to prevent development in floodplains and areas that affect watershed integrity, manage upland watersheds to encourage vegetation as a buffer against drought

<u>and land-use regulation programs</u> Current communities (eg. subalpine and alpine) can be maintained in the face of climate change by manipulating vegetation structure, composition, or disturbance regimes Manage current habitat as a reservoir until the community can be reestablished elsewhere Management to encourage change may be desirable in some areas Restoration of degraded communities would be beneficial and could be an outlet for managing rapid change (eg. planting species from further south in an area that was previously degraded) Seedbanks and captive breeding may be necessary when appropriate habitat is temporarily unavailable Simulation models to assess the success of different strategies are necessary Adaptive management and adequate monitoring are important tools International regulations or incentives for conservation will be important because many species or communities that become increasingly rare in the U.S. will actually become more common in Canada Individual species studies are important to understand the risk to threatened and endangered species Coping strategies will require a new level of cooperation among public and private land stewards and among nations Substantial investment in research and assessment will be needed to reduce uncertainties in the interactions between climate, land use, and biodiversity **Kupfer et al. 2005** Need to create a more robust model of Sky Island vegetation change using dynamic GCM and a broader range of environmental factors, in addition to including dispersal functions, invasibility functions, soils, and extreme events in the model	<u>Support efforts to reduce greenhouse gas emissions</u> **Communication/Education** Increase public awareness. Promote water conservation, encourage low water landscaping, encourage development of water recycling systems. Increase public awareness of water issues and ecosystem function **Research** <u>Develop models of habitat response to climate change and or drought</u> <u>Develop monitoring techniques for drought</u> Identify species sensitive to drought impacts Compile information on ecosystem change due to drought Compile information on the impacts of drought to wildlife and ecosystems Identify species at risk of loss of habitat due to climate change

McKenzie et al. 2004 Threats need to be assessed on a case-by-case basis Discussions among decision makers, public land managers, and stakeholders at local and regional scales can help in the development of resource management strategies that mitigate risk to ecosystems and sensitive species **Neilson and Cheney 1997** <u>Dramatic shifts in forest management policy</u> **Rehfeldt et al. 2006** Translocation **Sala et al. 2000** Integrated effort by climatologists, ecologists, social scientists, and policy makers needed to improve scenarios of future changes. Study of the interactions among factors to which local biodiversity is most sensitive is needed to make the models useful to managers Mitigation of negative impacts should encompass reduction of the stressors and development of specific regional management practices **Malcolm and Markham 2000** Increased connectivity among natural habitats within developed landscapes may help organisms to attain their maximum intrinsic rates of migration and help reduce species loss However, if past fastest rates of migration are a good proxy for what can be attained in a warming world, then radical reductions in greenhouse gas emissions are urgently required in order to reduce the threat of biodiversity loss	

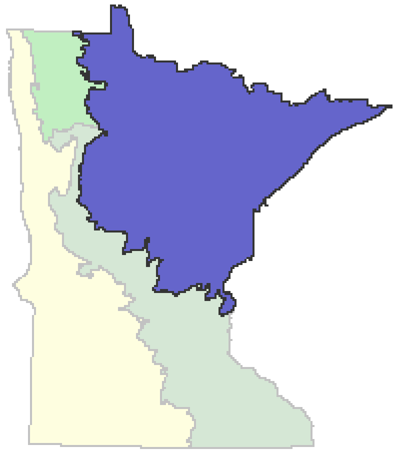
Appendix D. Minnesota literature and SWAP review



Habitat: Eastern Broadleaf Forest Province

Projections:
Walker et al. (2002) project increases in black cherry, black walnut, beech in the state
Possible declines in aspen, yellow birch, red pine, white pine, jack pine
Because dispersal is likely to occur more slowly than dieback, forests will become less diverse for some time, thereby challenging forest managers.
Iverson and Prasad (1998) project that **a**spen disappears from Minnesota.
Bachelet et al. (2003) project that by 2030 there is an increase in winter deciduous forest, mixed forest, and woodland replacing northern coniferous forest (NE) and grassland (SW). By 2095 there is no grassland, only either mixed forest or winter deciduous forest. No coniferous forest.
Aber et al. (2001) projects that conifer forest in north will be replaced by NE mixed forest.
Bachelet et al. (2001a) demonstrate that most of the state could be dominated by NE mixed forest, with some potential woodland OR it could be dominated by temperate deciduous forest
Hansen et al. (2001) project that aspen-birch and spruce-fir shift to oak-hickory and elm-ash-cottonwood.
Neilson and Drapek (1998) project that temperate mixed forest, boreal conifer forest, and temperate evergreen forest are the most sensitive to change.
Matthews et al. (2004) projects the following SGCC to potentially disappear from the state (not all species were modeled): common loon, black tern, American bittern, yellow-bellied sapsucker, least flycatcher, white-throated sparrow, swamp sparrow, golden-winged warbler, cerulean warbler, ovenbird, and winter wren.
The following SGCC are projected to decline: black-billed cuckoo, eastern wood-pewee, bobolink, rose-breasted grosbeak, sedge wren, and veery.
The following SGCC are projected to remain stable: northern harrier, willow flycatcher, and brown thrasher.
The following SGCC are expected to increase: red-headed woodpecker, whip-poor-will, common nighthawk, acadian flycatcher, eastern meadowlark, grasshopper sparrow, field sparrow, dicksissel, loggerhead shrike, and wood thrush.

SWAP: 25% of SGCC are unique to this province; no mention of climate change.

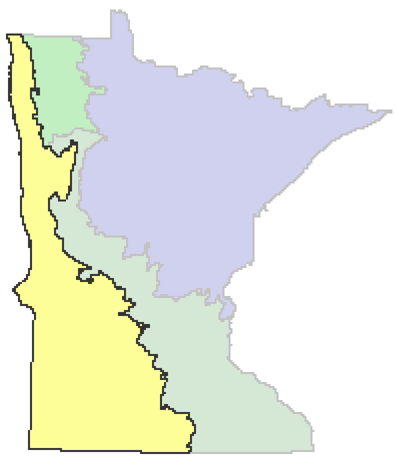


Habitat: Laurentian Mixed Forest Province (coniferous and mixed coniferous forest)

