VII. Case Studies

A number of climate change vulnerability assessments for species and ecosystems have been completed or are currently underway across the country. The following seven case studies provide examples of some of the different assessment approaches described in this guide and demonstrate the considerable variability that is possible in terms of assessment scale and scope.

The first four studies are broader, "coarse filter" approaches, which can provide users with a useful tool to compare relative vulnerability across a range of targets and at varying degrees of detail. These approaches are based primarily on static attributes of species, habitats, and ecosystems, and they do not involve the direct use of dynamic simulation models (although Case Studies 1 and 3 incorporate use of a tool for downscaling relevant climate data). Refuges, state agencies, or protected areas that are well staffed may have the capacity to conduct these types of assessments primarily with existing staff.

The fifth case study, which highlights a habitat-based assessment and a subsequent assessment of associated species, involved the use of a habitat response model to project the impacts of sea-level rise on coastal wetland communities, based on existing scenarios for sea-level rise. Approaches such as this often require the use of expertise that may not normally be available at one site but that may be accessible through partnerships with other agencies, organizations, or individuals.

The sixth study applied an integrated climate change assessment and adaptation framework in the Four Corners region of the Southwest, building on the completion of a state-wide vulnerability assessment and two adaptation-oriented workshops for natural resource managers in New Mexico. The assessment entailed evaluation of the level of climate exposure (based on regionally downscaled data) in relation to existing conservation priorities identified in the four states' Wildlife Action Plans and ecoregional assessments. This enabled managers to prioritize vulnerable landscapes for adaptation action.

The final case study is the broadest and most ambitious assessment described in this guide. The assessment encompasses a very large spatial scale and a broad range of habitats and species. The study incorporates elements of other approaches, including detailed species-specific data, dynamic climate projections, and climate–space niche models to identify vulnerable species, biodiversity "hotspots" at risk, and habitats at risk to climate-induced changes. Table 7.1 provides a general summary of each of these case studies.

Table 7.1: Summary of Case Studies

	1. Nature-Serve Nevada Species Assessment	2. EPA Endangered Species Framework	3. Species Assessment for the Middle Rio Grande	4. State-level Habitat Assessment for Mass.	5. Coastal Habitats and Species	6. Integrated Framework for the Four Corners	7. Pacific Northwest Assessment
Location and Extent	Nevada, statewide	National	New Mexico, regional	Massachusetts, statewide	Chesapeake Bay Region (two studies)	Southwest, Four Corners region	Pacific Northwest, regional
Status	In progress	Completed	Completed	Completed	Completed	Phase 1 Completed	In progress
Targets	263 priority animal species (invertebrates and vertebrates)	Six threatened and endangered vertebrate species	Terrestrial vertebrate species occupying riparian habitats	20 habitats	5.1: Coastal wetland habitats 5.2: Marsh bird species of concern	Species and habitats identified as conservation priorities	Species and habitats
Climate Change Models?	Yes, down-scaled climate data based on ClimateWizard	No (used published projections)	Yes, down-scaled climate data based on ClimateWizard, and published projections	No (used published projections)	No (used published projections)	Yes, down-scaled climate data based on ClimateWizard	Yes, down-scaled climate data based on multiple model simulations
Other Models?	General characterization	General characterization, expert opinion	General characterization, expert opinion	General characterization, expert opinion	Habitat and occupancy model (SLAMM)	General characteriza-tion, expert opinion	Climate niche, habitat, and hydrological models
Detail	Low	Moderate	Low	Moderate	Moderate	Low	High
Work/ Time	Low (application time per species = 30-45 minutes)	Moderate	Moderate	Moderate (1 year)	Low-Moderate 5.1=1 year 5.2=4 months	Moderate (2.5 years)	High (3-4 years)
Cost	$160,000	$60,000	$60,000	$70,000	5.1: $40,000 5.2: $25,000	$200,000	$800,000
Lead	B. Young	H. Galbraith	D. Finch	H. Galbraith	5.1: P. Glick 5.2: M. Wilson	C. Enquist	J. Lawler
Citations	Young et al. (in press)	U.S. EPA 2009	USDA Forest Service, Rocky Mountain Research Station 2010	Manomet Center for Conservation Sciences and MDFW 2010a, 2010b	5.1: Glick et al. 2008a, 2008b 5.2: Wilson and Watts 2009	Enquist and Gori 2008	Lawler et al. 2009, 2010

Case Study 1. NatureServe's Climate Change Vulnerability Index for Species in Nevada

This case study highlights how an accessible "vulnerability index" can be used to readily assess the impacts of climate change on species of concern at a state-wide scale. The state of Nevada is emerging as a leader in addressing how climate change alters the way states need to manage species and habitats to maintain biodiversity. In 2008, a coalition of Nevada state agencies and nonprofits initiated activities to revise their state Wildlife Action Plan to fully address the effects of climate change. These organizations are now well advanced in the research and review exercises that will form the basis of their revisions. This case study describes how one member of the coalition, the Nevada Natural Heritage Program, is contributing to this effort by using the Climate Change Vulnerability Index developed by NatureServe to conduct rapid assessments of the relative vulnerability of Conservation Priority Species.

Purpose

Although Nevada's original Wildlife Action Plan (2006) identified climate change as a stressor to key habitats and species, it did not go into detail about how climate warming could cause substantial ecosystem change or what management actions are necessary to stem the loss of wildlife.

Mike Peterson

By 2008, it was clear to the groups that had developed and were responsible for implementing the Plan that an amendment was necessary to adequately reflect the major changes needed to manage for biodiversity under conditions of rapid climate change. Updating the Plan to account for climate change would also position the state to receive federal funding that might come from climate change legislation. Additionally, funding was available through the Division of State Land's Question One Conservation Bond Program. Thus, the partners, including the Nevada Department of Wildlife, The Nature Conservancy, Nevada Natural Heritage Program, Lahontan Audubon Society, and Great Basin Bird Observatory, successfully applied for funding to develop this amendment.

Conservation Objective

The objective of the project is to broaden the applicability of Nevada's Wildlife Action Plan to understand the health of the state's wildlife, including vulnerability to

Lead authors: Bruce Young, Jennifer Newmark, and Kristin Szabo.

climate change, and to prescribe actions to conserve wildlife and key habitats before they become more rare and costly to protect. The Plan develops objectives and strategies for the conservation of 27 key habitats found in the state.

Assessment Targets

Nevada Natural Heritage is responsible for assessing the vulnerability of all 263 Conservation Priority species that were identified in the original Wildlife Action Plan. The species include 1 mussel, 74 snail, 40 fish, 7 amphibian, 20 reptile, 72 bird, and 49 mammal species. Once this assessment is completed, the outcome will contribute to habitat vulnerability models run by a partner organization. Nevada Natural Heritage hopes to eventually extend the vulnerability assessment to many more species, including plants and abundantly distributed species.

Scale and Scope

The Nevada assessment is restricted to a state-wide analysis. Developing future regional assessments that examine how species may expand into and retreat from states would be helpful to provide a more comprehensive picture of the complex changes in population size and location taking place. Currently, though, existing funding mechanisms favor state-based approaches. The time scale for the species vulnerability assessments is mid-century. Mid-century represents a time frame that is before the major climate models and emissions scenarios begin to have widely divergent predictions, resulting in less uncertainty than for longer time horizons.

In terms of cost and time, once the distribution of natural history information on a species is researched and compiled—NatureServe has already done this for many species (available at NatureServe Explorer, http://www.natureserve.org/explorer)—it can take as little as 30–45 minutes to rank a species. The cost of this assessment will be approximately $160,000.

Assessment Approach

The Nevada partners have divided the tasks according to each organization's strengths:

- The **Department of Wildlife** provides oversight and management of the project in coordination with the other partners. It organizes team meetings and helps solicit public comments on draft documents. The Department of Wildlife will also be responsible for interacting with the U.S. Fish and Wildlife Service to obtain formal approval for revisions to the Wildlife Action Plan.

- As stated above, the **Nevada Natural Heritage Program** is responsible for assessing the vulnerability of the individual Conservation Priority species to climate change.

- **The Nature Conservancy** will use a modeling approach to understand the vulnerability of Nevada habitats to climate change.

- The **Lahontan Audubon Society** will help facilitate workshops, work with the public, perform outreach activities, and help edit document drafts as they are written.

- The **Great Basin Bird Observatory** will use climate envelope models to estimate how bird distributions may shift as a result of climate change. Like the species assessments undertaken by Nevada Natural Heritage, the results of these models will form input into The Nature Conservancy habitat models.

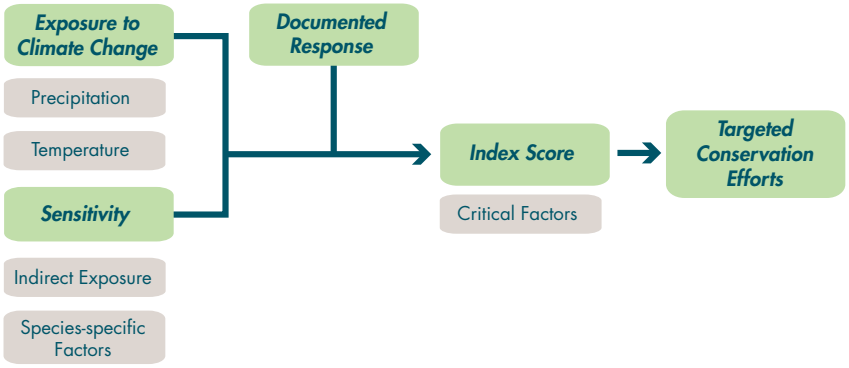

Figure C1.1. Framework for NatureServe's Climate Change Vulnerability Index.

Nevada Natural Heritage had a limited amount of funding and a short time frame for completing its task of reviewing the vulnerability of a large number of species. The program elected to use the Climate Change Vulnerability Index as a rapid and cost-efficient means of completing this task.

The Index separates a species' vulnerability into two main components: exposure to climate change within its range and inherent sensitivity to climate change (Williams et al. 2008) (see Figure C1.1). Data for these two components take the form of downscaled climate predictions across the range of the species within the assessment area (in this case, the state of Nevada) and scoring of the species against 17 factors related to its anticipated climate change sensitivity, such as dispersal ability and habitat specificity. Additional factors addressing exposure and adaptive capacity, such as natural or anthropogenic barriers to dispersal, as well as observed responses to climate change (if available) are also included. These factors are all documented in the scientific literature to be correlates or predictors of vulnerability to climate change. The outcome is one of six possible Index categories: three Vulnerable (Extremely, Highly, and Moderately), two Not Vulnerable (Presumed Stable, Increase Likely), and one Insufficient Evidence. The Index complements standard conservation status assessments such as the NatureServe G- and S-rank system that contributed to species' designation as Conservation Priorities in the original Wildlife Action Plan. More information about the Index as well as the Index itself can be found at http://www.natureserve.org/climatechange.

Biologists from Nevada Natural Heritage used distribution and natural history information from their databases together with climate predictions downloaded from the ClimateWizard to complete assessments for all 263 Conservation Priority species. Next, they convened a panel of independent biologists familiar with Nevada wildlife to review their work and confirm or adjust how the factors were scored for each species. This process is currently ongoing and will result in final assessments that feed into habitat vulnerability models that will form another section of the revised Wildlife Action Plan.

Assessment Results

Like most of the world, Nevada will experience significant warming. Mid-century climate predictions suggest warming of 2.6 to 3.2 degrees Celsius and slight decreases or increases in precipitation in different parts of the state (Maurer et al. 2007). Results for a preliminary assessment of 216 vertebrates and mollusks listed as Conservation Priority species in the Nevada Wildlife Action Plan revealed that the Index sorted taxa into widely differing levels of vulnerability to climate change (Figure C1.2). Mollusks and fish were the most highly vulnerable groups, whereas some mammals and fish may increase their abundance or expand their ranges in Nevada as the climate warms. Demonstrated adaptation to a limited range of precipitation regimes, migration to or through a few restricted and potentially vulnerable locations or lack of regular distribution shifts in response to environmental conditions, and dependence on specific vulnerable aquatic/wetland habitats were the factors that most commonly contributed to vulnerability to climate change. Surprisingly, anticipated land-use changes designed to reduce greenhouse gas emissions as a means to mitigate climate change (such as solar, wind, and geothermal projects) are another factor contributing to vulnerability for some species due to associated habitat loss and fragmentation. Good dispersal ability, broad physical habitat requirements, migration to broad geographical areas or a tendency to shift distribution in response to environmental conditions, and demonstrated adaptation to a broad range of temperatures were the factors that most commonly decreased vulnerability. One noteworthy outcome is that the Index flagged a number of currently common species (i.e., NatureServe global conservation status rank G4 or G5) such as the American pika, bighorn sheep, and sagebrush vole as vulnerable to climate change. Thus, conservation status is not a reliable proxy for vulnerability to climate change.

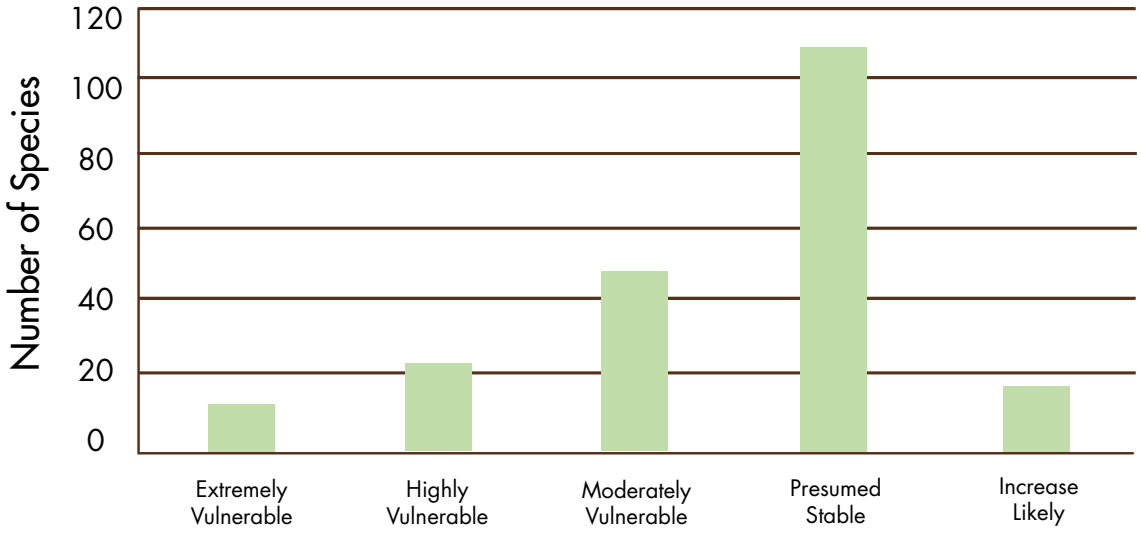

Figure C1.2. Vulnerability of Nevada Conservation Priority species as calculated by the Climate Change Vulnerability Index.

Uncertainties

This assessment addressed uncertainty in two ways. One source of uncertainty concerns the differing projections by climate models of mid-century temperature and precipitation regimes in Nevada. The Nevada Natural Heritage Program addressed this uncertainty by using an average of an ensemble of 16 global circulation models as the exposure data for the Climate Change Vulnerability Index. The results therefore are not tied to any single climate model.

A second source of uncertainty relates to how a particular species is scored against the Index sensitivity factors. Incomplete knowledge about a species' natural history and how it affects vulnerability for a particular factor can add uncertainty to the overall vulnerability score. The Index allows users to select more than one vulnerability value for each factor to reflect this uncertainty. The Index calculates an overall vulnerability score using an average of the values assigned for each factor, but also runs a Monte Carlo simulation to explore the probability that the overall score could change depending on what the "true" value might be for each factor scored with multiple values. The Index calculates a measure of confidence in species information (very high, high, moderate, or low) depending on the percentage of Monte Carlo runs that yield the same overall vulnerability score as calculated with the averaged data. For the Nevada species, the Monte Carlo simulations revealed that confidence in the Index score was very high or high for 61 percent, moderate for 27 percent, and low for 12 percent of the species (Young et al., in press).

