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Rapid Assessment of Plant and Animal Vulnerability to Climate Change

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Although scientists have been concerned about climate change for decades, many policy makers and resource managers have only recently recognized the urgency of the problem. Now resource managers are increasingly asked to identify which of the species on the lands and waters they oversee are most vulnerable to climate change-induced declines. Knowing which species are vulnerable and why is a critical input for developing management strategies to promote persistence of species as climates change. Comparing vulnerabilities across species is difficult, however, because species respond differently to change (Overpeck et al. 1991, Davis and Shaw 2001) and because climate change is likely to impact species both directly and indirectly. Further, the same species may respond differently in different places, due to variations in exposure to climate change or differences in key habitats or species interactions. Also, research on climate change vulnerability is growing rapidly (Brodie et al. this volume) and managers often have little time to keep abreast of new findings (Heller and Zavaleta 2009, Lawler et al. 2009a).

Climate change vulnerability is now on the agenda of international entities such as the European Union and the International Union for the Conservation of Nature (IUCN; CEC 2006, Foden et al. 2008). In the United States, state fish and wildlife agencies increasingly need ways to identify vulnerable species as they begin to revise state wildlife action plans. In the United States, state fish and wildlife agencies increasingly need ways to identify vulnerable species as they begin to revise state wildlife action plans. Wildlife action plans, mandated by the US Congress, require assessments of species and habitats at risk and the development of strategies to prevent species from becoming endangered (AFWA 2009). Revisions of these plans are required every 10 years, but revisions to specifically include climate change are not mandated at this time. Similarly, US federal land managing agencies are seeking ways to address species vulnerability as they begin to modify conservation strategies to account for climate change (Blay and Dombeck, this volume).

Most assessments of vulnerability to climate change tend to focus on single factors, such as changes in distribution (e.g., from bioclimatic models; Peterson et al. 2002, Midgley et al. 2003, Thomas et al. 2004, Lawler et al. 2009b) or changes in phenology and the potential for phenological mismatches (e.g., Bradley et al. 1999, Visser and Both 2005). More recently, scientists have emphasized how key behavioral or demographic characteristics may contribute to vulnerability (e.g., Humphries et al. 2004, Jiguet et al. 2007, Laidre et al. 2008) and to species response patterns at various organizational scales (Parmesan 2007, Willis et al. 2008). Further, several theoretical treatises describe potential frameworks for vulnerability assessments, including evaluations of exposure to climate change, inherent sensitivity, and adaptive capacity (Füssel and Klein 2006, Williams et al. 2008, Austin et al., this volume), as well as guidance on how to incorporate uncertainty and relative risk (Schneider et al. 2007).

Building on these findings, we have developed a "climate change vulnerability index" (hereafter, "index") to serve the needs of wildlife managers for a practical, multifaceted rapid assessment tool. The aim of the index is to provide a means of rapidly distinguishing species likely to be most vulnerable, defined as the degree to which a species is susceptible to detrimental change (Smit et al. 2000). After using the index, managers may wish to perform more in-depth (and resource-intensive) vulnerability analyses of species highlighted by the tool as being particularly vulnerable. The index relies on natural history and distribution factors that are associated with sensitivity to climate change and projections of climatic changes for the assessment area. It does not require advanced technical expertise, so it can be used efficiently by anyone with biological training and access to the relevant natural history and distribution information.

The index is flexible in that it can assess plants and animals from both terrestrial and aquatic habitats, and can handle missing data and uncertainty in species sensitivity measures. It can also handle input from studies that document vulnerability or project future suitable ranges, when available. Its output includes both a vulnerability category for the species of interest and a report on the key factors that have contributed to the ranking, which can help inform conservation actions. Here we discuss the mechanics of the index and report on preliminary results from a case study of vertebrates and mollusks included in Nevada's state wildlife action plan.

Climate Change Vulnerability Index

We divide vulnerability into exposure to changes in climate and species sensitivity (Schneider et al. 2007, Foden et al. 2008, Williams et al.

2008). Exposure is the magnitude of projected climate change across the portion of the range of the focal species that lies within the geographic area considered. Species sensitivity includes intrinsic factors such as natural and life-history traits that promote resilience to change (such as dietary versatility or identification as a habitat generalist), traits that indicate increased risk (such as a strong potential for disruption of key species interactions), and traits that indicate capacity to adapt to change (such as dispersal ability and genetic variation). The index scores a species in relation to multiple intrinsic and extrinsic sensitivity factors and then weights the score depending on the magnitude of climate change projected. Any information available on documented responses of the species to climate change is then combined with the vulnerability score to produce a final index score (figure 7.1).

For simplicity of use, we have developed the index as an MS Excel workbook (available at www.natureserve.org/climatechange) that allows users to enter exposure data and then select categorical answers to questions that assess how the species' natural history may influence its relative vulnerability to climate change. Extensive documentation provides criteria for determining how to "score" sensitivity for each factor, but the user can enter more than one value to indicate uncertainty in species information (Young et al. 2010). The workbook then calculates an index score from the entries on exposure and sensitivity, and converts it to a categorical vulnerability score (extremely vulnerable, highly vulnerable,