Projections: Shafer et al. (2001) project that paper birch, white spruce, and American basswood all contract ranges northward, moving out of Minnesota.
Walker et al. (2002) project increases in black cherry, black walnut, beech in the state
Possible declines in aspen, yellow birch, red pine, white pine, jack pine.
Because dispersal is likely to occur more slowly than dieback, forests will become less diverse for some time, thereby challenging forest managers.
Iverson and Prasad (1998) project that **a**spen disappears from Minnesota
Bachelet et al. (2003) project that by 2030 there is an increase in winter deciduous forest, mixed forest, and woodland replacing northern coniferous forest (NE) and grassland (SW). By 2095 there is no grassland, only either mixed forest or winter deciduous forest. No coniferous forest.
Aber et al. (2001) projects that conifer forest in north will be replaced by NE mixed forest.
Bachelet et al. (2001a) show that conifer forest disappears from north, but in one model it is retained.
Bachelet et al. (2001a) demonstrate that most of the state could be dominated by NE mixed forest, with some potential woodland OR it could be dominated by temperate deciduous forest.
Hansen et al. (2001) project that aspen-birch and spruce-fir shift to oak-hickory and elm-ash-cottonwood.
Matthews et al. (2004) projects that **b**alsam fir completely disappears from northern Minnesota (from Iverson and Prasad's models)
Bergengren et al. (2001) projects that the southern boreal forest transitions into temperate mixed or deciduous broadleaf forest.
Neilson and Drapek (1998) project that temperate mixed forest, boreal conifer forest, and temperate evergreen forest are the most sensitive to change.
Schmitz et al. (2003) project that due to projected decreased snow depth, wolves (SGCC) will actually decline and moose populations will increase, thereby causing a decline in balsam fir productivity. Forest cover will become more open and understory species composition will change. Decreased canopy closure will cause drying and lowered productivity.
Matthews et al. (2004) projects the following SGCC to potentially disappear from the state (not all species were modeled): common loon, black tern, American bittern, yellow-bellied sapsucker, least flycatcher, white-throated sparrow, swamp sparrow, cerulean warbler, black-throated blue warbler, ovenbird, and winter wren.
The following SGCC are projected to decline: black-billed cuckoo, eastern wood-pewee, bobolink, rose-breasted grosbeak, Canada warbler, sedge wren, and veery.
The following SGCC are projected to remain stable: northern harrier, willow flycatcher, and brown thrasher.

The following SGCC are expected to increase: red-headed woodpecker, whip-poor-will, common nighthawk, eastern meadowlark, grasshopper sparrow, field sparrow, and wood thrush.

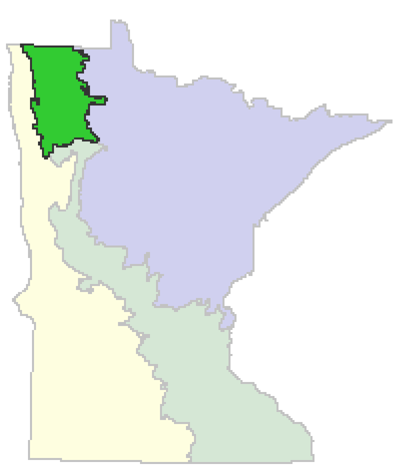
SWAP: 27% of SGCC are unique to this province; no mention of climate change.



Habitat: Prairie Parkland Province (historically tallgrass prairie)

Projections:
Bachelet et al. (2003) project that by 2030 there is an increase in winter deciduous forest, mixed forest, and woodland replacing northern coniferous forest (NE) and grassland (SW). By 2095 there is no grassland, only either mixed forest or winter deciduous forest. No coniferous forest.
Aber et al. (2001) projects a loss of woodlands and grasslands in southern part of state.
Johnson et al. (2005) project that central tall grasslands and northern tall grasslands in western portion of state could become more valuable to breeding waterfowl if temperatures rise and precipitation does not change.
Matthews et al. (2004) projects the following SGCC to potentially disappear from the state (not all species were modeled): common loon, black tern, American bittern, yellow-bellied sapsucker, least flycatcher, white-throated sparrow, swamp sparrow, cerulean warbler, ovenbird, and winter wren.
The following SGCC are projected to decline: black-billed cuckoo, eastern wood-pewee, bobolink, rose-breasted grosbeak, sedge wren, and veery.
The following SGCC are projected to remain stable: northern harrier, willow flycatcher, and brown thrasher.
The following SGCC are expected to increase: red-headed woodpecker, whip-poor-will, common nighthawk, eastern meadowlark, dicksissel, loggerhead shrike, grasshopper sparrow, field sparrow, and wood thrush.

SWAP: 9.3% of SGCC are unique to this province; no mention of climate change.



Habitat: Tallgrass Aspen Parklands Province (Prairie and open, fire-dependant woodland communities)

Projections:
Walker et al. (2002) project a possible decline in aspen.
Iverson and Prasad (1998) project that **a**spen disappears from Minnesota.

Bachelet et al. (2003) project that by 2030 there is an increase in winter deciduous forest, mixed forest, and woodland replacing northern coniferous forest (NE) and grassland (SW). By 2095 there is no grassland, only either mixed forest or winter deciduous forest. No coniferous forest.
Matthews et al. (2004) projects the following SGCC to potentially disappear from the state (not all species were modeled): common loon, black tern, American bittern, yellow-bellied sapsucker, least flycatcher, swamp sparrow, and ovenbird.
The following SGCC are projected to decline: black-billed cuckoo, eastern wood-pewee, bobolink, rose-breasted grosbeak, sedge wren, and veery.
The following SGCC are projected to remain stable: northern harrier, willow flycatcher, and brown thrasher.
The following SGCC are expected to increase: red-headed woodpecker, whip-poor-will, common nighthawk, eastern meadowlark, grasshopper sparrow, and field sparrow.

SWAP: 2.3% of SGCC are unique to this province; no mention of climate change.

Other types: These were not mentioned in the literature but are delineated in the SWAPs: wetland-nonforest, water.

Where do management recommendations agree, and where can the literature inform the SWAP?

Agree: None

Literature can inform SWAP:

1) Managers should develop contingency plans for uncertain futures
2) Monitoring should be configured to identify alternative conditions as they occur
3) Monitor for increased CO_2-induced water-use efficiency to assess whether predicted increases are accurate or whether the models need to be adjusted
4) Reduce atmospheric concentration of greenhouse gasses by reduced use of fossil fuels and less harvesting of large trees for short-turnover products and by establishing new locations and means of carbon storage.
5) If carbon storage by fast growing vegetation is used as a tool, this vegetation should not replace intact native vegetation with weed or invasive species.
6) Reduce human-induced disturbances
7) Reduce land-cover changes.
8) Manage human population growth, implement better land-use planning, and land-use regulation programs.
9) Current communities (eg. subalpine and alpine) can be maintained in the face of climate change by manipulating vegetation structure, composition, or disturbance regimes.
10) Manage current habitat as a reservoir until the community can be reestablished elsewhere.
11) Management to encourage change may be desirable in some areas.