Outcomes and Next Steps

As review of the assessments of the full set of Conservation Priority species is completed, The Nature Conservancy is assessing the vulnerability of key habitats to climate change. Subsequently, the partners will examine the Index results for each species, including the factors that most frequently led to species being categorized as vulnerable, the habitat model results, and the bird models produced by the Great Basin Bird Observatory to determine the management strategies necessary to create resilient wildlife populations and mitigate potential impacts to climate change. After receiving comments from the public, the partners will finalize the text of the climate change amendment to the Plan and submit it to the U.S. Fish and Wildlife Service for formal approval.

An amended Wildlife Action Plan will not accomplish its objective unless its recommendations are put into practice. The partners responsible for preparing the climate change amendment also make up the implementation team for the Plan. As part of their work on the team, they will work to incorporate the recommendations from the Plan into ongoing private, state, and federal management activities. These actions will take many forms depending on the purview of each agency. The Nevada Natural Heritage Program will use the results of the vulnerability assessment to target particularly vulnerable species for monitoring. Comprehensive information on the locations and biological conditions of vulnerable species will contribute to proactive management decisions that could result in decreased conflicts between wildlife and development in the future. For example, monitoring data for a species

that has limited dispersal ability or is encountering barriers to dispersal could provide an early indication of when translocations of populations should be considered.

In conjunction with implementation activities, the partners are participating with the Heinz Center and the Wildlife Habitat Policy Research Program to use performance measures to monitor the effectiveness of management actions. For priority conservation goals, they have begun to develop logic models that pictorially describe pathways by which factors can affect a conservation goal. The models point to specific indicators that can be measured to monitor progress toward each conservation goal. This approach allows the partners to gauge their success and alter their strategies when needed, before wasting resources on ineffective actions.

Challenges and Lessons Learned

One challenge in developing the Index was deriving and calibrating criteria for diverse plants and animals. Research in the past decade has led to a substantial increase in understanding about the factors that correlate with climate change vulnerability, but analyses are typically available only for selected taxonomic groups. Assembling an interdisciplinary team to develop, test, and refine the Index proved necessary to address how the myriad natural history attributes of North American plants and animals confer increased or decreased vulnerability to climate change.

Nevada's approach of having a general biologist perform preliminary assessments and then inviting specialists to review the results in a workshop setting proved to be successful. The specialists provided a broader interpretation of the criteria, and their individual expertise with particular species went beyond information found in the published literature. The general biologist provided leadership for the process and ensured that the criteria were applied consistently across taxa. Also, an advantage to carrying out the assessments within the Nevada Natural Heritage Program was the easy access to spatial information about the locations of populations of Conservation Priority species for calculating exposure.

Case Study 2. U.S. Environmental Protection Agency's Threatened and Endangered Species Vulnerability Framework

Purpose

This case study provides an overview of a framework developed to assess the relative vulnerabilities of threatened and endangered animal species to climate change and existing stressors.

Lead authors: Hector Galbraith and Jeff Price.

Conservation Objective

Organisms listed as Threatened or Endangered (T&E) under the Endangered Species Act suffer a significant risk of extinction due to the adverse effects of current natural or anthropogenic stressors. Climate change, either acting alone or by exacerbating the effects of these existing stressors, may constitute an important new threat for many of these species (Peters 1992; Schneider and Root 2002). If future conservation priorities, strategies, tactics, and resource allocations are to reflect these changing circumstances, there is a need to develop new conservation tools. In particular, tools are needed that integrate the likely effects of both current and climate change stressors to identify the T&E species that may face the greatest increased risk of extinction or major population reductions, and the specific climatic, physiological, and/or ecological factors that contribute to these increased risks.

Assessment Targets

For this study, the T&E vulnerability framework was tested on six T&E species: bald eagle (now removed from the T&E list), golden-cheeked warbler, salt marsh harvest mouse, Mount Graham red squirrel, desert tortoise, and the Lahontan cutthroat trout. These species were selected because they are very different in their ecologies, demographics, status and distribution, population trends, and susceptibilities to different stressors and, because of these differences, provide an adequate test of the framework.

Steve Maslowski/USFWS

Scale and Scope

This framework can be applied at a range of spatial and temporal scales, depending on the habitat range of the focus species as well as the climate change scenarios used.

Assessment Approach

Framework Structure

The framework for evaluating risks to a T&E species due to climate change and other stressors comprises four connected modules and a narrative (Figure C2.1). Module 1 categorizes the comparative vulnerabilities of T&E species to existing stressors (i.e., not including climate change). This "baseline" vulnerability is subsequently combined with the categorization in Module 2 (evaluating vulnerability to climate change) into an estimate of overall future vulnerability in Module 3. Module 4 combines certainty scores from Modules 1 and 2 into an evaluation of the overall degree of certainty that we can assign to the framework predictions. The narrative that accompanies each species' evaluation details the rationales and justifications for the assigned scores in Modules 1 and 2.

The Narrative. Most categorizations in Modules 1 through 4 will be based largely on the results of literature reviews for each species being evaluated and on expert

judgment. The narrative module of the framework reports the relevant results of those reviews and opinions, and it includes the justifications for the individual categorization scores in the modules. Thus, the primary aim of the narratives is to make the thought process and assumptions that result in the scores in Modules 1 through 4 transparent.

The narratives have three additional important aims:

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

2. To identify and describe the roles of the main stressors (climate and non-climate) in the estimate of vulnerability of the study species

3. To qualitatively describe potential population responses of the study species to the addition of climate change to the already existing stressors, and any resulting change in extinction risk

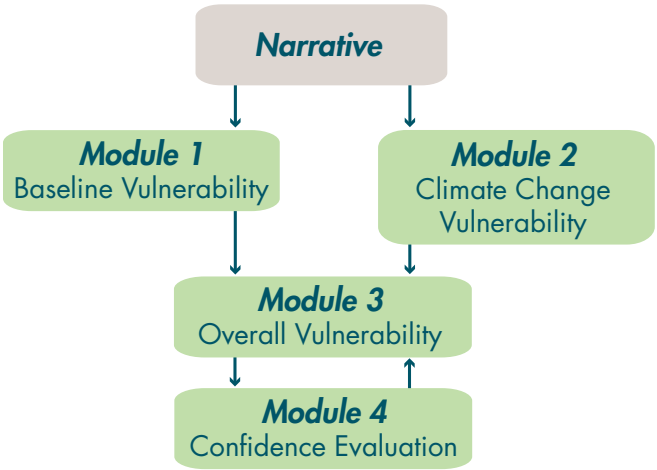

Figure C2.1. Framework for T&E Species Vulnerability Assessment.

Narratives for the species evaluated in this case study are available in the full (U.S. EPA 2009) publication.

Module 1—Evaluating Baseline Vulnerability. The probable baseline (i.e., current) vulnerability of the study species to extinction or major population reduction is categorized by scoring those elements of its ecology, demographics, and conservation status that influence the likelihood of its survival or extinction (irrespective of the potential effects of future climate change). There are 11 variables included in this module: (1) current population size, (2) population trend in the last 50 years, (3) current population trend, (4) range trend in last 50 years, (5) current range trend, (6) current (non-climate) stressors, (7) likely current stressor future trends, (8) individual replacement time, (9) future vulnerability to stochastic events, (10) future vulnerability to policy/management changes, and (11) future vulnerability to natural stressors. Each of these variables is assigned a numerical score (e.g., 1 for current population size of <100 vs. 6 for current population size of >50,000), reflecting their ordinal rankings. These individual scores are then combined in Module 1 into one of four baseline vulnerability rankings: critically vulnerable (Vb1) for those with a score of less than 18; highly vulnerable (Vb2) for a score of 18–25; less vulnerable (Vb3) for a score of 26–33; and least vulnerable (Vb4) for a score greater than 33.

Module 2—Evaluating Vulnerability to Climate Change. In this module, the likely vulnerability of a species to future climate change is assessed and categorized by scoring those elements of its physiology, life history, and ecology that will likely be

important determinants of its responses. This is based on determining ordinal rankings for 10 Module 2 variables: (1) physiological vulnerability to temperature, (2) physiological vulnerability to precipitation change, (3) vulnerability to climate change–induced extreme weather events, (4) dispersive capability, (5) degree of habitat specialization, (6) likely extent of habitat loss due to climate change, (7) abilities of habitats to shift at same rate as species, (8) habitat availability within new range of species, (9) dependence on temporal interrelationships, and (10) dependence on other species. Again, each of these variables is assigned a numerical score (e.g., 1 for high sensitivity to a temperature increase vs. 4 for a species likely to benefit from temperature increase). The numerical scores for the 10 variables are then combined into an overall evaluation of the species' potential vulnerability to climate change: critically vulnerable (Vc1); highly vulnerable (Vc2); less vulnerable (Vc3); and least vulnerable (Vc4), likely to benefit from climate change.

Module 3—Evaluating Overall Vulnerability. In this module, the "best estimate" scores from Modules 1 and 2 are combined into a matrix to produce an overall best estimate evaluation and score of the species' vulnerability to climate change and important existing stressors (Table C2.1).

Module 4—Certainty Evaluation. The approximate level of certainty with which each "best estimate" score in Modules 1, 2, and 3 is categorized separately in the modules. These are codified as high (approximate probability of 70 percent or more), medium (approximate probability between 30 and 70 percent), or low (less than approximately 30 percent). These qualitative scores correspond to numeric scores of 3, 2, and 1, respectively. In Module 4, the best estimate certainty scores assigned to each of the variables in Modules 1 and 3 are combined into an index of the certainty associated with the overall vulnerability score in Module 3. The total minimum score (Modules 1 and 2 combined) is 20, while the maximum is 60. The numeric range between the two is arbitrarily and approximately equally divided into three categories: High, Medium, and Low certainties and a final certainty evaluation applied to each species.

Table C2.1. Module 3 - Overall Vulnerability Best Estimate Scoring Matrix

	Baseline (Module 1) Vulnerability Scores			
Climate change (Module 2) Vulnerability scores	Vb1	Vb2	Vb3	Vb4
Vc1	Vo1	Vo1	Vo2	Vo3
Vc2	Vo1	Vo1	Vo2	Vo3
Vc3	Vo1	Vo2	Vo3	Vo4
Vc4	Vo1	Vo2	Vo3	Vo4
Vc5	Vo2	Vo3	Vo4	Vo4

Important Framework Attributes

Process Transparency. The intended end result of the framework is to produce evaluations of the relative vulnerabilities of T&E species to climate change and other stressors. However, it is important that the process and reasoning through which the evaluation was arrived at be well documented and transparent. This will be essential in modifying species evaluations if new data are gathered that cast doubt on

previous assessments. Ensuring process transparency and documenting important assumptions is as important a component of the framework as producing predictive scores.

Framework Precision and Accuracy. The results of a predictive framework will be speculative. Thus, in the absence of a posteriori knowledge, this framework provides approximations of species' ranked vulnerabilities. It is not intended that its results be considered completely accurate or precise estimations of a species' absolute vulnerability—the results should be regarded as indications of the comparative vulnerabilities of T&E species.

Treatment of Certainty/Uncertainty. See below.

Sources of Information and Expert Opinion. Some of the scores determined in this framework may be based on quantitative and empirical data (e.g., abundance estimates based on actual census data) published in peer-reviewed scientific or "gray" literature. However, for many less well-studied species, it is likely that many of the framework scores will be based not on actual empirical data, but will comprise rankings based on expert opinion.

Some species may benefit from climate change. Not all species may be adversely affected by climate change; it is possible some may benefit from new climatic regimes (for example, due to their habitats being expanded, or to their competitors or predators being adversely affected). It is essential that an effective framework reflect this reality.

Table C2.2. Summary of Species Evaluation Results

Species	Module 1 Baseline Scores	Module 2 Climate Change Scores	Module 3 Best Estimate Scores	Module 3 Alternate Scores	Module 4 Certainty Score
Golden-cheeked warbler	Vb2 (highly vulnerable	Vc1 (critically vulnerable)	Vo1 (critically vulnerable)	Vo2 (highly)	High
Bald eagle	Vb3 (less vulnerable)	Vc3 (less vulnerable)	Vo3 (less vulnerable)	Vo2, Vo4 (highly, least)	High
Salt marsh harvest mouse	Vb2 (highly vulnerable	Vc2 (highly vulnerable)	Vo1 (critically vulnerable)	Vo1, Vo2 (critically, highly)	Medium
Mount Graham red squirrel	Vb2 (highly vulnerable)	Vc2 (highly vulnerable)	Vo1 (critically vulnerable)	Vo1, Vo2 (critically, highly)	High
Desert tortoise	Vb3 (less vulnerable)	Vc2 (highly vulnerable	Vo2 (highly vulnerable)	Vo1, Vo3 (critically, less)	Medium
Lahontan cutthroat trout	Vb2 (highly vulnerable)	Vc2 (highly vulnerable)	Vo1 (critically vulnerable)	Vo1, Vo2 (critically, highly)	Medium

Assessment Results

The results of running the evaluative framework on the six test T&E species is shown in Table C2.2. The golden-cheeked warbler, salt marsh harvest mouse, Mount Graham red squirrel, and Lahontan cutthroat trout were categorized as "critically vulnerable." The desert tortoise was ranked "highly vulnerable," and the bald eagle (no longer listed as threatened or endangered, except for the Southwest population) was scored "less vulnerable." Species that are most vulnerable tend to be: restricted in their distributions, small in population size, undergoing population reductions, habitat specialists, and found in habitats that are likely to be most adversely affected by future climate change. Conversely, species like the bald eagle, which are widely distributed, are flexible in their habitat preferences and are considered to be stable or increasing, scored least vulnerable. Thus, the predictions of the model are consistent with what might be expected based on the ecologies and demographics of the test species.

Uncertainties

Uncertainty is inevitable when attempting to anticipate the effects of future stressors on organisms. Such uncertainty may have many sources, including the specifics or variability of likely future climates, the physiological sensitivity of the species, uncertainty about its demographics, population dynamics, or habitat ecology, or about the likely responses of habitats, or critical habitat components, to climate change. Any prediction regarding future vulnerability would be of limited practical value without an evaluation of the certainty/uncertainty associated with it. In this framework the degree of certainty is assessed in two ways. First, when scoring each module variable, "best estimate" and alternate (possible but less likely) scores are assigned by those applying the framework, based on the information gleaned in the literature. These are intended to capture the range of responses that may occur, rather than focusing on a single "point estimate" of responses. Second, each individual variable score is assigned a ranking certainty evaluation (i.e., high, medium, or low level of certainty). This three-point ranking is based on the five-category scale developed for the IPCC Third Assessment Report (Moss and Schneider 2000) (see Chapter V). These rankings are then combined into an assessment of the degree of certainty that should be associated with the final assessment of the species' overall vulnerability. For the species tested, the greatest uncertainties are associated with our relatively poor knowledge about the potential for direct, physiological effects on animal species; relationships between changes in temperature and precipitation regimes and the physiologies and behaviors of animals are apparently poorly understood.

Outcomes and Next Steps

This framework was developed for the U.S. Environmental Protection Agency's Office of Research and Development. The full report is currently awaiting publication and general release. For information on when this will occur or for a copy of the full report, readers should contact Susan Herrod-Julius at: Julius.susan@epa.gov.

Case Study 3. Species Vulnerability Assessment for the Middle Rio Grande, New Mexico

Summary

This case study describes a method for scoring terrestrial species that have potential to be vulnerable to climate change. The assessment tool seeks to synthesize complex information related to projected climate changes into a predictive tool for species conservation. The tool was designed to aid managers in prioritizing species management actions in response to climate change projections. We describe an application of the scoring tool to terrestrial species in a specific geographical region, the Middle Rio Grande of New Mexico, and provide a synopsis of the results of this regional assessment.