12) Restoration of degraded communities would be beneficial and could be an outlet for managing rapid change (eg. planting species from further south in an area that was previously degraded).
13) Seedbanks and captive breeding may be necessary when appropriate habitat is temporarily unavailable.
14) Simulation models to assess the success of different strategies are necessary.
15) Adaptive management and adequate monitoring are important tools.
16) International regulations or incentives for conservation will be important because many species or communities that become increasingly rare in the U.S. will actually become more common in Canada.
17) Individual species studies are important to understand the risk to threatened and endangered species.
18) Coping strategies will require a new level of cooperation among public and private land stewards and among nations.
19) Substantial investment in research and assessment will be needed to reduce uncertainties in the interactions between climate, land use, and biodiversity.
20) Restoration of eastern portions of PPR may be necessary to ameliorate impacts.
21) Wetland modeling could be improved to make its output more meaningful to managers.
22) Integrated effort by climatologists, ecologists, social scientists, and policy makers needed to improve scenarios of future changes.
23) Study of the interactions among factors to which local biodiversity is most sensitive is needed to make the models useful to managers.
24) Mitigation of negative impacts should encompass reduction of the stressors and development of specific regional management practices.
25) Develop models of climate-ecosystem linkages
26) Investigate complexity of ecological communities and ecosystems
27) Explore how to scale across key organizational hierarchies in ecosystems

Which recommendations made in the SWAP potentially conflict with climate change recommendations?

1) Stabilize and increase SGCC populations
2) Minnesota’s overall approach may conflict with climate change, because they only focus conservation efforts on core areas that currently or historically supported SGCC. This leaves the rest of the state open to degradation, including areas that may become more important in the future.
3) Selective acquisition of key habitats

Which recommendations made in the SWAP, NOT specific to climate change, might be appropriate under a climate change scenario?

1) Improve knowledge about SGCC
2) Enhance people’s appreciation and enjoyment of SGCC
3) Manage emerging issues affecting specific SGCC populations
4) Survey SGCC populations and habitats
5) Research populations, habitats, and human attitudes/activities

6) Monitor long-term changes in SGCC populations and habitats
7) Develop outreach and recreation actions
8) Manage invasive species
9) Use prescribed fire and other practices to maintain savanna
10) Encourage oak savanna restoration efforts
11) Enforce existing laws
12) Land conservation
13) Monitor long-term trends in SGCC populations

Synopsis

Minnesota's SWAP was fairly light on specifics. They admittedly took a 'course filter' approach and therefore did not address specific threats to specific habitats and species. There were few details that could be pulled out to make comparisons with the literature.

Appendix E. Tennessee literature and SWAP review

Habitat: Bottomland hardwood forest (Bald cypress and water tupelo)

Projections:
Aber et al. (2001) projects that SE fires become more of a landscape feature. SE especially susceptible to sudden drought induced dieback after an initial increase in productivity**.** Temperate deciduous forest could shift to SE mixed forest type.
Kirilenko and Soloman (1998) project that significant areas become occupied by unique non-analog temperate forest biomes – depauperate temperate deciduous forest.

SWAP: Climate change is expected to affect forest composition, water quality and wildlife in Tennessee by the year 2100

Habitat: Upland hardwood forest (oak and hickory with maple, beech and birch)

Projections:
Iverson and Prasad (1998) project that flowering dogwood remains throughout Tennessee.
Bachelet et al. (2003) project that by 2030 winter deciduous forest could be replaced by coniferous forest or by grassland in the western part of the state. Some models show it as stable. By 2095 the results were the same except that some models show savanna throughout the state.
Aber et al. (2001) projects that SE fires become more of a landscape feature. SE especially susceptible to sudden drought induced dieback after an initial increase in productivity**.** Temperate deciduous forest could shift to SE mixed forest type. Oak-hickory forest expected to experience severe carbon loss**.** Overall, a huge decline in carbon storage is expected for the area.
Hansen et al. (2001) projects some increase in pine, but still dominated by oak-hickory
Kirilenko and Soloman (1998) project that significant areas become occupied by unique non-analog temperate forest biomes.
Lucht et al. (2006) project that evergreen plant functional types will increase their fractions at the expense of deciduous vegetation.

SWAP: Climate change is expected to affect forest composition, water quality and wildlife in Tennessee by the year 2100

Habitat: Shortleaf pine-oak forest and woodlands

Projections:
Iverson et al. (1999) project that Virginia pine retreats almost entirely out of the state, except for the eastern edge where densities are currently highest.
Bachelet et al. (2001a) projects that mixed forest could be replaced by SE conifer forest or woodland and a likely decrease in LAI.
Hansen et al. (2001) projects some increase in pine, but still dominated by oak-hickory

Iverson et al. (2004) project an increase in southern red oak, slight decrease or range shift of sourwood, increase in sweetgum, and large increase in loblolly pine. BUT the likelihood of new area being colonized for all species was low.
Kirilenko and Soloman (1998) project that significant areas become occupied by unique non-analog temperate forest biomes – depauperate temperate deciduous forest
Lucht et al. (2006) project that evergreen plant functional types will increase their fractions at the expense of deciduous vegetation

SWAP: Climate change is expected to affect forest composition, water quality and wildlife in Tennessee by the year 2100

Habitat: Prairie or grasslands

Projections: Bachelet et al. (2003) project that by 2030 winter deciduous forest could be replaced by coniferous forest or by grassland in the western part of the state.

SWAP: Nothing

Habitat: Glades (treeless shallow soil upland areas with endemic spp.)

Projections: None

SWAP: Nothing

Habitat: Montane forest of Cumberland Plateau (Hemlock-hardwood or pine)

Projections:
Iverson and Prasad (1998) project that flowering dogwood remains throughout Tennessee.
Bachelet et al. (2003) project that by 2030 winter deciduous forest could be replaced by coniferous forest or by grassland in the western part of the state. Some models show it as stable. By 2095 the results were the same except that some models show savanna throughout the state.
Aber et al. (2001) projects that SE fires become more of a landscape feature. SE especially susceptible to sudden drought induced dieback after an initial increase in productivity**.** Temperate deciduous forest could shift to SE mixed forest type. Oak-hickory forest expected to experience severe carbon loss**.** Overall, a huge decline in carbon storage is expected for the area.
Hansen et al. (2001) projects some increase in pine, but still dominated by oak-hickory
Kirilenko and Soloman (1998) project that significant areas become occupied by unique non-analog temperate forest biomes.
Lucht et al. (2006) project that evergreen plant functional types will increase their fractions at the Iverson et al. (1999) project that Virginia pine retreats almost entirely out of the state, except for the eastern edge where densities are currently highest.

Iverson et al. (2004) project an increase in southern red oak, slight decrease or range shift of sourwood, increase in sweetgum, and large increase in loblolly pine. But the likelihood of new area being colonized for all species was low.

SWAP: Climate change is expected to affect forest composition, water quality and wildlife in Tennessee by the year 2100

SGCC that were modeled by Matthews et al. (2001), but that were not listed by habitat type in the SWAP.

Disappear from the state: blue-winged warbler, least flycatcher, winter wren, savannah sparrow
Decline: grasshopper sparrow, Kentucky warbler, cerulean warbler, prairie warbler, whip-poor-will, wood thrush, Yellow-throated vireo
Stable: acadian flycatcher, black-throated green warbler, hooded warbler, black-throated blue warbler, northern parula, orchard oriole, prothonotary warbler, red-headed woodpecker, worm-eating warbler, yellow-billed cuckoo, yellow-throated warbler
Increase: Bachman's sparrow, brown-headed nuthatch, chuck-will's-widow, dicksissel, eastern wood-pewee, great egret, little-blue heron, loggerhead shrike, Mississippi kite (passes through as range shifts north), painted bunting, scissor-tailed flycatcher, white-eyed vireo

Where do management recommendations agree, and where can the literature inform the SWAP?

Agree:
Coupled with other problems such as invasive exotic species, low-level ozone accumulation, pathogens, and potentially climate change, acid rain has decimated the high elevation spruce-fir forest.

Literature can inform SWAP:
1) Tennessee is expected to have biodiversity refuges – avian models show many species that decline in the north to increase in the Appalachian range
2) Humans may need to hasten dispersal and migration rates by moving propgules to new locations
3) Managers should develop contingency plans for uncertain futures
4) Monitoring should be configured to identify alternative conditions as they occur
5) Reduce atmospheric concentration of greenhouse gasses by reduced use of fossil fuels and less harvesting of large trees for short-turnover products and by establishing new locations and means of carbon storage.
6) If carbon storage by fast growing vegetation is used as a tool, this vegetation should not replace intact native vegetation with weed or invasive species.
7) Reduce human-induced disturbances.
8) Reduce land-cover changes.
9) Manage human population growth, implement better land-use planning, and land-use regulation programs.

10) Current communities can be maintained in the face of climate change by manipulating vegetation structure, composition, or disturbance regimes.
11) Manage current habitat as a reservoir until the community can be reestablished elsewhere.
12) Management to encourage change may be desirable in some areas.
13) Restoration of degraded communities would be beneficial and could be an outlet for managing rapid change (eg. planting species from further south in an area that was previously degraded).
14) Seedbanks and captive breeding may be necessary when appropriate habitat is temporarily unavailable.
15) Simulation models to assess the success of different strategies are necessary.
16) Adaptive management and adequate monitoring are important tools.
17) Individual species studies are important to understand the risk to threatened and endangered species.
18) Coping strategies will require a new level of cooperation among public and private land stewards and among nations.
19) Substantial investment in research and assessment will be needed to reduce uncertainties in the interactions between climate, land use, and biodiversity.
20) Integrated effort by climatologists, ecologists, social scientists, and policy makers needed to improve scenarios of future changes.
21) Study of the interactions among factors to which local biodiversity is most sensitive is needed to make the models useful to managers.
22) Mitigation of negative impacts should encompass reduction of the stressors and development of specific regional management practices.
23) Reduction in rate of climate change (and hence, earliest reduction of greenhouse gas concentrations) may be much more important than previously suggested
24) A substantial focus on climatic and non-climatic causes of ecosystem change is required in the next several years to advance the reliability of available projections of land biosphere change.
25) Given the important role of biodiversity in the provision of several ecosystem services, further efforts for protection should be considered. Such measures could focus on reducing habitat conversion, both by controlling direct drivers such as agricultural expansion, and by controlling indirect drivers such as population growth and consumption. Limiting climate change to the extent possible by minimizing emissions and sequestering carbon will also reduce biodiversity losses.

Which recommendations made in the SWAP potentially conflict with climate change recommendations?

Acquire priority tracts of habitat
Reintroduce extirpated populations of SGCC
Develop/implement ecosystem-based management plans for conservation areas in the state.

Which recommendations made in the SWAP, NOT specific to climate change, might be appropriate under a climate change scenario?

Participate in land use planning activities
Restore degraded wetlands
Restore in-stream flows to channelized streams.
Reintroduce prescribed fire to priority habitats.
Conduct rapid assessments of priority habitats for invasive exotics.
Develop formal management agreements with private landowners
Acquire priority tracts of habitat
Incentives for private landowners to improve water quality
Increase compliance monitoring of permits
Legislation to restrict import of invasive species
Develop standards for instream flow for wildlife
Propose legislation to create dedicated funding for conservation
Develop faunal and/or habitat working groups of academics & other expert biologists.
Expand network of volunteers to conduct monitoring of GCN species and habitats.
Develop multi-media public outreach campaign to promote issues for GCN species.
Establish a propagation facility to increase populations of GCN species.
Conduct scientific surveys for lesser known GCN species.
Participate in regional conservation planning activities sponsored by NGOs or other groups.
Conduct research on problems affecting GCN species and habitats.
Encourage municipal/county governments to offer incentives for "green" construction.
Encourage programs that advocate usage of native plants in horticulture, erosion control, and wildlife plantings.

Synopsis
Tennessee barely mentioned climate change in their SWAP, and the only 2 sentences that did mention climate change contradicted each other. One said that climate change is expected to begin to impact wildlife and habitat by 2100. The other said that climate change, in concert with acid rain and other stressors, has already decimated spruce-fir forests.

Appendix F. Advisory Board – Affiliations shown at the time of this study: 2007-2008

ADVISORY BOARD

Name	Title	Affiliation	Phone/Fax/Cell	Email
Ashe, Daniel (Dan)	Science Advisor to the Director	U.S. Fish and Wildlife Service 1849 C St., NW, Room 3024 Washington, DC 20240	(p) 202-208-4700 (f) 202-208-6965	Dan_Ashe@fws.gov
Bachelet, Dominque	Director, Climate Change Science	The Nature Conservancy 120 East Union, Suite 214 Olympia, WA 98501	(p) 360-943-1146 (f) 360-956-9445 (c) 206-604-5549	bachelet@fsl.orst.edu
Berner, Ruth	Forest Planner	National Forests in North Carolina Supervisor's Office 160A Zillicoa St Asheville, NC 28802	(p) 828-257-4862 (f) 828-257-4263	rberner@fs.fed.us
Chadwick, Dave	Wildlife Diversity /Teaming with Wildlife, Director	Association of Fish & Wildlife Agencies 444 North Capitol St. NW, Suite 725 Washington DC 20001	(p) 202-624-5429 (f) 202-624-7891	chadwick@fishwildlife.org
Figg, Dennis	Conservation Biologist	Missouri Department of Conservation, Wildlife Division P.O. Box 180 Jefferson City, MO 65102	(p) 573-751-4115 x3309	dennis.figg@mdc.mo.gov
Francis, Joyce	GIS Senoir Analyst Nongame Branch	Arizona Game & Fish Department 2221 West Greenway Road Phoenix, AZ 85023	(p) 602-789-3734 (f) 602-789-3939	jfrancis@azgfd.gov
Kostyack, John	Senior Counsel	National Wildlife Federation 1400 16th Street, NW, Suite 501	(p) 202-797-6879	kostyack@nwf.org