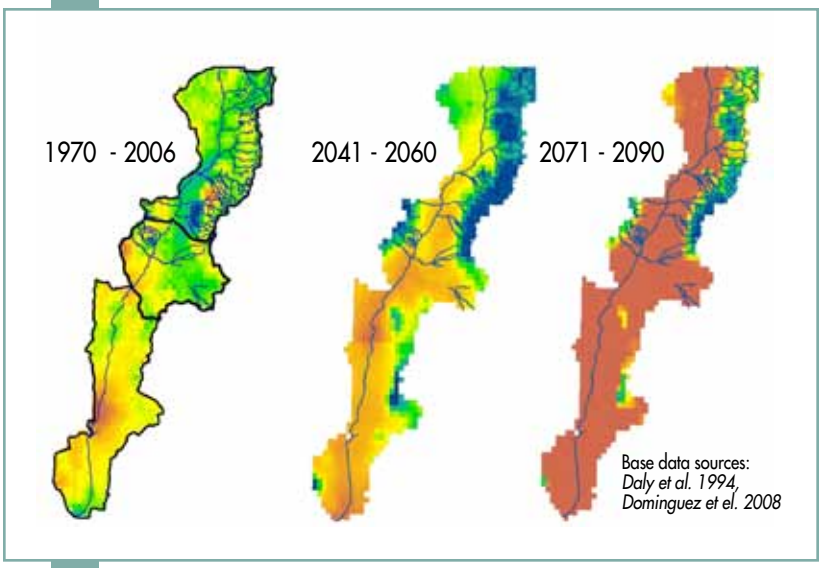

Figure C3.1. Current and future moisture stress in Upper and Middle Rio Grande. 1970—2006 = trend in moisture deficit. Preliminary future forecast: 2041–2060 = departure (difference) in deficit relative to 1951–2006 baseline; 2071–2090 = departure in deficit relative to 1951–2006 baseline (Bosque Working Group 2008).

Background

Land managers need adaptation and mitigation strategies to manage species within the context of ecosystem responses to a changing climate and varying responses of individual species. The U.S. Forest Service Rocky Mountain Research Station (RMRS) in Albuquerque is creating scientifically based decision-support tools for managers to anticipate climate-related changes and respond strategically to managing those effects. Vulnerability of species and populations to changes induced by global warming will be assessed using a scoring system being designed by RMRS. This system assigns scores from synthesized information related to the probability of climate-related population declines due to a number of factors, including: natural disturbances (e.g., flooding, wildfire); breeding requirements (e.g., link with seasonal food resources, breeding ponds); nonbreeding requirements (e.g., habitat changes, stopover sites); dispersal potential (e.g., connectivity of habitats, mobility); and exacerbating factors (e.g., rarity, proximity to human populations). Scores for an individual species are then combined to create an overall prediction of vulnerability to climate change.

Lead authors: Deborah M. Finch, Megan M. Friggens, and Karen E. Bagne.

The Bosque or riparian forest along the Middle Rio Grande has high value for wildlife but because of competing land and water uses is also vulnerable to degradation. Global climate predictions include higher temperatures in the Southwest, more variable rainfall, and more drought periods, which are conditions that will exacerbate the present issues (Christensen et al. 2007). Moisture stress along the Upper and Middle Rio Grande is projected to increase dramatically through this century (Figure C3.1). In addition, human populations in the region are expected to grow considerably, putting more pressure on natural systems competing for resources. Management actions can often be taken to mitigate impacts, but is most effective when scientifically based and anticipatory rather than reactionary. Land managers for the Middle Rio Grande Bosque would benefit from knowledge related to projected effects of climate change on species in their area. Depending on actions and magnitude of climate change effects, this strategy will help conserve biodiversity.

Purpose

This case study documents a new method for assessing the relative risk to persistence of individual species under projected changes in temperature, precipitation, and related climate phenomena (Bagne and Finch 2008). The RMRS assessment consists of a scoring system focused on simple predictive criteria for terrestrial vertebrate species and was specifically designed to be applied by managers. Relative vulnerability is assessed through the use of scores generated for individual species. The assessment is a flexible system that allows the user to incorporate data and information from a variety of sources. In addition, new information can be incorporated into the scoring process as climate modeling becomes more sophisticated and predictions more precise. Identification of the most vulnerable species, those with the highest scores, is one step toward implementing an effective management program.

In this case study, we summarize results from a final report (USDA Forest Service RMRS 2010) delivered April 2010 to our sponsors, U.S. Fish and Wildlife Service Region 2 (Bosque Improvement Initiative) and the U.S. Forest Service, Washington Office. The final report describes an application of the tool to species in a specific geographical region known as the Middle Rio Grande.

Conservation Objective

Global climate change has the potential to affect habitats and species worldwide within a relatively short period of time and, in fact, appears to already be altering ecosystems (reviewed by McCarty 2001; Peñuelas and Filella 2001; Root et al. 2003). In addition to current conservation challenges such as habitat loss, toxins, and exploitation that have long been part of species management programs, current climate change is relatively new and its impact is expected to grow. Already a number of species have been identified as at risk to changes in climate in New Mexico. With increasing droughts projected, populations of those species sensitive to drought conditions such as white-tailed ptarmigan, southwestern willow flycatcher, and Goat Peak pika are likely to decline (Enquist and Gori 2008). Particular habitat types, such as alpine tundra, are expected to decline along with the species dependent on them (Walther et al. 2005).

Assessment Targets

This assessment focused on the terrestrial vertebrate species occupying riparian habitats (known locally as "the Bosque," a Spanish word meaning "forest") along the Middle Rio Grande in New Mexico. This area is bounded by Elephant Butte Reservoir to the south and Cochiti Dam to the north. We created a future climate scenario for the Middle Rio Grande Bosque as well as upland areas surrounding the Bosque. Vertebrate species for the region were initially identified using the *Field Guide to the Plants and Animals of the Middle Rio Grande Bosque* (Cartron et al. 2008). Archival Middle Rio Grande data on birds, amphibians, reptiles, and bats (from D. M. Finch, RMRS) were also used to identify species for scoring. We removed species that were not resident within the Middle Rio Grande Bosque for at least part of the year, as well as those species that occur primarily in upland habitats. Rare species were included only if they were known to breed within the Bosque. Species that used the riparian corridor solely for migration, or otherwise had an intermittent or transient presence within the Bosque, were not included in the assessment list.

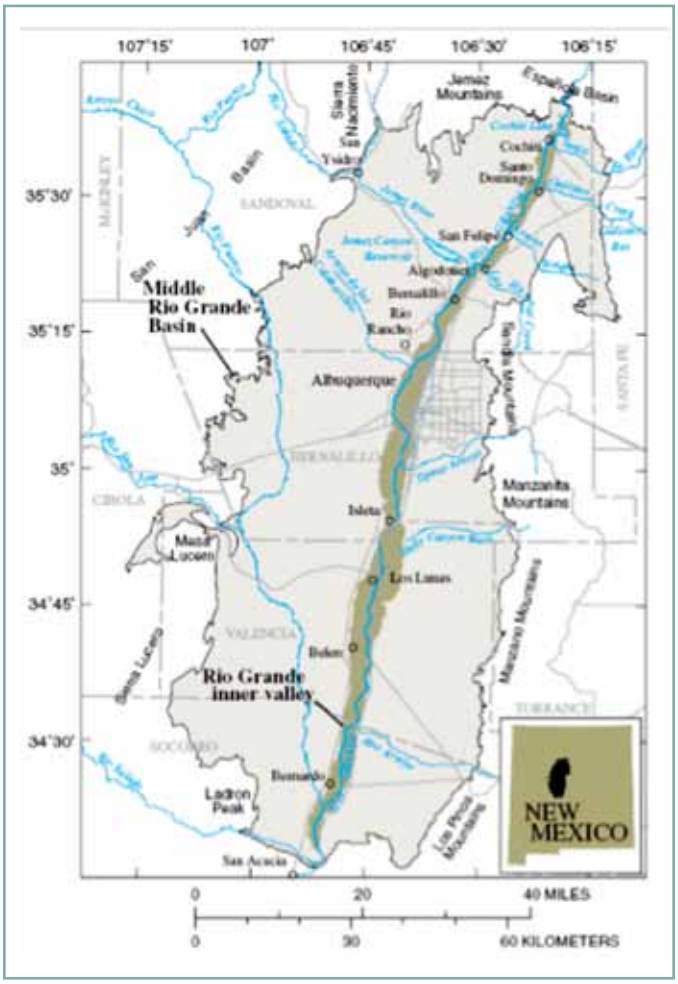

Figure C3.2. Major physiographic and hydrologic features of the Middle Rio Grande Basin.

Scale and Scope

Vulnerability of species and populations to changes induced by global warming was assessed using a scoring system similar to that developed for identifying avian populations at risk by Partners in Flight (Panjabi et al. 2005). A detailed account of the scoring for each species resulted. Scores are adjustable as new information arises. The basic process was as follows:

- Compile information on vertebrate species of the Middle Rio Grande Bosque
- Compile information on projected climate change effects for the Middle Rio Grande Basin
- In consultation with experts, create scores for individual species for each variable
- Create composite scores and prioritize species by vulnerability

The assessment for this case study evaluated the full array of terrestrial vertebrate species inhabiting riparian woodlands along the Middle Rio Grande in New Mexico. The geographical boundaries of the Middle Rio Grande are demarcated as the stretch of the river from Cochiti Dam (at its northernmost edge) downstream 160 miles to San Marcial and Elephant Butte Reservoir, and the Bosque portion of it extends south to San Acacia (Figure C3.2). The Middle Rio Grande Valley includes four New Mexico counties (Sandoval, Bernalillo, Valencia, and Socorro) and six Indian pueblos (Cochiti, Santo Domingo, San Felipe, Santa Ana, Sandia, and Isleta).

Assessment Approach

The system assigns scores from synthesized information related to probability of population declines as related to anticipated changes that directly or indirectly result from climate change. Possible scoring variables are: exposure to natural disturbance (e.g., flooding, wildfire); breeding requirements (e.g., link with seasonal food resources, temperature range, breeding ponds); nonbreeding requirements (e.g., habitat changes, stopover sites); dispersal potential (e.g., geographic barriers, mobility); and exacerbating factors (e.g., specialist species, physiological limitations, competition with invasive species). Scores in each category are assigned to individual species on an ordinal scale from lowest to highest risk. For example, when looking at natural disturbance a species may have a high score if it negatively responds to wildfires, which are predicted to increase. A species may have a low score if it responds positively to disturbances that are expected to increase or if its habitat is not threatened by these sources of disturbance.

The assessment comprises a series of questions that focus around variables or traits believed to reflect the potential impacts of climate change on the ability of individual species to survive and reproduce. Each question is accompanied by a series of potential responses that, in turn, are associated with a simple score of 1 (vulnerable), 0 (neutral or unknown), or −1 (resilience). Variables related to climate change effects on species were identified from four broad categories or factors: habitat, physiology, phenology, and biotic interactions.

In addition, we considered whether traits exhibited three primary functions of good scoring variables for assessment designs (Beissinger et al. 2000): (1) repeatability, (2) relation to quantitative values, and (3) independence from other scoring variables. Our adherence to these criteria, however, was limited because quantitative data currently available for species' response to climate change are rare and inherently imprecise for future projections. A separate score for uncertainly that reflects the quantity and quality of data used to score a species is also included.

Two types of scores are provided for different purposes: categorical scores and overall scores. Overall scores can be used to rank species and identify the most vulnerable or resilient species. Alternatively, overall scores can also be used to categorize species into broad vulnerability levels. Because not all species attributes translate to equal risk from climate change, composite scores allow for prioritization of species vulnerabilities for complex information. Categorical scores can be used to identify specific areas or traits related to vulnerability.

Scores for individual criteria can identify vulnerable and resilient characteristics that could aid in single-species management decisions. Identified areas of vulnerability or resilience and their relative influence can be used to target the most effective management actions (i.e., creation of corridors, land acquisition, captive breeding). In addition, scores can be adjusted and categories added as effects of climate change manifest or threats are identified by new research. Prioritization of species for management will have to additionally consider issues such as current vulnerability, economic feasibility, and regulations. Managers can also incorporate their own knowledge and local issues into considering species prioritization.

Middle Rio Grande Bosque Climate and Habitat Projections

We gathered information on projections for climate and related phenomena as well as disturbances and vegetation types to use for our assessment of the Middle Rio Grande species. To maintain relevance to management planning, we used projections for a period 20 to 50 years in the future. We used ClimateWizard to estimate changes in precipitation and temperatures for the region. We used vegetation projections created by Rehnfeldt et al. (2006) to estimate changes in area and distribution of major vegetation types (Brown et al. 1998). We also outlined specific predictions regarding changes to the riparian and upland habitat of the region using additional information from primary literature sources. Finally, we considered the effect of extreme weather conditions and disturbances, which although more difficult to accurately project, may be more critical to wildlife populations than average changes.

Results

The southwestern United States is expected to experience relatively large temperature increases and specific predictions for the region include an increase in the severity and duration of drought periods, more heat waves, greater variation in precipitation, increased wildfires and insect outbreaks, and increased evapotranspiration and salinization (Easterling 2000; Field et al. 2007; Garfin and Lenart 2007). Perhaps of greatest consequence will be the impact of these changes on southwestern water resources. Specifically, the Southwest is expected to experience a change in seasonal flood regimes, reduced snowpack, and an overall reduction in river and stream flows (Seager et al. 2007).

We predict there will be less open water, shorter duration for ephemeral ponds, and a decline in wetland habitats in the Middle Rio Grande Bosque. These changes will lead to a general loss of riparian vegetation and a narrowing of the riparian corridor. In addition, invasive tamarisk species are likely to increase to the detriment of native cottonwood species. Specific vegetation projections for 2030 showed decreases in Great Basin conifer woodlands (from 10 percent to 1 percent), semi-desert grasslands (38 percent to 25 percent), and a complete loss of Plains grasslands (estimated to comprise 52 percent of the current habitat). Chihuahuan desert scrub was predicted to increase from 0 percent to 74 percent.

Amphibians. Of the nine species of amphibians assessed, five species are found to be vulnerable to climate change. The most vulnerable species was the western chorus frog; three species had

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neutral scores; and only one, the American bullfrog, appears to be somewhat resilient to climate change effects. Species with water-dependant larval or adult life stages were most vulnerable to future climate projections. The three species of spadefoot toads and the Great Plains toad tended toward lower scores because we predicted that the scrub and grassland habitats used by these species would increase in the Middle Rio Grande region.

Reptiles. Nineteen of 29 reptiles are vulnerable to climate change in the Middle Rio Grande Valley. Five species had high vulnerability scores. The Great Plains skink was the most vulnerable species, while the common kingsnake was the least vulnerable. In general, species that have a specific reliance on riparian habitat show some level of vulnerability to the future expected changes.

Birds. Of the 40 species of birds assessed, 25 species (51 percent) had scores reflecting an overall vulnerability to climate change. The southwestern willow flycatcher was ranked as the most vulnerable and the bank swallow was the least vulnerable. Fourteen species had neutral scores and five species may benefit from future warming trends. The southwestern willow flycatcher (federally listed as endangered), the western yellow-billed cuckoo (a candidate for federal listing), and the common yellowthroat depend on riparian habitat and were among the most vulnerable to potential population declines under future climate projections. The primary habitat of these species is expected to decline, they are sensitive to heat, and they rely on climate-driven cues and/or resource pulses, which are likely to change under future scenarios. The three most resilient species, spotted towhee, house finch, and brown-headed cowbird, are habitat generalists with a good capacity to respond to resource variation.

Most of the bird species we assessed that forage aerially on insects obtained positive overall scores, reflecting vulnerability (cliff swallow, barn swallow, ash-throated flycatcher, northern rough-winged swallow, and bank swallow). An exception to this trend was the eastern bluebird. The three species of woodpeckers had positive scores. Of the four species of raptors, three had

Bruce Stein

positive overall scores; western screech owl was the most vulnerable, followed by Cooper's hawk and great horned owl. By contrast, the score for American kestrel was negative.