		Washington, DC 20036		
Neilson, Ron	Bioclimatologist	USDA Forest Service, Pacific Northwest Research Station,, 3200 S.W. Jefferson Way, Corvallis, Oregon 97331	(p) 541-750-7303	rneilson@fs.fed.us
Pairis, Amber	Science and Research Liaison	Association of Fish & Wildlife Agencies 444 North Capitol St. NW, Suite 725 Washington DC 20001	(p) 202-624-7890	apairis@fishwildlife.org
Pellant, Mike	Great Basin Restoration Initiative Coordinator	Bureau of Land Management 1387 S. Vinnell Way Boise, ID 83709	(p) 208-373-3823 (f) 208-373-3805	Mike_Pellant@blm.gov
Stenquist, Brian	Planner/Facilitator	Division of Ecological Services Minnesota Department of Natural Resources Box 25 500 Lafayette Road St. Paul, MN 55155	(p) 651-297-4889 (f) 651-296-1811	brian.stenquist@dnr.state.mn.us
Theobald, Dave	Associate Professor	245 Forestry Department of Natural Resources Recreation & Tourism Warner College of Natural Resources Colorado State University Fort Collins, CO 80523	(p) 970-491-5122 (f) 970-491-1965	davet@warnercnr.colostate.edu

Appendix G. Contacts made during the Study. Affiliations shown at the time of this study: 2007-2008

CONTACTS

Name	Title	Affiliation	Phone/Fax/Cell	Email
Biasi, Frank	Director, Conservation Projects	National Geographic Society National Geographic Maps Washington, DC 20036	(p) 202-857-7248	FBiasi@ngs.org
Brisendine, Amy	Acting Senior Permit Biologist	U.S. Fish and Wildlife Service 4401 N. Fairfax Drive, Rm. 653 Arlington, Va 22203	(p) 703-358-2005	Amy_Brisendine@fws.gov
Brown, Charles (Chuck)	Program Evaluator	Planning, Budgeting and Evaluation Colorado Division of Wildlife Department of Natural Resources 6060 Broadway Denver, CO 80216	(p) 303-291-7450	chuck.brown@state.co.us
Butler, Dorothy	Heritage Coordinator	Missouri Department of Conservation PO Box 180 Jefferson City, MO 65102	(p) 573-522-4115 x3639 (f) 573-526-5582	Dorothy.Butler@mdc.mo.gov
Cleveland, Terry	Director	Wyoming Game and Fish Department 5400 Bishop Boulevard Cheyenne, WY 82006	(p) 307-777-4600 (f) 307-777-4699	
Collins, Sally	Associate Chief	U.S. Forest Service Sidney R. Yates Federal Bldg 201 14th Street SW Washington, DC 20024	(p) 202-205-1491	scollins@fs.fed.us

Copeland, Holly	Spatial Ecologist	The Nature Conservancy Wyoming Chapter 258 Mina Street #200 Lander, WY 82520	(p) 307-335-2120 (f) 307-332-2974	hcopeland@tnc.org
Davison, Robert	Senior Scientist	Defenders of Wildlife 26658 Sulphur Springs Rd. Corvallis, OR 97330	(p) 541-745-5521	bdavison@defenders.org
Dellasala, Dominick	Executive Director of Conservation Science and Policy Programs	National Center for Conservation Science and Policy 84 Fourth Street Ashland, OR 97520	(p) 541-482-4459 x302 (f) 541-482-7282	dominick@nccsp.org
DonCarlos, Kathy	Policy Section/Planning	Minnesota Department of Natural Resources Division of Fish and Wildlife 500 Lafayette Road St. Paul, MN 55155	(p) 651-259-5201	kathy.doncarlos@dnr.state.mn.us
Enquist, Carolyn	Climate Change Ecologist	The Nature Conservancy	(c) 520-904-7098	cenquist@tnc.org
Fleishman, Erica	Director, Conservation and Resource Management Program	National Center for Ecological Analysis and Synthesis 735 State Street, Suite 300 Santa Barbara, CA 93101	(p) 805-892-2530	fleishman@nceas.ucsb.edu
Fortunate, Muyambi	Warden in Research and Monitoring	Uganda Wildlife Authority		mfbenda@yahoo.com
Han, Cindy	Associate Editor, Outdoor American	Izaak Walton League of America 707 Conservation Lane Gaithersburg, MD 20878	(p) 301-548-0150 x205	cindy@iwla.org
Hayward, Greg	Wildlife Ecology Program Leader	USDA, Forest Service Rocky Mountain Region 740 Simms St Golden, CO 80401	(p) 303-275-5022	ghayward01@fs.fed.us

Honey, Leslie	Director of Information Products & Services	NatureServe 1101 Wilson Blvd, 15th Floor Washington, DC 22209	(p) 703-908-1858	leslie_honey@natureserve.org
Kimball, Abigail (Gail)	Chief	U.S. Forest Service Sidney R. Yates Federal Bldg 201 14th Street SW Washington, DC 20024	(p) 202-205-1661	akimball@fs.fed.us
Klein, Mary	President and CEO	NatureServe 1101 Wilson Boulevard, 15th Floor Arlington, VA 22209	(p) 703-908-1802 (f) 703-908-1917	mary_klein@natureserve.org
Kyhl, Sharon	Wyoming Capital City Coordinator	USDA, Forest Service Herschler Building, 3rd Floor West, Rm 3603 122 W. 25th Street Cheyenne, WY 82002	(p) 307-777-6087	skyhl@fs.fed.us
Langner, Linda	Resource Use and Valuation Research, Staff Specialist	U.S. Forest Service, Resource Use and Valuation Research Rosslyn Plaza, Bldg C 1601 N. Kent St. Arlington, VA 22209	(p) 703-605-4886	llangner@fs.fed.us
Lawler, Joshua	Assistant Professor	College of Forest Resources University of Washington Box 352100 Seattle, WA 98195-2100	(p) 206-685-4367 (f) 206-616-6101	jlawler@u.washington.edu
Mall, Amy	Forest Policy Specialist	Natural Resources Defense Council 1809 Mariposa Avenue Boulder, CO 80302	(p) 720-565-0188	amall@nrdc.org
McDonald, Barbara	Social Scientist	USDA, Forest Service Science Quality Services	(p) 706-559-4224 (f) 706-559-4245	babmac@earthlink.net

Mealey, Steve	Board Member	Sporting Conservation Council 42112 Holden Creek Lane Springfield, OR 97478	(p) 541-896-3817	STEVEMEALEY@msn.com
Price, Carol	Wildlife Action Plan Coordinator	NC Wildlife Resources Commission 1721 Mail Service Center Raleigh, NC 27699	(p) 919-707-0227	carol.price@ncwildlife.org
Regan, Claudia	Vegetation and Landscape Ecology Program Leader	USDA, Forest Service Rocky Mountain Region 740 Simms St Golden, CO 80401	(p) 303-275-5004	cregan@fs.fed.us
Robertson, Sean	Teaming with Wildlife Coalition and Communications Assistant	Association of Fish & Wildlife Agencies 444 North Capitol St. NW, Suite 725 Washington DC 20001	(p) 202-624-5363 (c) 202-425-4047 (f) 202-624-7891	srobertson@fishwildlife.org
Schreiner, Tom	Energy Policy Liaison	Colorado Division of Wildlife 6060 Broadway Denver, CO 80216	(p) 303-291-7162 (f) 303-291-7105	Tom.Schreiner@state.co.us
Steele, Dale	Program Manager	Wildlife Species Conservation Program California Department of Fish and Game Sacramento, CA 95814	(p) 916-445-0803 (c) 916-698-1146	Dsteele@dfg.ca.gov
Stein, Bruce	Vice President and Chief Scientist	NatureServe 1101 Wilson Blvd, 15th Floor Washington, DC 22209	(p) 703-908-1830	bruce_stein@natureserve.org
Van Metter, Elise	MS Candidate	Conservation Biology and Sustainable Development Program University of Maryland College Park, MD 20742		elisevanmetter@gmail.com

Wagner, Mary	Deputy Regional Forester, Resources and State and Private Forestry	USDA FS 324 25th Street Ogden, UT 84410	(p) 801-625-5605	mwagner@fs.fed.us
Willcox, Louisa		Natural Resources Defense Council P.O. Box 70 109 West Callender, Rm 8 Livingston, MT 59047	(p) 406-222-9561	lwillcox@nrdc.org
Wright, Robert	Wildlife GIS Specialist	Minnesota Department of Natural Resources	(p) 651-296-3292	robert.wright@dnr.state.mn.us
Zimmerman, Anne	Director, Wildlife, Fish, and Watershed and Air Staff	National Forest Systems USDA FS Yates Building Washington, DC	(p) 202-205-1671	azimmermann@fs.fed.us

Appendix H. Keywords used to classify 828 pieces of climate change literature based on habitat, taxon, location, and subject matter. The keywords WEST, CENTRAL, EAST, Alaska, and Hawaii refer to regions delineated on the U.S. map in Figure 1. Additional keywords not listed here include individual states of the U.S. The number of citations pertaining to each keyword is given.

Habitat or species	No.	Subject	No.	Region	No.
Alpine	28	Agriculture	53	Africa	26
Boreal forest	81	Background information	18	Alaska	42
Coastal	37	Biodiversity	78	Antarctic	2
Desert	32	Carbon sequestration	1	Arctic	24
Forest	223	Climate model	2	Asia	9
Freshwater	34	CO_2 fertilization	37	Australia	14
Grassland	95	Competing models	79	Canada	40
Marine	12	Disease	49	CENTRAL	40
Oak woodland	11	Dispersal	78	Central America	17
Peatland	9	Downscaling	3	China	4
Riparian	6	Drought	58	EAST	60
Savanna	49	Economics	5	Europe	137
Shrubland	43	Ecosystem services	18	Great Basin Region	7
Subalpine forest	18	El Niño	24	Great Lakes Region	4
Subtropical forest	7	Evolution	24	Great Plains Region	11
Temperate forest	151	Extinction	94	Greenland	2
Tropical forest	40	Genetic diversity	11	Gulf Coast Region	3
Tundra/taiga	45	Invasive species	24	Individual U.S. states	282
Vegetation	369	Land use	106	Mexico	7
Wetlands	44	Mgmt recommendations	158	Mid-Atlantic Region	10
		Paleoecology	30	Middle East	1
Mammals	102	Past effects	130	Midwestern U.S.	9
Birds	183	Phenology	102	New Zealand	1
Reptiles	23	Policy	25	North America	31
Amphibians	56	Population increase	8	Northeastern U.S.	8
Invertebrates	68	Productivity	60	Northern U.S.	4
Fish	25	Range shift	241	Pacific N.W.	21
		Resilience	4	Puerto Rico	1
		Risk assessment	10	Rocky Mtn region	22
		Sea level rise	29	Russia	8
		Timber harvest	19	SE Asia	1
		Topography	41	South America	17
		Translocation	2	Southeastern U.S.	14
		Uncertainty	42	Southern U.S.	15
		Wildfire	68	South Pacific	1
				Southwestern U.S.	16
				Tropics	32
				U.S.	344
				WEST	99
				World	100

Appendix I. Detailed list of terminology used to categorize management recommendations made in the literature, used in Table 1.

Term	Application
Adaptive management	For our purposes, this term included adaptive management specifically as well as any call for flexibility in management approach. Adaptive management entails incorporating data collection and an experimental design into a management plan in order to increase understanding of the system and revise management plans as needed based on new data.
Biodiversity maintenance	Most often the authors were interested in maintaining biodiversity in order to ensure adaptability (such as maintaining genotypes that are better suited to future climates). Biodiversity is also considered desirable because higher species richness can make ecosystems more resilient to climate change and invasive species.
Collaboration	References to groups working together or communication among different groups were classified as collaboration. Scientists, land managers, politicians, community groups, states, and countries will need to communicate and develop common goals in order to maintain wildlife populations that are likely to move across borders.
Connectivity	References to corridors or connected habitat in order for species to move from one area to another were listed as connectivity. Often this category was paired with land acquisition when authors suggested that land be added to a preserve or natural area to enhance movement.
Education	Providing information on climate change to the general public.
Habitat manipulation	Any thinning activity, prescribed burns, or other physical manipulation of the habitat in response to climate change was listed as habitat manipulation. Habitat manipulation could also include removing native species from an area or providing irrigation if the climate becomes drier. In contrast, controlling invasive species was considered “restoration” rather than “habitat manipulation”.
Inform managers	Providing information to land managers about climate change projections, potential mitigating factors or adaptation strategies.
Land conservation	Land conservation included all acquisition of land or promotion of conservation principles on privately held

	land, including easements.
Modeling	Modeling could include PVA, risk analysis, climate models, or suggesting the use of regional models instead of global models.
Monitor to detect threshold	Some studies suggested that specific regions (northern or southern boundaries) or indicator species (such as amphibians) can be monitored to detect changes to the system. Similarly, changing conditions may reach a transition point where dominant species are no longer viable and desirable species should be introduced.
Other policy	Other policy recommendations included changes to water policy, changes to land use policy, etc..
Policy	Political solutions were often suggested, such as expanding programs to promote habitat conservation on private lands or providing water rights for wildlife.
Research and monitoring	Research and monitoring included, for example, suggestions for studies of species trends, habitat needs, improved climate models, and data collection.
Restoration and resilience	The term "restoration" was used when some functionality of the ecosystem was suggested to be restored. Invasive species control, restoration of natural stream flow, removal of levees, removal of livestock, relocation of trails or roads, etc. would all be included, and these same measures are called for in order to increase the resilience of a system to climate change.
Slow climate change	Many authors suggested that the most effective way to deal with potential impacts to wildlife and/or habitat is to reduce CO_2 emissions or increase sequestration. Many impacts are already being felt, but some of the more serious impacts can be prevented if drastic action is taken immediately.
Translocation	Due to the fast rate of climate change and fragmentation of habitat, many authors suggested that translocation (assisted migration) of species from one area to another will be necessary to retain specific habitats and for species persistence. Some examples in the literature include reseeding logged areas with species typically found further south, moving desirable southern species into an area to preempt invasion by exotics, and promoting genetic diversity by moving individuals from one population to another.