Mammals. Thirty-six mammals were assessed for their potential vulnerability to climate change in the study region. The New Mexico meadow jumping mouse appears most vulnerable, while the desert shrew was the least vulnerable to future expected changes. Sixteen percent of the mammal species were vulnerable to climate change effects, 44 percent appear to be only slightly impacted, and 5 percent may benefit from future projected changes. In general, species that appear most at risk given future climate change predictions are animals with a high reliance on riparian areas (the New Mexico meadow jumping mouse and beaver), require dense vegetation or specific vegetation features (the woodrat), or are at risk of mismatch between critical resources and breeding (the hoary bat and black bear). Species not expected to be overly influenced by future climate changes tended to be opportunistic breeders (jackrabbit, desert shrew), with a wide diversity of habitat associations including habitats that are expected to increase in the future.

Uncertainties

All species assessments are prone to errors relating to uncertainties regarding species biology. We found considerable variation in the data available for each species under review. To account for this, we include an uncertainty score. For each of the categories, Habitat, Physiology, Phenology, and Biotic Interaction, we score a species based on the quality and quantity of data that was available for completing the assessment question. These scores are then added at the end of the assessment for an overall uncertainty score. This score is useful not only for estimating the potential for errors in our assumptions regarding species vulnerability but clearly identifies areas that are in need of further monitoring or research efforts.

Assessments of species vulnerability to climate change also have sources of uncertainty specific to the aim of predictions based on future climate scenarios. First, uncertainties exist regarding climate projections produced by climate models. To reduce the impact of individual error attributed to variations in a single model, we used temperature ranges and precipitation estimates that were produced in ensemble models, which average values from several individual models. Vegetation projections and other sources of data regarding future climate conditions are also prone to errors related to methodological procedures. We used most of these tools to gain a perspective on the trends of change rather than define definitive future scenarios. For vegetation projections, we relied less on subtle changes (slight loss or shift in certain habitat types), than on projections of severe change (total loss of habitat). We

also considered predicted loss of vegetation type to be a robust result, whereas estimates of habitat shifts or invasion are more tenuous given the greater unpredictability of potential plant invasion and establishment and the time lag under which these transitions will occur.

Finally, there is uncertainty regarding the realized response of species to climate change. We have attempted to consider a comprehensive suite of traits that allow us to gauge species capacity to tolerate greater variation in resources, higher temperatures, and habitat changes. We have also attempted to account for species interactions within the framework of our tool. Though these efforts have improved the applicability of our tool, it is likely that there remain unpredictable consequences of climate change for species.

Outcomes and Next Steps

We will take these results and identify management (adaptation) strategies and actions for terrestrial species in the Middle Rio Grande Basin. We have also expanded the application of the vulnerability assessment scoring tool to other locations in the American Southwest, including scoring of endangered species on the Coronado National Forest, southeastern Arizona, and on the military bases Fort Huachuca and Barry Goldwater Range. Manuscripts that describe the scoring tool in detail and a Rocky Mountain Research Station General Technical Report that provides the full results of the Middle Rio Grande vulnerability assessment are in review. We are also beginning the process of developing a Web-based version of the tool that will be added to an appropriate Website such as the U.S. Forest Service Climate Change Resource Center Website (http://www.fs.fed.us/ccrc/).

Case Study 4. Vulnerability of Massachusetts Fish and Wildlife Habitats to Climate Change

Purpose and Conservation Objective

This case study describes the use of expert elicitation to assess the vulnerability of habitats at a state-wide scale. Funded by a grant from the Wildlife Conservation Society, Manomet Center for Conservation Sciences began working in early 2008 with the Massachusetts Division of Fisheries and Wildlife and other partners, including The Nature Conservancy, to make the state's existing Wildlife Action Plan "climate-smart." We are presenting the results of

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Lead authors: Hector Galbraith and John O'Leary.

Table C4.1. Habitat Types Evaluated
Forested habitats
Spruce-fir forest
Northern hardwood forest
Southern/central hardwood forest
Pitch pine-scrub oak forest
Freshwater aquatic habitats
Cold water Rivers and Streams
Large cold water lakes
Smaller cold water lakes and ponds
Warm water ponds, lakes and rivers
Cold water kettle ponds
Connecticut and Merrimack mainstems
Freshwater wetland habitats
Emergent marsh
Shrub swamp
Spruce-fir boreal swamp
Atlantic white cedar swamp
Riparian forest
Hardwood swamp
Vernal pools
Coastal habitats
Intertidal mud/sandflats
Saltmarsh
Brackish marsh

this project in a series of reports. This first report provides background on the project by describing how biodiversity conservation is currently carried out by the Massachusetts Division of Fisheries and Wildlife, the history, objectives, and methods of the Wildlife Action Plan, and how the climate in Massachusetts has been changing and how it is expected to change over the remainder of this century. In subsequent reports, we address habitat and species vulnerabilities, likely ecological shifts under climate change, and potential management/conservation options.

It is important to note that, when we began this study, our assumption was that climate change was a new and separate issue apart from all of the current stressors that affect the resources we are responsible for and that we had already identified in the Wildlife Action Plan. Once we realized that climate change impacts were not a separate issue but would interact with existing stressors and could be thought of as an exacerbating factor to current stressors, it made it easier to understand how the assessment process could be used to look at the combined impacts from current stressors under climate change conditions. Also, one of the most important lessons learned from this study is that staff buy-in is critical for the assessment as well as the implementation phase.

Scale and Scope

This assessment focused on state-specific species and habitats under the scenarios of a doubling and tripling of CO_2 concentrations in the atmosphere. In terms of time and cost, the project took about 12 months to complete and cost approximately $70,000, including travel and in-kind costs.

Assessment Targets

Twenty Massachusetts habitats were selected for evaluation (Table C4.1). These cover most of the habitats listed in the Wildlife Action Plan, although they differ from the Action Plan habitats in two respects. First, some habitats listed in the Plan are unlikely to be vulnerable to climate change (caves and mines, rocky ridgelines and talus slopes, rocky coastlines) and were not considered in our analyses. Second, some important habitat types are subsumed within the overall habitat

categories listed in the Action Plan. For example, there are many types of upland forest in Massachusetts, each of which may differ in their responses to climate change. For this reason we divided the Action Plan upland forest category into several distinctly different habitat types (e.g., spruce–fir forest, northern hardwoods, central hardwoods, etc.) and evaluated each separately (for example, see the evaluation for northern hardwoods forest at the end of this case study). These habitat subdivisions were based on information contained in Swain and Kearsley (2000).

Assessment Approach

The primary questions addressed in this phase of our adaptation work are:

- How do the Wildlife Action Plan fish and wildlife habitats rank in terms of their likely comparative vulnerabilities to climate change?

- How will the representation of these habitats in Massachusetts be altered by a changing climate?

- What degree of confidence can be assigned to the above predictions?

- Which vertebrate Species in Greatest Need of Conservation are likely to be most vulnerable to climate change?

To answer these questions we formed an expert panel of Massachusetts Division of Fisheries and Wildlife, Nature Conservancy, and Manomet Center ecologists and wildlife biologists. The panel included much of the professional expertise in Massachusetts on the status, distribution, conservation, and threats to fish, wildlife, and their habitats.

The main purpose of this expert panel was to provide answers to the vulnerability questions raised above.

The entire expert panel met twice at the beginning of the evaluative process and were provided with the following materials:

- A PowerPoint presentation on how the climate is projected to change in Massachusetts over the present century. This presentation was based on the most recent and detailed climate modeling studies that had been performed in the Northeast, particularly those of Hayhoe et al. (2006), and was intended to be a "primer" for non–climate change scientists on the details of likely future climate change (e.g., temperature, type, amount and timing of precipitation, extreme events, etc.).

- A list of the important habitat variables that should be considered when evaluating climate change impacts, based on existing literature on the intrinsic and extrinsic factors that determine the likely vulnerabilities of species and habitats (e.g., Parmesan and Galbraith 2004; Parmesan and Yohe 2003; Root et al. 2003; Schneider and Root 2002).

- An appraisal of how, in general, climate change is likely to affect habitats and biomes. This was based on previous work on the relationships between habitat distribution and extent and climate change and how habitats around the world are currently responding to climate change (e.g., Parmesan and Galbraith 2004; Parmesan and Yohe 2003; Root et al. 2003; Schneider and Root 2002; IPCC 2007c).

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- A habitat vulnerability scoring system developed in collaboration with Division of Fisheries and Wildlife staff. This provides a framework for evaluating the comparative vulnerabilities of Massachusetts habitats. It is based on prior work evaluating the vulnerabilities of species to climate change and extends across the spectrum of expected responses, from habitats that may be at risk of being entirely eliminated from the state (scoring 7), to habitats likely to be relatively unaffected by climate change (scoring 4), to habitats that may extend their distributions greatly within the state in response to climate change (scoring 1).

- A three-point scoring system for assessing the levels of confidence that can be ascribed to vulnerability scores. This confidence scoring system was modified from one developed for the IPCC process (Moss and Schneider 2000).

After the meetings of the entire expert panel, three habitat subgroups were formed (freshwater aquatic habitats, forested habitats, freshwater wetlands). For each habitat type, a preliminary or straw-man vulnerability analysis was prepared in advance of the subgroup meetings and deliberations. This background information was not intended as a definitive analysis but only to generate and guide thought and discussion among the expert-panel members.

Based on above materials and their expert judgment, participants in each of the subgroups were asked in face-to-face discussions to evaluate the comparative vulnerabilities of the habitats for which they have expertise under the two emissions scenarios, asked to score them on the vulnerability scale, identify likely future ecological trajectories, assign confidence scores, and identify other non-climate stressors that could interact with and exacerbate the effects of climate change. Immediately after this subgroup meeting, the straw-men analyses were revised to reflect the subgroup discussions. These modified analyses were then circulated to the subgroups for further comment and finalization. At the conclusion of the subgroup process, the finalized habitat analyses were compiled into a unified report and circulated round the entire expert panel so that all could have an opportunity for comment, irrespective of habitat type. These comments were incorporated into this finalized analysis.

Assessment Results

This section summarizes the assessments described above by presenting the vulnerability scores, the levels of confidence associated with them, likely ecosystem trajectories under climate change, and potential adaptation options.

The vulnerability scores and confidence evaluations for the 20 habitat types are presented in Figure C4.1 and Table C4.2. For nine of the 20 habitat types the vulnerability scores for a tripling of CO_2 exceed that for the doubling, although by relatively small increments. This reflects the more extreme climate changes expected under the former. However, for 10 of the habitats the two emissions scenarios resulted in identical vulnerability scores and for one (shrub swamp) the tripling scenario resulted in a lower vulnerability score. These data indicate that a doubling of CO_2 is sufficient to trigger major effects on the habitats and that extending the exposure to a tripling has relatively small additional impacts.

Drawing from the habitat impacts, assessment participants were able to identify some of the associated Species in Greatest Need of Conservation (SGNC) that are likely to be most at risk under the various scenarios for CO_2 concentration (Tables C4.3 and C4.4).

Uncertainties

This assessment relied on expert elicitation to quantify levels of uncertainty. The confidence scores for the habitats in Table C4.2 range from High (n = 15), to Medium (n = 18), to Low (n = 6). Having developed and used these scores we are confident that: (1) a score of High indicates that the habitat is more likely than not to conform to the allocated vulnerability score. Thus, spruce–fir forest scores High vulnerability

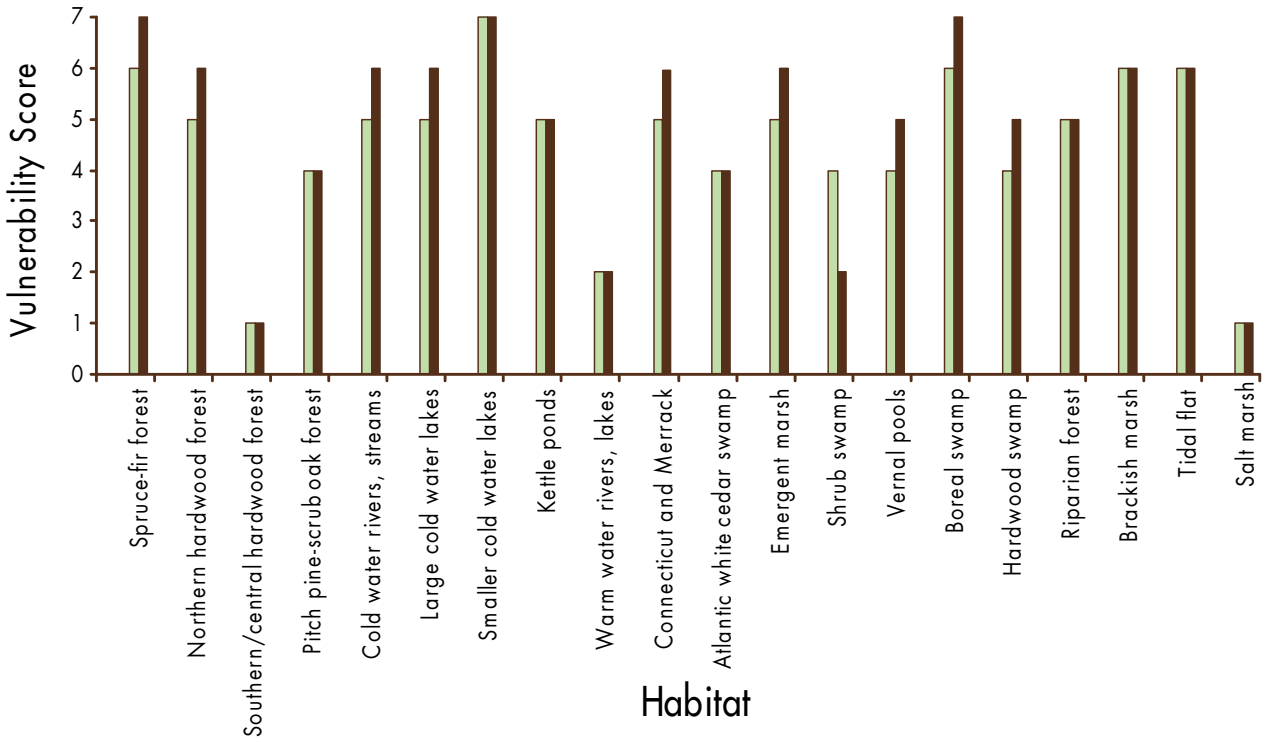

Figure C4.1. Habitat vulnerability to climate change. The lefthand bar in each pair represents a doubling of CO_2, while the righthand bar is a tripling.

Table C4.2. Vulnerability and Confidence Scores (in parentheses)		
Habitat	**Lower Emissions Scenario**	**Higher Emissions Scenario**
Forested Habitats		
Spruce-fir forest	6 (High)	7 (High)
Northern hardwood forest	5 (Medium)	6 (Medium)
Central/southern hardwood forest	1 (Medium)	1 (Medium)
Pitch pine-scrub oak forest	4 (Medium)	4 (Medium)
Freshwater aquatic habitats		
Cold water Rivers and Streams	5 (High)	6 (High)
Large cold water lakes	5 (Medium)	6 (Medium)
Smaller cold water lakes and ponds	7 (High)	7 (High)
Cold water kettle ponds	5 (Low)	5 (Low)
Warm water ponds, lakes and rivers	2 (Medium)	2 (Medium)
Connecticut and Merrimack main-stems	5 (Medium)	6 (Medium)
Wetland Habitats		
Emergent marsh	5 (High)	6 (High)
Shrub swamp	4/5 (Medium)	2 (Medium)
Spruce-fir boreal swamp	6 (High)	7 (High)
Atlantic white cedar swamp	4 (Medium)	5 (Medium)
Riparian forest	5 (Low)	5 (Low)
Hardwood swamp	4 (Medium)	5 (Medium)
Vernal pools	4 (Low)	5 (Low)
Coastal Habitats		
Intertidal mud/sandflats	6 (High)	6 (High)
Saltmarsh	1 (High)	1 (High)
Brackish marsh	6 (High)	6 (High)

(6 or 7) and High confidence. To us, this indicates that it is very unlikely that the "actual" vulnerability score for this habitat would deviate from 6 or 7; and (2) a habitat that has a confidence score of Medium is less certain. However, we consider it unlikely that the "actual" vulnerability of such a habitat would deviate much from the allocated score. For example, we consider it possible that a habitat that scores 4 on the vulnerability score and had a Medium uncertainty score could in fact have an actual vulnerability score of 3 or 5, but not 2 or 6. We are much less certain about habitats that have Low confidence scores and these should be read as implying considerable uncertainty in our scorings.