Appendix J: Species of greatest conservation concern (SGCC) data dictionary:

Data Element	Description
ID	Access database (developed by RMRS) id code
NS_EGT_ID (NatureServe)	The unique global identifier for the species in NatureServe's Biotics database.
NS_EST_ID (NatureServe)	The unique subnational identifier for the species in NatureServe's Biotics database.
STATE	Alpha state abbreviation
TAXA	Taxonomic class
COMMON NAME (SWAP)	Common name as entered in the State Wildlife Action Plan
GENUS (SWAP)	Genus as entered in the State Wildlife Action Plan
SPECIES (SWAP)	Species as entered in the State Wildlife Action Plan
SUBSPECIES (SWAP)	Subspecies as entered in the State Wildlife Action Plan
POPULATION (SWAP)	Population as entered in the State Wildlife Action Plan
FULL_SCI_NAME (SWAP)	Merged name of Genus, Species, and Subspecies as entered in the State Wildlife Action Plan
TAXONOMIC LEVEL	A code created to sort through the infra species designations. Codes are as follows: 1=listed at the species level and: (a) no infraspecific designation given in the State Wildlife Action Plan (SWAP), or (b) both full species and infraspecies are listed. In the latter case the infraspecies entries would get coded as a "7" and the full species entry would get coded as a "1". 2=listed with an infraspecific designation, monotypic within the state (i.e., the only subspecies/population that occurs within that state), treat as a de facto species. 3=listed with an infraspecific designation, polytypic within the state (i.e., multiple subspecies/populations occur), all infraspecific types are listed as sgcc in SWAP, collapse infraspecies into a single de facto species. 4=listed with an infraspecific designation, polytypic within the state, not all infraspecies that occur in the state are listed as a sgcc in the SWAP, do not treat as a de facto species. 5=listed with an infraspecies designation, taxonomy invalid, subspecies is now regarded as a species, and we should treat it as a species. 6=listed with an infraspecies designation, reference appears to be an error (e.g., incorrect subspecies identified for the state), can't regard a de facto species until resolved. 7=listed with an infraspecies designation, but the state chose to list at the species level as well. The infraspecies do not qualify as a de facto species since the full species is listed as a SGCC. 8 = Listed at the species level; taxonomy nonstandard; species is now considered conspecific with another species; do not treat as a species.
G-RANK (SWAP)	The NatureServe Conservation Status (as entered in the State Wildlife Action Plan) of a species from a global (i.e., rangewide) perspective, characterizing the relative rarity or imperilment of the species. For more detailed definitions and additional information see http://www.natureserve.org/exploreer/granks.htm.
N-RANK (SWAP)	The NatureServe Conservation Status (as entered in the State Wildlife Action Plan) of a species from a nation (i.e., State) perspective, characterizing the relative rarity or imperilment of the species. For more detailed definitions and additional information see

	http://www.natureserve.org/exploreer/sranks.htm.
S-RANK (SWAP)	The NatureServe Conservation Status (as entered in the State Wildlife Action Plan) of a species from a subnational (i.e., state) perspective, characterizing the relative rarity or imperilment of the species. For more detailed definitions and additional information see http://www.natureserve.org/exploreer/sranks.htm.
CC_THREAT (SWAP)	Identifies those species that are thought to be impacted by climate change in the State Wildlife Action Plan
NOTES (SWAP)	Entries from the State Wildlife Action Plans worth noting or comments entered by Rocky Mountain Research Station. Most deal with some aspect of taxonomy or natural history.
COMMON NAME (NatureServe)	The common name that NatureServe is tracking for the species according to NatureServe's standard taxonomic sources.
GENUS (NatureServe)	The genus name that NatureServe is tracking for the species according to NatureServe's standard taxonomic sources.
SPECIES (NatureServe)	The species name that NatureServe is tracking for the species according to NatureServe's standard taxonomic sources.
SUBSPECIES (NatureServe)	The subspecies name that NatureServe is tracking for the species according to NatureServe's standard taxonomic sources. NatureServe does not always have a standard entry for subspecies in their database
FULL_SCI_NAME (NatureServe)	The scientific name that NatureServe is tracking for the species according to NatureServe's standard taxonomic sources. This simply merges Genus, Species, and Subspecies entries.
TAXONOMIC CONFLICT WITH NatureServe	This is a code that we created to categorize taxonomic conflicts with NatureServe during the quality assurance checking stage of database construction. Codes are as follows: 1=The SWAP name is a recognized synonym of the name tracked by NatureServe. 2=The SWAP name is based on a nonstandard taxonomy according to NatureServe and could involve an unrecognized synonym, matching a nonstandard taxonomic name, or an unrecognized subspecies. 3=The SWAP name is taxonomically valid but not geographically correct according to NatureServ's taxonomic standards. The entry in FULL_SCI_NAME (NatureServe) is the name tracked by NatureServe for the species within a particular state.
CLASS_STAT (NatureServe)	A field indicating if the FULL_SCI_NAME is considered a standard name, provisional name, or a non-standard concept according to NatureServe's standard taxonomic sources.
ELEVATE (NatureServe)	A field indicating with a "Y" value if NatureServe provided parent species data for a subspecies record that is a valid name but for which NatureServe is not currently tracking in a state.
NOTES (NatureServe)	NatureServe comments regarding the reconciliation of species taxonomy and geographic location with NatureServe's database.
G_RANK (NatureServe)	The NatureServe Conservation Status of a species from a global (i.e., rangewide) perspective, characterizing the relative rarity or imperilment of the species. This entry reflects the species status as of 03 April 2008 and was requested from NatureServe to bring all the Conservation Status ranks reported in the SWAPs to a current and common date. For more detailed definitions and additional information, please see: http://www.natureserve.org/explorer/granks.htm.
RND_G_RANK (NatureServe)	The Global conservation status rank (G_RANK) rounded to a single character. This value is calculated from the G_RANK field using a rounding algorithm to systematically produce conservation status values that are easier to interpret and summarize. Rounded ranks are current to 03 April 2008.
N_RANK (NatureServe)	The NatureServe Conservation Status of a species from a national (i.e., United States) perspective, characterizing the relative rarity or imperilment of the species. This entry reflects the species status as of 03 April 2008 and was requested from NatureServe to bring all the Conservation Status ranks reported in the SWAPs to a current and common date. For more detailed definitions and additional information, please see: http://www.natureserve.org/explorer/nranks.htm.