Outcomes and Next Steps

This assessment shows that different ecological systems are more or less vulnerable to climate change and, consequently, that we can expect to see

major changes in their distributions across the Massachusetts landscape. What forms will these changes take? Until relatively recently our dominant model of change was for habitats or biomes to slowly replace each other as their optimum climatic conditions shifted. Thus, we might expect to see the highly vulnerable spruce–fir forests at upper elevations being replaced by northern hardwood forest as it moved upslope to track its optimum climatic conditions. This model of entire communities shifting has been an important step in our evaluations of what may occur to habitats under climate change (e.g., VEMAP 1995). However, it is simplistic and may not represent what may actually occur.

Different organisms have different intrinsic rates of response to climate change. For example, a northeastern warbler such as the American redstart can potentially shift its breeding range northward by several hundred kilometers in only a few days. However, the majority of the plants that make up the breeding habitat of this species are far less able to respond as rapidly—a similar shift could take decades or centuries. Rather than entire ecosystems or communities shifting their distributions across the landscape, we are much more likely to see them dissociating and separating, depending on their intrinsic response rates, and reconfiguring, into potentially novel combinations, upslope or further north. This dissociation and

Table C4.3. Habitats and associated vertebrate SGNC most at risk from a doubling of atmospheric CO_2 concentration.

Spruce-fir Forest	Spruce-fir Boreal Swamp	Smaller Cold Water Ponds	Brackish Marsh	Intertidal Mud and Sand Flat
Sharp-shinned hawk	Blue-spotted salamander	Northern leopard frog	Diamondback terrapin	Peregrine falcon
Blackpoll warbler	Sharp-shinned hawk	American eel	American bittern	Piping plover
White-throated sparrow	American woodcock	White sucker	Least bittern	Ruddy turnstone
Moose	Moose	Green heron	Northern harrier	Sanderling
Bobcat		Water shrew	King rail	Red knot
			Common tern	Snowy egret
			Short-eared owl	American oystercatcher
			American black duck	Short-billed dowitcher
			Snowy egret	Whimbrel
			Black-crowned night-heron	
			Sora	
			Saltmarsh sharp-tailed sparrow	
			Seaside sparrow	
			Eastern meadowlark	

Table C4.4. Habitats and additional vertebrate SGNC most at risk from a tripling of atmospheric CO_2 concentration.

Northern Hardwood Forest	Coldwater Rivers and Stream	Large Coldwater Lakes	Mainstem Rivers	Emergent Marsh
Jefferson salamander	Spring salamander	White sucker	American shad	Northern leopard frog
Blue-spotted salamander	Longnose sucker	Common loon	Shortnose sturgeon	Spotted turtle
Bog turtle	Slimy sculpin	Bald eagle	Atlantic sturgeon	Bog turtle
Ruffed grouse	Blacknose dace		Alewife	Blanding's turtle
Broad-winged hawk	Brook trout		American shad	Pied-billed grebe
Canada warbler	Burbot		American eel	American bittern
Rock shrew	Atlantic salmon		Atlantic salmon	Least bittern
Indiana Myotis	Louisiana waterthrush		Fallfish	King rail
Eastern small-footed bat			Green heron	Sora
Southern bog lemming			Bald eagle	Black-crowned night-heron
				Green heron
				Snowy egret
				Common moorhen
				Sedge wren
				Willow flycatcher
				Moose

reconfiguring is the current dominant model of how ecological communities may be affected by climate change.

How will this be expressed in Massachusetts fish and wildlife habitats? It is unlikely that over the next century we will see the northern hardwood forest community, with all its associated plant and animal species, simply move uphill to occupy a vacuum left by a retreating spruce–fir forest and all its associated plant and animal species. What is perhaps more likely is that in the shorter term (the next few decades) we will begin to see the elimination of the most climatically vulnerable components of the spruce–fir forest, while the forest may retain much of its overall structure and composition. At the same time that this is happening, the spruce–fir forest may be increasingly colonized by lower-elevation species that are able to tolerate cooler temperatures and move upslope quickly. Thus, the northern hardwood forest will permeate the spruce–fir. This permeation zone will spread uphill as the climate continues to warm and as lower-elevation plants spread uphill and cold-adapted species die out.

The process of uphill permeation by northern hardwood forest species and uphill retreat by spruce–fir forest species will result in the shorter term (the next 50 to 100 years) in a spectrum of forest types replacing the original spruce–fir. In lowest elevation areas where the spruce–fir forest originally occurred, it will likely be replaced by a community resembling higher-elevation northern hardwoods. At somewhat higher elevations, the new forest type will likely comprise a mixture of the two community types. At the highest elevation types of spruce and fir trees may

persist, but it is likely that the understory will now comprise many lower-elevation species. Given enough time (perhaps by the end of this century) the spruce–fir forest may be gone. This does not necessarily mean that it has been entirely replaced by the northern hardwood community: some species that are today characteristic of spruce–fir forests may persist, while others that are characteristic of northern hardwoods may not be able to move far enough uphill. Thus, while we do anticipate community movement, it is less deterministic than some of our early models might predict and resembles a long-term community reshuffle, rather than complete replacement.

The description above implies a long, slow process of reshuffling of species. However, it is possible that the transitions could happen much more quickly if stochastic events intrude. For example, the warming temperatures could greatly benefit some of the invertebrate pests that afflict northeastern forests. This is already happening with mountain pine beetle in the West (Carroll et al. 2003) and the northward spread of hemlock wooly adelgid in the East (NECIA 2006). More frequent or increased-intensity attacks by such pests could result in a greater incidence of tree die-off, much more standing dead timber, and larger and more intense fires. If severe enough, these circumstances could "flip" the affected system, causing a much more rapid transition to the new habitat type.

The considerations described above apply to all climate-induced transitions that we may see in Massachusetts habitats over the next century. What this means for conservationists, planners, or land managers is that while we can identify the major elements of large-scale change, we must be wary of relying entirely on deterministic models (e.g., northern hardwood forest and all its associated species will oust spruce–fir forests from higher elevations), think more probabilistically, and be prepared for unforeseen surprises.

Example:
Northern Hardwoods Forest Vulnerability Evaluation
NTWHCS category: Appalachian northern hardwood forest
State ranking: S5
Vulnerability score: 5 and 6 (lower- and higher-emissions scenarios, respectively)
Confidence evaluation: High
Rationale

With the distributional range of this habitat extending from Quebec in the north, to high-elevation areas of Virginia and West Virginia, Massachusetts is close to the center of this community type's geographical distribution. In Massachusetts, where it is the predominant hardwood forest, it is generally restricted to an altitudinal range of about 1,000 to 3,000 feet, being more adapted to colder temperatures and shorter growing seasons than southern/central hardwood forest (but less so than spruce–fir forest). Mature northern hardwood forest tends to be dominated by sugar maple, yellow birch, and American beech, mixed with white pine, and eastern hemlock at lower elevations, with red spruce and balsam fir becoming important at the highest elevations where it grades into spruce–fir forest (Swain and Kearsley 2000). Black cherry, white ash, red maple, white birch, and gray birch often dominate early-successional northern hardwood forest following disturbance.

Within the broad matrix of northern hardwood forest a number of variants occur, depending on local conditions. These include rich mesic forests (dominated by sugar maple, basswood, and a unique assemblage of herbaceous plants), hemlock groves (on cool north-facing slopes or in ravines), and transition forests (which include oaks, hickories, and other species more typical of southern/central hardwood forest). Northern hardwood forest is not a fire-adapted community and human fire suppression over the past three centuries may have extended the range of this habitat in New England at the expense of oak forest, which is fire tolerant (J. Scanlon, pers. comm.). This forest type is vulnerable to attack by insects, including gypsy moth and hemlock wooly adelgid, and beech scale disease. Disturbance from blowdown, logging, or fire can lead to the (at least temporary) dominance of white pine over other species. In areas closer to human habitation or powerline cuts, nonnative plant species, including Japanese barberry, Japanese knotweed, etc., can form dense growths.

Being mainly a higher-elevation and northern community, it may be expected that this habitat will contract its range in Massachusetts as the climate warms. This contraction may be latitudinal and elevational. At the highest elevations it is likely to replace spruce–fir forest. At lower elevations it is likely that at least some of the species considered characteristic of northern hardwoods and that are most temperature sensitive (e.g., sugar maple, hemlock) will be replaced by elements of the southern/central hardwood forest (e.g., white oak, hickories, etc.). Thus, what is currently northern hardwood forest over much of low- and middle-elevation Massachusetts could transition to a southern/central hardwood community. Based on an elevation lapse rate of 1.8 degrees Fahrenheit for every 330 feet (http://www.spc.noaa.gov/exper/soundings/help/lapse.html), even the low-emissions scenario could contract the lower edge of this community upward by at least 1,000 feet. If this were the case, then its range would be restricted to higher elevations (>2,000 feet) in the Berkshires. Under the high-emissions scenario this upward movement potential could be close to 2,000 feet. This would mean that this habitat type might occur only at the highest elevations, where it has replaced spruce–fir. Based on this, a vulnerability score of 5 has been assigned under the low-emissions scenario and a score of 6 under the high-emissions scenario, with a confidence evaluation of Medium.

The confidence score is only Medium because uncertainties exist regarding how this community type might be affected by climate-related and non-related factors. Northern hardwood forest is vulnerable to fire. In contrast, southern/central hardwood forests are more fire tolerant. If a consequence of increasing temperatures, droughts, and soil drying is more frequent or hotter fires, this could accelerate the transformation of areas currently dominated by the former habitat type to areas dominated by the latter.

Other stressors that could be exacerbated by change and inflict adverse impacts on northern hardwoods include insect pests (wooly adelgids are already eliminating large tracts of hemlocks in Massachusetts, and emerald ash borer and Asian longhorned beetle are spreading rapidly north toward and into the state).

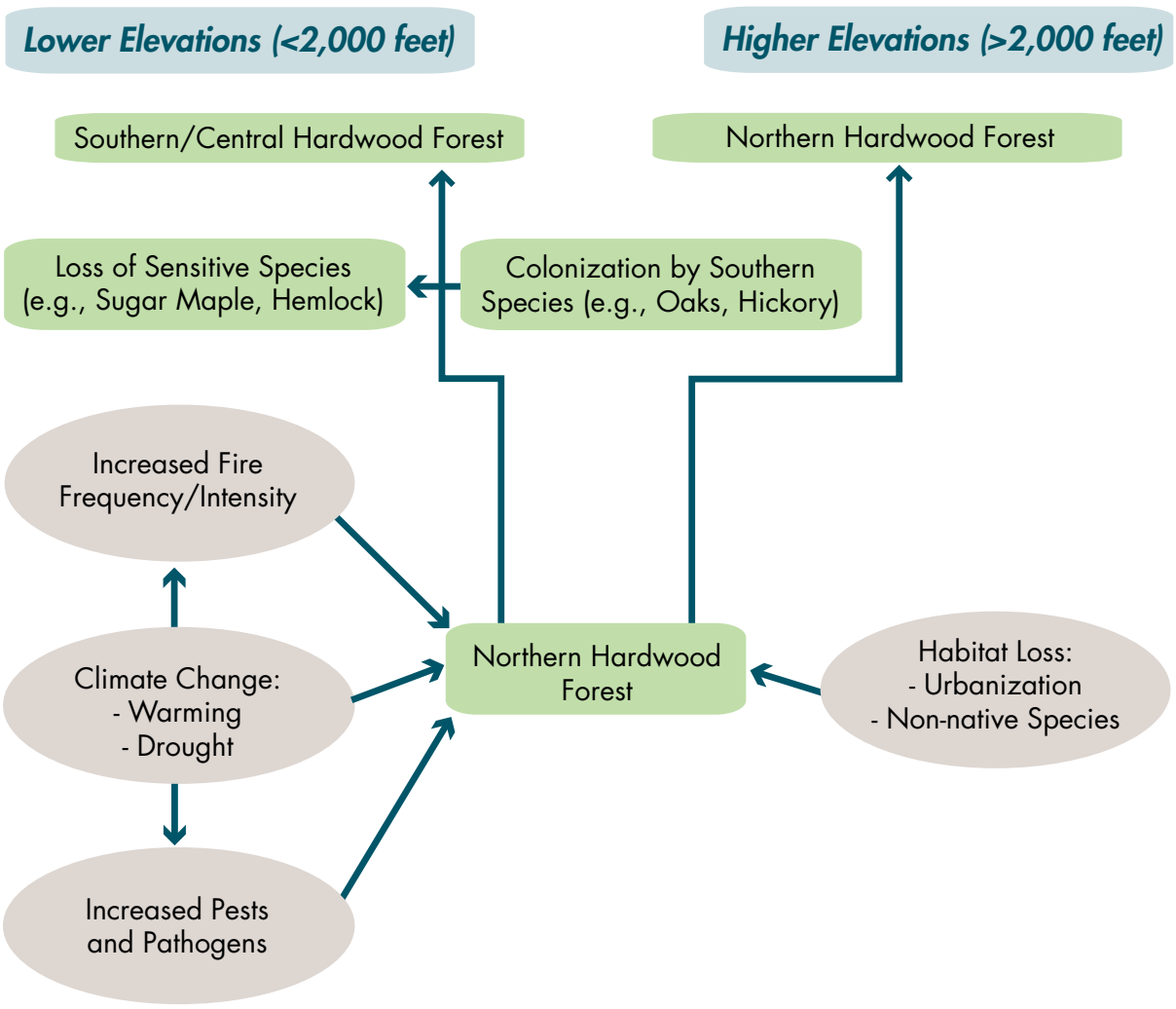

Figure C4.2. Conceptual model of how climate change and other stressors might affect Northern Hardwood Forest in Massachusetts.

If, as seems likely, warming temperatures facilitate overwinter survival of these pests and allow them to spread further north or upwards in elevation in Massachusetts, the northern hardwood forest could be adversely affected. Under the higher-emissions scenario, an increased frequency and severity of fire, and greater intensities and frequencies of insect/pathogen attack, could potentially eliminate this habitat type from the state. Moreover, this community type is currently under stress from human rural development and from colonization by nonnative plant species, as the state's population and peoples' housing expectations continue to grow. These factors could be major influences on the future status of this habitat. A conceptual model of how climate and non-climate stressors might affect northern hardwoods in Massachusetts is shown in Figure C4.2. Thus, while we conservatively score the vulnerability of this habitat type as 5 and 6 under the lower- and higher-emissions scenarios, it is possible that this might underestimate its vulnerability.

Case Study 5. Vulnerability to Sea-Level Rise in the Chesapeake Bay

This case provides an example of climate change vulnerability assessments for both habitats and species in the Chesapeake Bay region. Specifically, it highlights two studies, one building off the other, to identify how sea-level rise is likely to affect coastal wetland habitats and associated marsh bird species in the region.

National Wildlife Federation Coastal Habitat Study

In 2007, the National Wildlife Federation, working with Warren Pinnacle Consulting, Inc., initiated a study to identify the potential impacts of sea-level rise on coastal wetland habitats in the Chesapeake Bay region, including Delaware Bay and the ocean beaches of southern New Jersey, Delaware, Maryland, and Virginia.

Purpose

Local, state, and federal agencies, non-governmental organizations, and other stakeholders have already begun to develop climate change adaptation strategies for the region to help fish, wildlife, and people cope with the expected changes to their habitats and communities, including sea-level rise, as well as build in the flexibility to deal with unforeseen impacts. The purpose of this assessment is to provide decision-makers involved in this process with information about the vulnerability of the Chesapeake Bay region's coastal habitats to sea-level rise.

Conservation Objective

This assessment is intended to enhance and support efforts to address the impacts of climate change as part of the ongoing regional strategy to restore and protect the ecological integrity of the Chesapeake Bay and surrounding coastal areas.

Assessment Targets

The study focused specifically on coastal wetland habitats based on categories established for the U.S. Fish and Wildlife Service's National Wetlands Inventory. Habitat types include: swamp, tidal swamp, inland fresh marsh, tidal fresh marsh, transitional marsh, irregularly flooded (brackish) marsh, saltmarsh, estuarine beach, tidal flat, and ocean beach.

Scale and Scope

This was a regionally focused study, covering coastal habitats from Delaware Bay to the north, the Chesapeake Bay, and the ocean beaches from southeastern New Jersey down to the Virginia–North Carolina border. In terms of temporal scale, the study looked at a range of sea-level rise scenarios from the 2001 IPCC assessment, ranging from 0.31 meters to 0.69 meters in eustatic sea-level rise by 2100 (building over 25-year time steps from year 2000 levels). The study also modeled a rise of up to 2 meters by 2100 to accommodate for recent studies that suggest a

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significantly greater sea-level rise is possible during this century (Vermeer and Rahmstorf 2009; Overpeck and Weiss 2010; Rahmstorf et al. 2007). This study cost approximately $40,000 and took just under 1 year to complete.

Assessment Approach

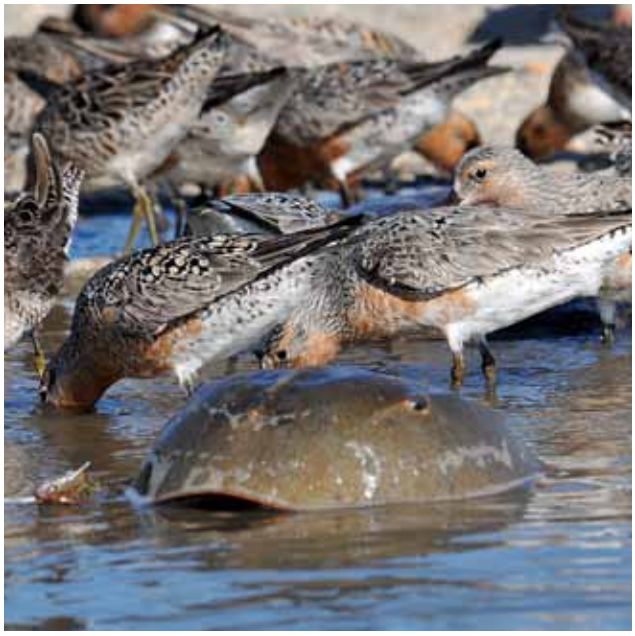
The assessment was conducted by applying Version 5.0 of the SLAMM model, which was designed to simulate the dominant processes involved in wetland conversions and shoreline modifications among a multitude of different habitat types under various scenarios of sea-level rise. There are a number of modeling tools available to assess the impacts of sea-level rise, ranging from simple "bathtub" models that show general inundation of coastal lands based on relative land elevation (e.g., DGESL 2003) to more detailed models that can simulate dynamic ecological processes at multiple spatial scales (e.g., Barataria-Terrebonne Estuarine Landscape Spatial Simulation Model, or BTELSS) (McLeod et al. 2010; Reyes et al. 2000). The SLAMM model was first developed two decades ago and has been applied in a number of studies. (Craft et al. 2009; Galbraith et al. 2002; Lee et al. 1992; Park et al. 1989). It provides an accessible, middle-of-the-road tool that allows for fairly detailed, scientifically sound regional assessments within the constraints of relatively limited data availability, budgets, and time.

Data inputs for SLAMM are generally readily available in most areas of the United States. For example, habitat composition data are based on the National Wetlands Inventory; coastal elevation data are available through the U.S. Geological Survey's National Elevation Dataset, which in many places has been significantly improved through high-vertical-resolution Light Detection and Ranging (LiDAR) data; historic sea-level trends and the salt boundary (the elevation below which lands are periodically inundated by salt water) are calculated using National Oceanic and Atmospheric Administration tidal gauge data; and factors contributing to relative sea-level change can be determined through the scientific literature, expert opinion, and other sources.

USFWS

The SLAMM model addresses the relative sensitivity of habitat types to sea-level rise based on known ecological traits such as the tolerance for salinity of associated plant species. Elements of exposure to sea-level rise are based on land elevation as well as the scenarios of sea-level rise modeled. Adaptive capacity is addressed

in terms of both intrinsic and extrinsic factors. One of the most important features of SLAMM is its ability to capture important localized differences in relative sea level. As mentioned previously in this guide, estimates of global sea-level rise due to climate change are based on what is called eustatic sea-level rise, which refers to the changes in ocean volume due to thermal expansion and the melting of glaciers and ice sheets. At the localized level, the amount of relative sea-level rise can vary due to factors (both natural and human-influenced) that determine changes in vertical land elevation, such as land subsidence, sedimentation, and marsh primary production. In the Chesapeake Bay, for example, many areas have been naturally subsiding (declining in elevation), which increases the amount of relative sea-level rise affecting the region, making those areas more vulnerable. In contrast, some coastal habitats such as marshes and beaches may at least to some extent be able to accommodate moderate changes in sea level by increasing in elevation due to the buildup of sediments. Rates of change among these variables can be included in the model. In addition, SLAMM can incorporate areas where habitats may not be able to move inland as sea level rises due to the existence of coastal armoring such as seawalls and dikes (factors that reduce the adaptive capacity of these habitats). Finally, the model output can be displayed as percentage changes in habitat area as well as shown on maps, both of which are useful for decision-makers.



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Assessment Results

Model results vary considerably across the region, but overall the most significant changes to coastal wetlands and other habitats occur in the eastern and southern regions of the Chesapeake Bay, most of Delaware Bay, and along the coastal barrier islands and beaches. For example, under the scenario of a 0.69-meter sea-level rise, which is the IPCC's (2001a) A1B Max scenario for the year 2100, coastal marshes would be inundated with salt water, converting 83 percent of brackish marsh to saltmarsh or open water (see Table C5.1). Overall, the area of tidal marshes (including tidal freshwater marsh, irregularly flooded marsh, transitional saltmarsh, and saltmarsh) declines by 36 percent under this scenario. Ocean and estuarine beaches

	Pct of Init. Cond Map	Init. Cond. (ha)	A1B-Mean Yr. 2100 (ha)	A1B-Mean Pct. Change	A1B-Max Pct. Change	1 Meter Pct. Change
Global SLR by 2100 (m)			**0.387**	**0.387**	**0.694**	**1**
Dry Land	59.0%	4,152,259	4,019,563	-3%	-4%	-5%
Developed	4.2%	292,323	292,323	-0%	-0%	-0%
Swamp	6.9%	482,570	533,811	11%	8%	7%
Cypress Swamp	0.1%	4,535	4,551	0%	0%	0%
Inland Fresh Marsh	0.5%	32,635	33,202	2%	-1%	-3%
Tidal Fresh Marsh	0.2%	14,441	14,102	-2%	-16%	-36%
Trans. Marsh	0.1%	10,511	26,209	149%	229%	275%
Irregularly Flooded Marsh	2.7%	193,289	113,146	-41%	-83%	-88%
Saltmarsh	0.4%	27,438	100,516	266%	183%	100%
Estuarine Beach	0.5%	32,065	9,982	-69%	-58%	-53%
Tidal Flat	0.4%	27,278	7,962	-71%	9%	15%
Ocean Beach	0.0%	2,051	771	-62%	-69%	-91%
Inland Open Water	0.8%	55,190	54,325	-2%	-2%	-3%
Estuarine Open Water	19.8%	1,393,904	1,532,910	10%	19%	24%
Open Ocean	3.1%	216,847	227,220	5%	5%	6%
Inland Shore	0.0%	3,059	1,967	-36%	-38%	-44%
Tidal Swamp	0.7%	51,300	27,787	-46%	-57%	-68%
Rocky Intertidal	0.0%	5	1	-90%	-95%	-98%
Riverine Tidal	0.7%	46,614	37,969	-19%	-22%	-25%
Tidal Creek	0.0%	11	11	0%	0%	0%
Sum of Categories (ha)		**7,038,326**	**7,038,326**			

Table C5.1. Percentage changes in habitat area for entire study site (Glick et al. 2008a).

also fare poorly, declining by 69 percent and 58 percent, respectively. In addition, more than half of the region's important tidal swamp is at risk, declining by 57 percent by 2100. Many coastal plant and animal species have adapted to a certain level of salinity, tidal influence, and habitat composition, so these shifts will make habitats more favorable for some species and less so for others.

Figure C5.1 shows map-based model results for the Blackwater National Wildlife Refuge, Maryland, and surrounding areas under the 0.69-meter scenario (IPCC A1B Max) (just one of multiple scenarios run). Significant changes in the composition and extent of coastal habitats occur at this site, including a loss of 39 percent of dry land, 92 percent of inland freshwater marsh, and 94 percent of irregularly flooded (brackish) marsh, much of which converts to open water. One of the reasons this area is so vulnerable is because, in addition to facing eustatic sea-level rise, land subsidence is greater than for many other parts of the Chesapeake Bay due to groundwater withdrawal for agriculture (U.S. FWS 2005). In addition, marshes in much of the Eastern Shore appear to have relatively lower rates of natural accretion (Kearney et al. 1998). It is important to note that high-quality LiDAR data were used for this study site.

Uncertainties

It is important for decision-makers to recognize that, as with all predictive models, SLAMM has its limitations and is subject to uncertainty. One element of uncertainty is associated with projections for future sea-level rise. The SLAMM model itself does not project changes in eustatic sea level—it relies instead on sea-level rise scenarios developed by others, such as the IPCC. As discussed above, there is currently

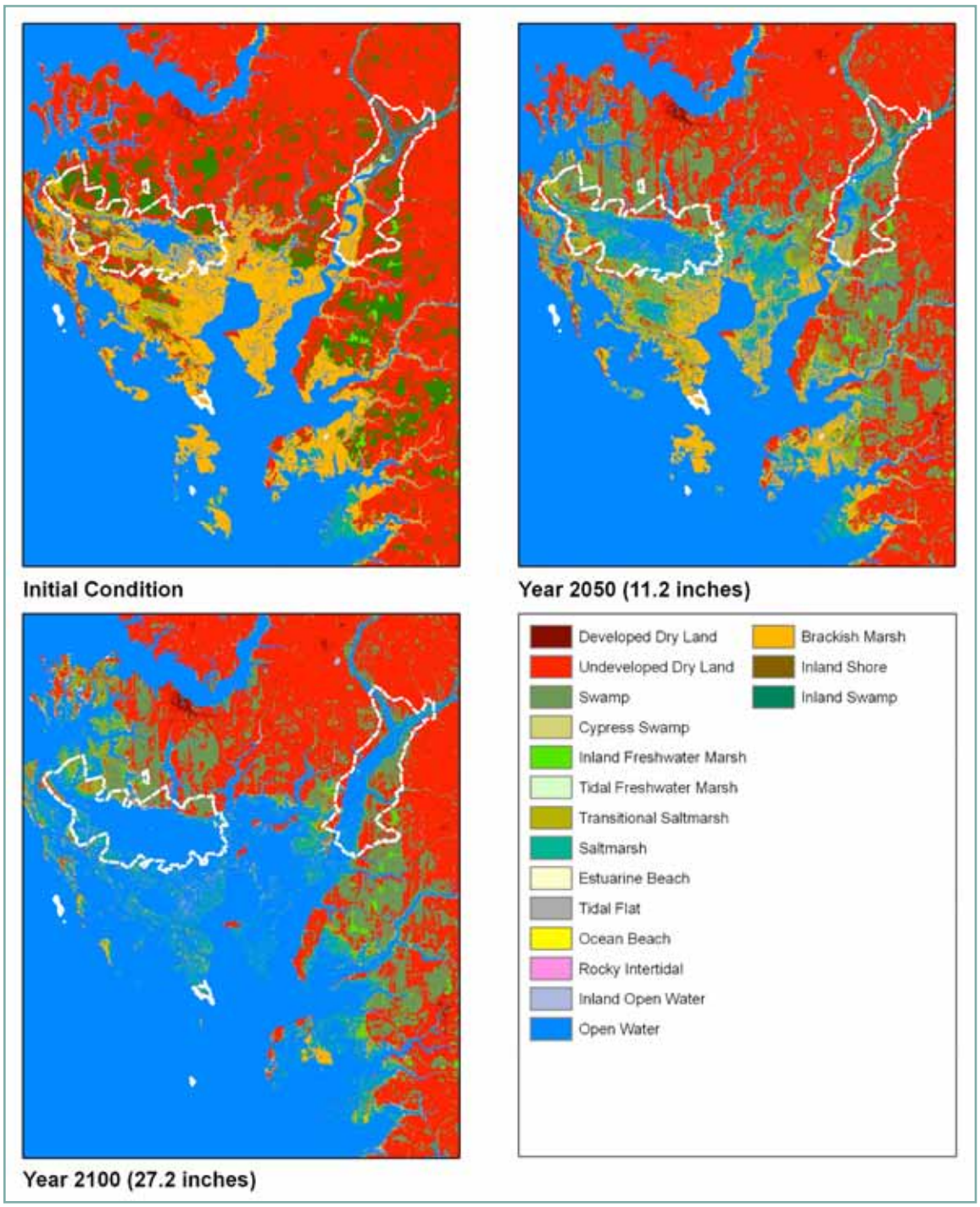


Figure C5.1. Sea level rise and marsh conversion projections for Blackwater National Wildlife Refuge, Maryland (Glick et al. 2008a).

a wide range of possible scenarios for sea-level rise, depending on the assumptions and factors used. Rather than choosing any one scenario, we applied multiple scenarios in our analysis to inform potential management responses.

Apart from any uncertainties in the sea-level rise projections themselves, confidence in SLAMM projections depends in large part on the quality of the data inputs. For example, areas where LiDAR elevation data are unavailable have a wider "zone of uncertainty" with respect to the delineation of vulnerable lands at or below a specific elevation, a factor that we address qualitatively in the results for this particular study. In addition, given that it is a relatively simple model, SLAMM does not capture some of the more complex systematic changes that could occur over time, which may include dynamic changes in marsh accretion or localized geomorphology. For example, the SLAMM model used for this assessment (Version 5.0) includes a simplifying assumption that rates of accretion (and subsidence) will remain linear into the future. This assumption, in particular, has been a source of criticism of the SLAMM model (e.g., Cahoon and Guntenspergen 2010; Kirwan and Guntenspergen 2009). It is important to note that newer versions of SLAMM (e.g., Version 6.0), incorporate dynamic feedbacks for marsh accretion based on elevation, distance to river or tidal channels, and salinity (Clough et al. 2010).

However, the use of the simplifying assumption for rates of relative sea-level changes in this or similar studies does not mean that its results are not useful. As with any vulnerability assessment, what is important is that the major model assumptions and areas of uncertainty are made transparent when communicating the study results. Users can then use their own judgment about their relevance for informing decisions regarding coastal restoration and management actions. Ultimately, the response strategies will vary for different areas, and more detailed, site-specific studies may be warranted to supplement these findings by identifying factors that have not been effectively captured by the model or remain uncertain.

Outcomes and Next Steps

The results of this analysis were published as two documents, including a detailed technical report (Glick et al. 2008a) and a summary (Glick et al. 2008b). In addition, the National Wildlife Federation has made all data and model results available to interested parties, including local, state, and federal agencies, academic institutions, and non-governmental organizations, to support additional analyses.