RND_N_RANK (NatureServe)	The National conservation status rank (N_RANK) rounded to a single character. This value is calculated from the N_RANK field using a rounding algorithm to systematically produce conservation status values that are easier to interpret and summarize. Rounded ranks are current to 03 April 2008.
S_RANK (NatureServe)	The NatureServe Conservation Status of a species from a subnational (i.e., state) perspective, characterizing the relative rarity or imperilment of the species. This entry reflects the species status as of 03 April 2008 and was requested from NatureServe to bring all the Conservation Status ranks reported in the SWAPs to a current and common date. For more detailed definitions and additional information, please see: http://www.natureserve.org/explorer/sranks.htm.
RND_S_RANK (NatureServe)	The Subnational conservation status rank (S_RANK) rounded to a single character. This value is calculated from the S_RANK field using a rounding algorithm to systematically produce conservation status values that are easier to interpret and summarize. Rounded ranks are current to 03 April 2008.
S_ORIGIN (NatureServe)	A field indicating if a species is of native, exotic, or unknown/undetermined origin within a state; a species can have more than one value in this field. Entry reflects the origin status as of 03 April 2008.
N_ORIGIN (NatureServe)	A field indicating if a species is of native, exotic, or unknown/undetermined origin within the United States; a species can have more than one value in this field. Entry reflects the origin status as of 03 April 2008.

Appendix K. Vegetation classes used in the MC1 model for the VINCERA Project[5]

MC1 vegetation classes as related to the Kuchler Vegetation Classes.

Code	MC1 Vegetation Class Name	Code	Kuchler Vegetation Class Name
1	Tundra	52	Alpine meadows and barren
2	Boreal coniferous forest	15	Western spruce-fir forest
		21	Southwestern spruce-fir forest
		93	Great Lakes spruce-fir forest
		96	Northeastern spruce-fir forest
3	Maritime temperate coniferous forest	1	Spruce-cedar hemlock forest
		2	Cedar-hemlock-Douglas fir forest
		3	Silver fir-Douglas fir forest
		4	Fir-hemlock forest
		5	Mixed conifer forest
		6	Redwood forest
4	Continental temperate coniferous forest	8	Lodgepole pine-subalpine forest
		10	Ponderosa shrub forest
		11	Western ponderosa forest
		12	Douglas fir forest
		13	Cedar-hemlock-pine forest
		14	Grand fir-Douglas fir forest
		16	Eastern ponderosa forest
		17	Black Hills pine Forest
		18	Pine-Douglas fir forest
		19	Arizona pine forest
		20	Spruce-fire-Douglas fir forest
		95	Great Lakes pine forest
5	Cool temperate mixed forest	28	Mosaic of 2 and 26 (Oregon oakwoods)
		106	Northern hardwoods
		107	Northern hardwoods-fir forest
		108	Northern hardwoods-spruce forest
		109	Transition between numbers 104 and
		110	Northeastern oak-pine forest
6	Warm temperate mixed forest	29	California mixed evergreen forest
		89	Blackbelt
		90	Live oak-sea oats
		111	Oak-hickory-pine forest
		112	Southern mixed forest
7	Temperate deciduous forest	26	Oregon oakwoods

[5] The MC1 Vegetation Class names are from Bachelet et al. (2001b) and the association to Kuchler Vegetation Classes is from the VEMAP members (1995). The naming convention for the VEMAP classes differs slightly from the MC1 classification; however the Kuchler associations are the same. In VEMAP, type 3 is Temperate maritime coniferous forest; type 4 is Temperate continental coniferous forest; type 6 in VEMAP is Warm temperate/subtropical mixed forest and in VEMAP type 13 is Temperate deciduous savanna.

		98	Northern floodplain forest
		99	Maple-basswood forest
		100	Oak-hickory forest
		101	Elm-ash forest
		102	Beech maple forest
		103	Mixed mesophytic forest
		104	Appalachian oak forest
10	Temperate mixed xeromorphic woodland	30	California oakwoods
		31	Oak-juniper woodland
		32	Transition between 31 (Oak-juniper woodland) and 37 (Mountain mahogany-oak scrub)
		36	Mosiac of 30 and 35
		37	Mountain mahogany-oak scrub
11	Temperate conifer xeromorphic woodland	23	Juniper-pinyon woodland
12	Tropical thorn woodland[6]		
13	Temperate subtropical deciduous savanna	61	Mesquite-acacia savanna
		71	Shinnery
		81	Oak savanna
		82	Mosaic of numbers 74 and 100
		84	Cross timbers
		87	Mesquite-oak savanna
		88	Fayette prairie
14	Warm temperate subtropical mixed savanna	60	Mesquite savanna
		62	Mesquite-live oak savanna
		83	Cedar glades
		85	Mesquite-buffalo grass
		86	Juniper-oak savanna
15	Temperate conifer savanna	24	Juniper steppe woodland
17	C3 grasslands	47	Fescue-oatgrass
		48	California steppe
		50	Fescue-wheatgrass
		51	Wheatgrass-bluegrass
		63	Foothills prairie
		64	Grama-needlegrass-wheatgrass
		66	Wheatgrass-needlegrass
		67	Wheatgrass-bluestem-needlegrass
		68	Wheatgrass-grama-buffalo grass
18	C4 grasslands	53	Grama-galleta steppe
		54	Grama-tobosa prairie
		65	Grama-buffalo grass
		69	Bluestem-grama prairie
		70	Sandsage-bluestem prairie
		74	Bluestem prairie

[6] No Kuchler vegetation types were shown for Tropical thorn woodland in VEMAP members (1995)

		75	Nebraska Sandhills prairie
		76	Blackland prairie
		77	Bluestem-sacahuista prairie
19	Mediterranean shrubland	33	Chaparral
		34	Montane chaparral
		35	Coastal sagebrush
20	Temperate arid shrubland	38	Great Basin sagebrush
		39	Blackbrush
		40	Saltbrush-greasewood
		55	Sagebrush steppe
		56	Wheatgrass-needlegrass shrubsteppe
		57	Galleta-three awn shrubsteppe
21	Subtropical arid shrubland	41	Creosote bush
		42	Creosote bush-bur sage
		43	Palo verde-cactus shrub
		44	Creosote bush-tarbush
		45	Ceniza shrub
		58	Grama-tobosa shrubsteppe
		59	Trans-pecos shrub savanna