Center for Conservation Biology Marsh Bird Study

Purpose

Based on the results of the National Wildlife Federation's sea-level rise study described above, scientists at the Center for Conservation Biology at the College of William and Mary and Virginia Commonwealth University have conducted assessment of the potential impacts of sea-level rise on the population size of saltmarsh breeding birds within the Chesapeake Bay (Wilson and Watts 2009). The Chesapeake Bay region supports 30 percent of the total saltmarsh cover along

the Atlantic Coast and is an important breeding area for several marsh bird species of concern. Based on assessments by the National Wildlife Federation, the U.S. Climate Change Science Program (U.S. CCSP 2009b), and others, it is clear that the saltmarsh ecosystem of the region is highly vulnerable to the impacts of sea-level rise.

Conservation Objective

The objective of this assessment was to examine the potential impact of sea-level rise on the capacity of the Chesapeake Bay region to support saltmarsh bird populations during the breeding season. Because marsh bird abundance and distribution are influenced by the physical characteristics of marshes such as salinity, vegetation, patch size, and elevation, the impact of sea-level rise on the population size of each species is more complex than simply calculating net changes in marsh area alone. Given that SLAMM is able to identify changes in the composition of coastal wetland habitats, as well as their extent, the National Wildlife Federation study provides an excellent platform for this assessment.

Assessment Targets

This assessment focused on several marsh birds of concern, including the willet, black rail, saltmarsh sparrow, clapper rail, Virginia rail, marsh wren, and seaside sparrow. Each of these species has specific habitat requirements based on the composition of coastal marsh types. The willet, black rail, and saltmarsh sparrow, for example, rely exclusively on high marsh, which is only inundated during extreme high-tide events and dominated by plants such as saltmeadow hay, saltgrass, and often interspersed with shrubs such as marsh elder or saltbush. Clapper rails, Virginia rails, marsh wrens, and seaside sparrows, on the other hand, use both low and high marsh but reach their highest densities in the low marsh, which is inundated with each tidal cycle and dominated by smooth cordgrass and black needlerush.

Scale and Scope

The GIS-based study used the National Wildlife Federation study's habitat change projections for several of the sea-level rise scenarios, including 0.39 meters by 2100, 1 meter by 2100, and 2 meters by 2100 (Glick et al. 2008a). For their purposes, some of the habitat types were aggregated into high saltmarsh, low saltmarsh, and transitional saltmarsh to correspond with the marsh types preferred by various marsh bird species. This study cost approximately $25,000 and took about 4 months to complete.

Assessment Approach

For the purposes of this study, each GIS raster cell from the National Wildlife Federation SLAMM analysis was assigned a value for the dominant habitat cover category. We then converted the rasters for emergent tidal marshes that were coded as high salt marsh, low salt marsh, and transitional salt marsh into vector-formatted polygons using ArcMap 9.1 (Environmental Systems Research Institute 2005) and grouped any like-valued cells ≤30 meters from each other into a single marsh patch. This grouping allowed neighboring cells to share the identity of a larger marsh complex while cells >30 meters away from an aggregation would be

grouped into a different marsh complex. We placed the resulting aggregations into one of five marsh area classes: (1) <1 hectare, (2) 1–5 hectares, (3) 5–10 hectares, (4) 10–50 hectares, and (5) >50 hectares.

Bird population sizes for each map iteration were identified by extrapolating known values of bird density (birds/ha), based on research conducted within the Chesapeake Bay. Available habitat was delimited for each species by its (1) geographic distribution over the study area, (2) habitat associations, and (3) patch-level incidence rates for each area class. These associations were then incorporated into an equation that calculated changes in species' populations associated with projected changes in marsh habitat area due to sea-level rise.

To address potential uncertainty, confidence intervals were calculated for each population estimate by substituting the upper and lower 95 percent confidence interval values of each bird density for patch area class values in their modeling equation. As these factors change over time due to sea-level rise, so do the population sizes and distribution of associated marsh bird species.

Assessment Results

The total area of saltmarsh was reduced between initial conditions and the year 2100 for all sea-level rise scenarios. These changes were dominated by reductions of high marsh. Sea-level rise was also responsible for a shift in the rank order of abundance between low marsh and high marsh. In turn, model results suggest that the current rates of sea-level rise will reduce the size of breeding populations of widespread species 35 to 40 percent between the years 2000 and 2100. These reductions likely represent conservative estimates since global rates of sea-level rise are predicted to accelerate. Population reductions of 69 to 80 percent are possible if sea levels increase by 1 meter or greater.

The differential impacts of sea-level rise on high versus low marsh are projected to result in dramatic changes in the bird community on a regional scale. Marsh birds such as the black rail and saltmarsh sparrow that rely exclusively on high marsh habitat will be at very high risk of extirpation from the region. Habitat area for these species is projected to decline to about 50 percent of current area under the 0.39-meter scenario. Habitat for both the black rail and saltmarsh sparrow was reduced 89 percent from the 1-meter scenario and 99 percent from the 2-meter scenario for each species, respectively. In addition, populations of clapper rails, Virginia rails, willets, seaside sparrows, and marsh wrens were projected to decline by about 40 percent in the 0.39-meter scenario, about 80 percent in the 1-meter scenario, and about 75 percent in the 2-meter scenario.

Uncertainties

(Addressed above.)

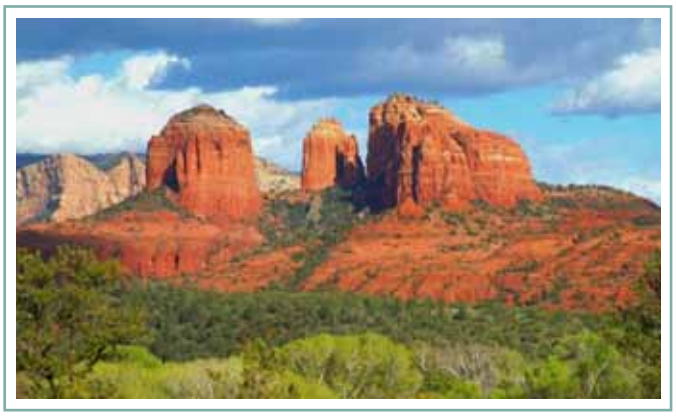
Outcomes and Next Steps

The results of this study illustrate the need to address specific management actions that reduce the adverse impacts of sea-level rise on marsh birds. Because significant loss of marsh area is likely, particularly under the higher projections for eustatic sea-level rise, there will be an increasing need to protect remaining marsh patches to compensate for these losses.

Case Study 6. An Integrated Climate Change Assessment Framework in the Four Corners Region

Summary

This case study describes the use of a regional-scale vulnerability assessment framework that includes identification of potential management responses. In the western United States, temperatures have exceeded global averages by 70 percent relative to the 20th century (Saunders et al. 2008). The region faces a 90 percent chance of continued declining snowpack, earlier peak flows in rivers and streams, and higher rates of evaporation from reservoirs, leading to increased competition for already over-allocated water resources (IPCC 2007b). Warming trends are projected to continue, with climate in the semiarid Southwest resembling "Dust Bowl" conditions by mid-century (Seagar et al. 2007). Ecological consequences of these effects are already being observed and documented in the region, including recent widespread forest dieback and population changes in native species (Inouye et al. 2000; Breshears et al. 2005). Natural resource professionals need to better understand the regional impacts of climate change so that they can take informed adaptive action in managing the landscapes that provide ecosystem services to human communities and habitat for a diversity of species. To address the need for information and guidance on responding to the potential consequences of climate change, The Nature Conservancy initiated the Southwest Climate Change Initiative (SWCCI), a collaborative effort between The Nature Conservancy and partners (state, federal, non-governmental organizations, universities) in the Four Corners states. More information about this study can be found at: http://nmconservation.org/projects/new_mexico_climate_change/.



B. Klein

Purpose and Conservation Objective

In 2006, the New Mexico Chapter of The Nature Conservancy first launched its own climate change ecology and adaptation program. Building on the completion of a state-wide climate change assessment and two adaptation-oriented workshops for natural resource managers in New Mexico (Enquist and Gori 2008; Enquist et al. 2008), The Nature Conservancy then launched the SWCCI. The Initiative specifically seeks to further develop and apply an integrated assessment approach that examines regional climate impacts, prioritizes adaptation actions based on potential vulnerability, and identifies specific climate adaptation strategies in

Lead authors: Patrick McCarthy and Carolyn Enquist.

priority landscapes in the region using an adaptation planning framework. The conservation objective of the project is to provide a straightforward approach for integrating climate change into existing conservation and management planning and decision-making processes. Ultimately, with continued refinement and development of this suite of nested-scale approaches, the project seeks to cultivate dialogue and collaboration between conservation practitioners, managers, and policy-makers from multiple jurisdictions, so that they can work toward reducing the vulnerability and increasing the resilience of current and future conservation priorities to ongoing climate change.

Scale and Scope

The assessment covers an area that comprises four states of the southwestern United States: Arizona, Colorado, New Mexico, and Utah. The New Mexico state-level climate and vulnerability analyses took 2.5 years to complete, with an approximate cost of $75,000, including significant in-kind contributions from external partners. The expanded SWCCI project conducted the baseline regional assessment in 1 year; the adaptation planning workshops in each of the four states were implemented over the course of 1.5 years (Phase 1). Together, the first phase of the SWCCI project cost approximately $200,000.

Assessment Approach and Targets

Regional Assessment

The SWCCI integrated framework begins with a spatially explicit rapid regional assessment of climate exposure using the ClimateWizard analysis tool. Specific climate metrics include departures and trends in temperature, precipitation, and moisture stress (i.e., evaporative demand). We mapped and analyzed these metrics

Michael D. Peterson

across the four states both retrospectively and prospectively. For historical analyses, ClimateWizard uses publicly available PRISM climate data set at a cell resolution of 4 square kilometers (Daly 1994). We used an ensemble of 16 IPCC AR4 global circulation models statistically downscaled to 12 kilometers for the future analyses (Maurer et al. 2007). Annual and seasonal trends were evaluated for the time periods analyzed (1950 to 2006, 1970 to 2006, 2020 to 2039, and 2069 to 2099). Statistical summaries were generated for each climate metric and time period for the region and for each state, ecoregion, and watershed. To identify potential vulnerability, we next evaluated climate change exposure in relation to existing conservation priorities, or targets (e.g., geographies, habitats,

and sensitive species), identified in the four states' Wildlife Action Plans and ecoregional assessments. We used species occurrence data provided by NatureServe for our species-focused analyses, NatureServe vegetation analysis data for habitats, and spatial data of The Nature Conservancy's network of conservation areas for priority geographies.

Landscape Adaptation Planning

The second part of the SWCCI integrated framework aims to identify a suite of place-based adaptation strategies for potentially vulnerable species, ecosystems, or natural processes in priority landscapes. We specifically use an approach recently developed by a Wildlife Conservation Society–National Center for Ecological Analysis & Synthesis working group comprising managers and scientists from academia, non-governmental organizations, and federal agencies. This framework allows local scientific experts and managers to work in a transparent, participatory process to identify climate change threats and impacts and translate this information into a portfolio of strategies that are applicable to the landscape of interest. The proposed strategies can then be evaluated in the social, political, regulatory, and economic contexts that motivate and constrain management goals and policies. Subsequent iterations allow the incorporation of newly available information.

As the **first step** in this process, participants select a target and related management goals. In the **second step,** we define a plausible *climate change scenario* (e.g., warmer–drier with increased climate extremes) to apply to the target and goal. The **third step** involves building a *conceptual ecological model* and assessing known and potential climate change impacts. As part of this model, we consider other social, political, economic, and ecological constraints on the system, how they are interconnected, and how they will likely be affected by the selected climate change scenario. In the **fourth step,** we identify management *intervention points* for the target, or the components of the system that management can affect. We then identify management actions, or adaptation strategies, that can be taken at those points to address climate change impacts. The **fifth step** consists of *evaluating the identified adaptation strategies* based on their effectiveness (e.g., ability to affect target), robustness to variations in the climate change scenario and/or management objective, and the ability to monitor success. We also address the issue of uncertainty associated with a strategy, asking if the effect on the target will be "win-win" (where there could be multiple benefits), "no regrets" (less risky approach), or "proactive/anticipatory" (most risky).

Results

Regional Assessment

Temperature increased across the Southwest from 1951 to 2006, rising an average of 0.5 degrees Celsius (about 1 degree Fahrenheit) every 30 years. The temperature increase was consistent across scales, rising significantly across 70 to 100 percent of the watersheds, habitats, ecoregions, and states that we evaluated. Precipitation also increased across the region in the historic period, increasing by about 10 percent every 30 years. However,

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this trend was less consistent across scales, rising in only 36 to 75 percent of the units we evaluated. Several areas were actually drier, but none of these were significant. Climate change models predict that temperature will continue to rise in future, between 1 to 3 degrees Celsius by 2020 to 2039 and 3 to 5 degrees Celsius by 2080 to 2099. The temperature rise pattern is fairly consistent across scales. Predicted changes in precipitation are less consistent across time and space, ranging from −6 percent to +6 percent in 2020 to 2039 and −13 percent to +11 percent in 2080 to 2099.

Our preliminary analyses suggest that many sensitive-species-rich watersheds are among those that have been (1951 to 2006) and will continue to be exposed to extreme temperature changes. In particular we found that the Lower Colorado-Lake Mead (Arizona) and Upper Colorado-Dirty Devil (Utah) watersheds may be the most vulnerable places in the Southwest given these criteria and large percentage of freshwater and endemic species. Conversely, there are sensitive-species-rich watersheds that have experienced less exposure during the past 55 years. These places may be the ones that may have more resilience to predicted future temperature changes—at least in the shorter term. These include the Upper Pecos (New Mexico) and Upper Arkansas (Colorado) watersheds.

Landscape Adaptation Planning

Using the results of the regional assessment in a convened meeting of stakeholders, we identified case study landscapes in each of the Four Corners states for implementation of the collaborative Wildlife Conservation Society (WCS) and National Center for Ecological Analysis and Synthesis (NCEAS) adaptation planning process. We subsequently have engaged representatives from local agencies and non-governmental organizations to plan and implement the process in medium-sized workshops in each landscape for local resource managers. The goal of the workshops is to translate available climate change science, so that managers can overcome uncertainty paralysis and begin to identify strategies for helping species and ecosystems adapt to climate change. Specific objectives of the workshops are

to (1) provide background information on climate change and its effects in the focal landscapes and (2) identify opportunities for learning, collaboration, and application of the adaptation planning process for natural resource management in the focal landscapes. As of December 2009, we have held two workshops in the Jemez Mountains of New Mexico and the Gunnison Basin of Colorado. Additional workshops are being planned for the Four Forest Restoration Initiative focal area in the vicinity of Flagstaff, Arizona (April 2010), and for the Bear River Basin of Utah (May 2010).

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Uncertainties

Assessment Climate Data

At a spatial resolution of 4 square kilometers, the PRISM model estimates monthly temperature and precipitation using a combination of climate station data, a digital elevation model, and expert-based knowledge of complex climatic processes, such as rain shadows and temperature inversions. As a statistically interpolated raster data set, there are inherent uncertainties associated with data that are further away from points (or data cells) with actual station data. These "inbetween" areas should be interpreted with some caution, particularly those values associated with a single data cell. Problems with station data can also exist, as some of these may have shorter periods of record or may have been physically moved during the course of data collection. Furthermore, geographical areas with complex topography may be particularly subject to data anomalies (e.g., the mountainous area of Colorado). Uncertainty associated with downscaled future climate models was also addressed.

Assessment Targets

We viewed conservation priorities as "surrogates of sensitivity" because we presumed all units of native biodiversity, especially drought-sensitive species, are likely to be sensitive on some level to rapid and abrupt climate change, despite adaptive ability (e.g., Sala et al. 2000). This may be especially true for species, ecosystems, or places that have formalized conservation status, given that they were identified at least in part because of

specific attributes (e.g., rarity, endemism, etc.) that may render them susceptible to human-induced threats. In a subsequent phase of the project, using results of the first phase as a guide, we will investigate specific climate-related sensitivities related to species of concern and habitat types. Although our approaches *do not specifically measure* a conservation priority's adaptive capacity, we generated hypotheses of which conservation priorities are most and least vulnerable to ongoing climate change were developed. These will be used to further develop and refine future analyses.

Outcomes and Next Steps

We are currently in the process of writing up the results of our regional assessment in a report format written for natural resource professionals from across the Southwest. Our target distribution date is June 1, 2010. Our target completion date is June 2010, when we will post it to the project's Website (see above). We also are in the process of writing a project team charter to identify specific next steps for refining and further developing our assessment methods and related funding opportunities.

Jemez Mountains Climate Change Adaptation Workshop

This was the first in a series of four workshops to be organized by the SWCCI, held on April 21 to 22, 2009, in Los Alamos, New Mexico. More than 50 representatives of state and federal agencies, tribal governments, and non-governmental organizations participated. Over the course of 2 days, managers, scientists, and conservation practitioners worked together to identify adaptation strategies under two climate change scenarios—one moderate and one more extreme—for two ecological process–based conservation features, fire and in-stream flows. Participants found that many of the conservation strategies already being planned or implemented in the Jemez Mountains can be used to prepare for climate change. But, even under the more conservative of the two climate change scenarios we explored, the scale, sequencing, priority, and cost of these strategies will likely need to be adjusted if management objectives are to be met. Examples of priority strategies identified by the overall group included: system-wide management planning for fire and climate change; improvement of riparian ecosystem health by fencing out elk and cattle or by reducing the landscape's elk herd; landscape-scale ecological fire management; widening the prescribed fire window (i.e., expanding the suite of weather conditions under which prescribed burning can be implemented); and applying forest thinning prescriptions to promote snowpack retention and maximum precipitation infiltration. Participants also listed numerous actions that could be taken to carry out these strategies, and they identified both barriers to and opportunities for implementation.

Gunnison Basin Climate Change Adaptation Workshop

This was the second workshop organized by the SWCCI, held on December 2 to 3, 2009, in Gunnison, Colorado. Fifty-seven representatives of 20 state and federal agencies, local governments, academic institutions, and non-governmental organizations participated. Using two climate change scenarios, managers identified strategies using the adaptation framework for three "conservation

features." Similar to the Jemez Mountains workshop, many strategies resemble existing ones. Examples of priority strategic actions that emerged from the workshop for the three conservation features include:

- **Gunnison sage-grouse:**

- Retain water in most vulnerable sage-grouse habitats via restoration of seeps and springs and implementing more efficient agricultural practices

- Improve and restore nesting and wintering sage-grouse habitats

- **Gunnison headwaters:**

- Manage upland vegetation for groundwater recharge and base flow maintenance

- Construct and/or restore wetland complexes

- **Alpine wetlands:**

- Build snow fences to augment water inputs

- Increase buffer zones around alpine wetlands

Participants of both workshops recognized that more work is needed to develop strategies to reduce the impacts predicted under extreme climate change scenarios. The ecological changes that could occur under these scenarios require more intensive and extensive management intervention or perhaps even wholesale changes in management goals. Participants expressed an interest in continuing to work together to refine our understanding of climate change, impacts to species, ecosystems, and ecological processes, and to refine the identified strategies. Participants also acknowledged that effective communication among local stakeholders and policy-makers is critical to building trust and to engaging people in the development of realistic management objectives as we face the possibility of undesired future conditions.

Overall workshop planners were pleased with the outcomes of the two workshops, noting that the planning framework gives managers the opportunity to document logic and assumptions, justify specific options in what is a relatively transparent process. Additionally, participants identified future information and research needs. Perhaps most importantly, the workshops provided a forum to promote landscape-level collaboration and continued dialogue via the formation of informal climate change learning networks.

A final, synthetic report of the four workshops describing emergent and divergent strategies, recommendations for moving the process forward, and lessons learned is targeted for completion by the autumn of 2010. Pending additional funding, we hope to conduct follow-up workshops focused on implementation, testing, and monitoring of identified management strategies using an adaptive management framework.

Case Study 7. Pacific Northwest Climate Change Vulnerability Assessment

Summary

This case study describes the early stages of a broad, regional-scale vulnerability assessment for species and habitats that is applying a range of assessment approaches. This collaborative project is creating a digital database of climate change sensitivities of species and systems in the Pacific Northwest and will identify which are inherently most sensitive to climate change. Species and systems sensitivities are based on physiology, habitat requirements, life history, dispersal ability, population growth rates, location, ecological climate effects, and disturbance regime effects. Sensitivity is being identified by experts, scientific literature, and pertinent data sets. This database will provide natural resource managers with critical information that can be combined with the management tools already in their toolbox to address climate change and better prepare for the future.

Background—Climate Change in the Pacific Northwest

Pacific Northwest temperatures have increased by about 0.8 degrees Celsius and models project warming of 2.0 degrees Celsius by the 2040s and 3.3 degrees Celsius by the 2080s (Mote and Salathé 2009). Precipitation is also projected to change, with general increases projected for the Pacific Northwest, and with a more intense seasonal precipitation cycle—autumns and winters may, in fact, become wetter and summers may become drier. Regional climate models indicate that overall extreme precipitation in western Washington will increase and the snowpack in the Cascades will decrease (Mote and Salathé 2009).

Veni

Purpose of the Vulnerability Assessment

The Pacific Northwest Vulnerability Assessment was developed in response to the considerable challenge that climate change poses to natural resource managers. Leading this voluntary approach, the University of Washington is partnering with key collaborators, such as scientists, natural resource managers, and conservation planners in the Pacific Northwest region to conduct a climate–ecological vulnerability assessment.

Lead authors: Michael Case and Josh Lawler.

David J. Mills

Conservation Objective

The assessment will provide managers and planners with information about which species and systems will be most vulnerable to climate change and in what ways they will be vulnerable. This information can be used to prioritize management actions, design adaptation strategies, and apportion scarce resources.

Assessment Targets

The assessment targets both species and ecological systems (habitats). One of the goals of this project is to develop a digital database of inherent climate change sensitivities for species and systems of concern throughout the Pacific Northwest and to provide resource managers and decision-makers with important information about how species and systems will likely respond to climate change. The project database and related modeling assessments will also allow researchers to address important scientific questions regarding the potential impacts of climate change on natural resources.

Scale and Scope

The assessment covers an area that extends beyond the borders of Washington, Oregon, and Idaho (see Figure C7.1). Current project funding to populate and analyze the database will continue until 2011. However, access and use of the database will continue into the future and will eventually cover a broader spatial scale.

The resource needs for this type of assessment are significant (the project will likely require a total of $800,000 and 3 to 4 years to complete), but it is being conducted at a regional scale, considers both selected species and broad habitat categories, and combines the resources of state and federal agencies, academic institutions, and non-governmental organizations.

Assessment Approach

This project is a collaboration among researchers, managers, and planners at the University of Washington, U.S. Geological Survey, The Nature Conservancy, the National Park Service, the U.S. Forest

Service, the Washington Department of Fish and Wildlife, the University of Idaho, the National Wildlife Federation, the Oregon Department of Fish and Wildlife, and Idaho Fish and Game.

The Pacific Northwest Climate Change Vulnerability Assessment includes two distinct components; the first is a database that will highlight and detail the sensitivity to climate change of species and habitats in the study region. For this project, sensitivity is defined as a measure of the inherent susceptibility to climate change. Some species and systems are inherently more susceptible to climate change than others. The estimated sensitivity of individual species is currently assessed on the following characteristics: ability of the species to disperse and whether dispersal barriers exist; dependency on disturbance regimes such as fire or flood regimes; physiology and ecology (i.e., sensitivity to temperature, precipitation, salinity, pH, CO_2); dependency on and persistence of climatically sensitive habitats (such as alpine areas, shallow wetlands, and perennial streams); whether the species is a generalist or specialist, and whether its existence is tied to other species. The sensitivity of ecosystems and communities will be based on hydrological sensitivities, component species sensitivities, proximity to the coast, and the effects of disturbance regimes. The database will be used in conjunction with a sensitivity index to produce a ranking of more than 400 species and systems with respect to their sensitivity to climatic change.

The second component of the assessment involves modeling the potential effects of climate change on species and habitats of the Pacific Northwest. The initial step of this part of the project is to statistically downscale climate change projections to produce projected changes in climate at approximately 1-square-kilometer resolution for at least six different future climate projections. This relatively high-resolution data will provide information

Figure C7.1. Study area.

that is more applicable to regional planning and natural resource management. We will then use these downscaled climate projections in conjunction with soils data as inputs to a dynamic global vegetation model to project potential changes in the vegetation of the region. Vegetation types will be defined by their relative composition of different basic plant functional types such as broad-leafed deciduous trees and grasses. These vegetation data will then be used to model the current and potential future ranges for 12 bird and mammal species in the

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Pacific Northwest. Specifically, we will use a hierarchical modeling approach to project future species distributions. First, we will use continental-scale models (e.g., Lawler et al. 2009) to predict future species distributions at a 50-square-kilometer resolution across the study region. These predictions will provide estimates of the future range boundaries of the each species. Then, within the projected future ranges, we will project future distributions at a 1-square-kilometer resolution using regional distribution models that take both changes in climate and changes in vegetation (habitat) into account.

Relevant uncertainties related to the data and analyses are highlighted throughout the project and database. For example, when entering species and system characteristics into the database experts are asked to assign uncertainties along with their answers and these uncertainties are reported in the database output. Additionally, the project assigns levels of uncertainty to the simulated climatic and bioclimatic changes and the simulated vegetation changes.

Assessment Results

While still in the early stages of populating the database, preliminary analysis has examined the overall sensitivity (calculated by the database index) of more than 20 species present on the Olympic Peninsula (see Figure C7.2). The results of this analysis highlight the potential vulnerability of species that rely on sensitive habitats and have stronger physiological sensitivities to climate change (Halofsky et al., in press). Species that occupy vulnerable habitats, such as the Olympic torrent salamander (headwater streams), Cascades frog and Van Dyke's salamander (aquatic habitats), Dogstar skipper butterfly (meadows), Makah copper butterfly (wetlands), and the Olympic marmot, mountain goat, Clark's nutcracker, and gray-crowned rosy finch (high-elevation habitats), were generally ranked as highly sensitive to climate change. Similarly, specialist species in terms of habitat and diet, such as Clark's nutcracker, northern spotted owl, gray-crowned rosy finch, Van Dyke's salamander, American marten, and northern flying squirrel, were ranked as moderately to highly sensitive to climate change. More generalist species, such as the barred owl, black bear, Roosevelt elk, snowshoe hare, and mountain beaver, were not ranked as highly for sensitivity to climate change.

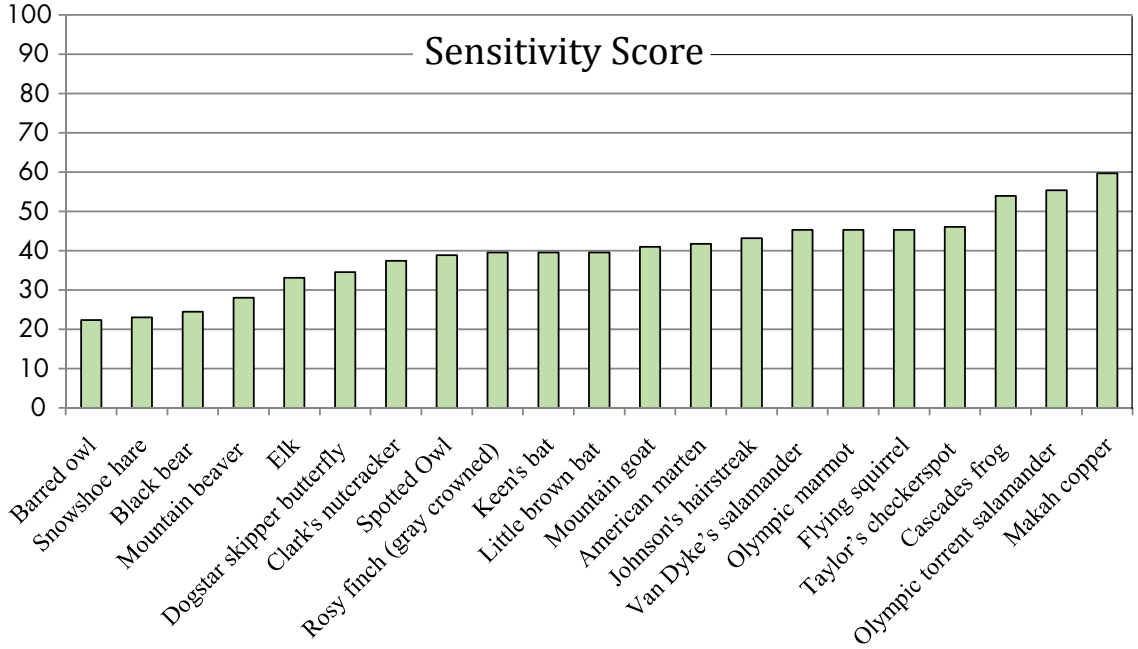

Figure C7.2. Climate change sensitivity scores for selected species on the Olympic Peninsula.

Uncertainties

There are many different types of uncertainty associated with forecasts of future climate changes (Giorgi 2005) and the impacts that these changes will have on species and ecosystems. These uncertainties are often not explicitly described in climate change studies, making it difficult for conservation planners to determine how much they should rely on particular results. In response, we are in the process of identifying and describing the uncertainties associated with the different results produced by our analyses. Examples of uncertainties include:

- Uncertainties associated with model simulations of particular variables (e.g., there tends to be more certainty in AOGCM temperature simulations than in AOGCM precipitation simulations)

- Temporal variations in uncertainties (e.g., the uncertainty in AOGCM future climate simulations tends to increase the farther out in time the predictions are from the present)

- Uncertainties created by variability among AOGCM simulations (e.g., one AOGCM may simulate dry winter conditions for a region while another AOGCM simulates wetter winter conditions for the same region)

- Uncertainties inherent in the vegetation and species distribution models

To compensate for the high uncertainty associated with future climate projections, this project will produce six maps (one for each of the six climate change simulations) of projected future ranges for each of the modeled species. By overlaying the projected distributions, we will be

able to highlight model agreement and disagreement for each species and to identify areas where species ranges are simulated to change the most.

Outcomes and Next Steps

Both the database and modeling components of this study make an important contribution to understanding the impacts of future climate change on the species and habitats of the Pacific Northwest. The database assesses the sensitivity of the Pacific Northwest's conservation targets to climatic changes. The analyses of the projected climate change and simulated vegetation change provide an indication of the potential magnitude and spatial character of future climate change (i.e., exposure). The modeled changes in species distributions reveal how climate change may affect the future distributions of key species in the region.

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The preliminary results presented above illustrate how this sensitivity assessment process can be useful in identifying species and groups of species that will likely be most sensitive to climate change. As demonstrated at the Olympic Peninsula expert meeting where some of the data were collected, this process can lead to useful discussions about how individual and groups of species may be affected by climate change. While the results of this initial analysis are still under development, project leads are in the process of incorporating recommendations and concerns. For example, in addition to the default index equation, database users will also be able to weight specific characteristics and thus influence their individualized output.

Ultimately, this study will integrate these results and produce an assessment of the climate change vulnerability of species and systems in the Pacific Northwest. Using these data, we will describe and assign a level of uncertainty to the projected changes and, as in the other parts of the study, we will work with conservation scientists to produce documentation, analyses, and visual displays of data that will be useful in developing management and planning responses to climate change impacts. This project is committed to providing relevant and useful information and thus will continue to evolve to meet the needs of managers and decision-makers in the region.