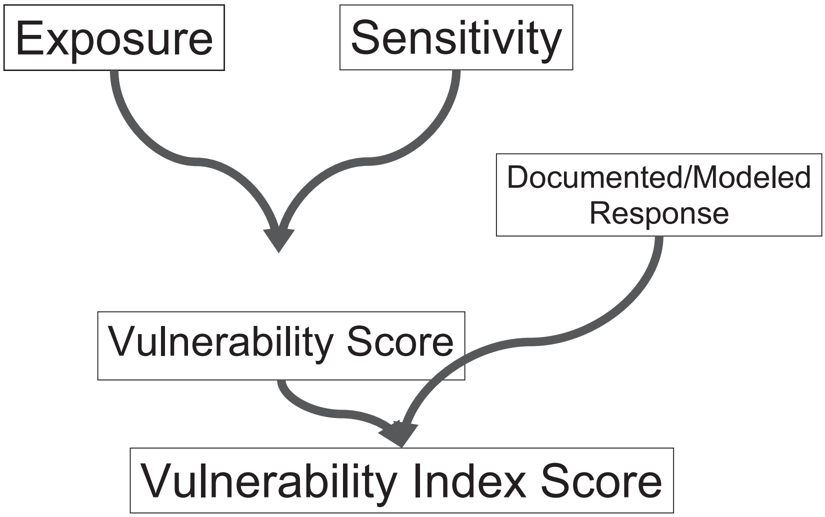

Figure 7.1. Major components of the climate change vulnerability index

moderately vulnerable, not vulnerable/presumed stable, not vulnerable/increase likely). If a minimum number of factors are not scored or if the exposure data are incomplete, the index reports a value of "insufficient evidence."

Relationship to Existing Conservation Status Assessments

We designed the index to work in concert with, and not duplicate, information contained in standard conservation status assessments such as the IUCN Red List, which is used worldwide, or NatureServe conservation status ranks, which are used extensively in the United States and Canada (Master et al. 2000, Mace et al. 2008). Factors such as population size and range size can influence vulnerability to climate change (Hampe 2004, Aitken et al. 2008, Laidre et al. 2008), but they are also fundamental inputs to assessments of conservation status. To avoid duplication, we have excluded these factors from the index. Because population and range size are major factors in determining conservation status, repeating them in our assessments would cause most threatened species to also be scored as vulnerable to climate change. The purpose of the index is to highlight species with other intrinsic and extrinsic factors that place them at risk.

Indirect Effects

In many cases, climate change impacts species both directly (e.g., by drought-induced declines in reproduction or survival) and indirectly through changes in interspecific interactions (Lawler et al. 2009a). To cite a popular example, the warming experienced in western North America over the past three decades has not directly caused the major declines documented in lodgepole pine (*Pinus contorta*). Instead, warmer winters have allowed mountain pine beetles (*Dendroctonus ponderosae*) to rapidly expand their range northward, leading to the decimation of large stands of pines (Carroll et al. 2004). While we recognize that shifts in competitive, predator-prey, or host-parasite interactions are likely to be very important, we have not attempted to incorporate them into this index. How such interactions change as a result of changes in climate is difficult to predict, even in controlled experiments (Suttle et al. 2007, Spiller and Schoener 2008, Tylianakus et al. 2008). The sheer magnitude of potential biotic and abiotic factors that could contribute to variations in the strength of interactions suggests that grappling with them in a climate-change context will continue to be a major challenge (Tylianakis et al. 2008). However, the index does reflect species' dependence on particular types of interactions (e.g., between plant and pollinator) because these interactions may be uncoupled if the component species respond differently to climate change.

Accounting for Exposure

The index accounts for direct exposure to climate change by integrating the magnitude of predicted change across the range of a species within the geographic area considered. The time horizon is 2050, a date far enough in the future for significant changes to have occured, but before temperature projections from different emissions scenarios and global circulation models diverge substantially (Meehl et al. 2007). Downscaled predictions of climate change are becoming more readily available to facilitate assessment of exposure (e.g., Maurer et al. 2007; data available for viewing and download at www.climatewizard.org).

We considered both the severity and the scope of climate change in our assessment of exposure. The index divides temperature increase and precipitation increase/decrease (severity) into categories and defines the percentage of the species' range within the analysis area that will experience each severity category of temperature and precipitation change (scope). We used multiples of the standard deviation of predicted mid-century change in annual mean temperature and precipitation in the conterminous United States (Maurer et al. 2007; medium [A1B] emission scenario, ensemble average of 16 global circulation models) to delimit categories describing the magnitude of climate exposure. More specific seasonal climatic factors might be more relevant for particular species (e.g., Carroll et al. 2004), but because this information is rarely known, we used the annual data as proxies for severity of climate change.

Indirect Exposure and Species Sensitivity

Next, the index presents four factors to assess extrinsic indirect exposure and 17 factors, each supported in the literature, to evaluate species sensitivity (table 7.1). For each factor, the species is scored according to how much the factor increases or decreases vulnerability to climate change.

Documented or Modeled Vulnerability

For a small but growing number of species, field or modeling studies provide an indication of their vulnerability, as in documenting how their populations have responded to climate change in the recent past. Because these findings are valuable indicators of vulnerability, the index captures them in four factors that are considered separately from exposure and sensitivity (table 7.1).

Table 7.1. Vulnerability factors and exposure weighting used in the index and importance of factors for Nevada test species. See text for descriptions of exposure ratings.

	Factor information			Nevada pilot species		
Factor	Description	References[1]	Exposure weighting	No. of species with adequate knowledge to assess	No. of species for which factor increased vulnerability	No. of species for which factor decreased vulnerability
Indirect exposure factors						
Exposure to sea level rise	Predictions of 0.8–2.0 meter increase in sea level this century suggest that species occurring in coastal zones and low-lying islands will be subject to rapid loss of habitat and vulnerable to associated storm surge.	15, 28	1.0	N.A.	N.A.	N.A.
Distribution relative to natural topographic or geographic habitat barriers	Geographical features of the landscape where a species occurs may naturally restrict it from dispersing to inhabit new areas.	3, 14, 23, 33, 18, 37, 16, 12, 21, 22, 29	Climate stress	216	14	0
Distribution relative to anthropogenic barriers	Dispersal of a species to areas with favorable climates may be hindered by intervening urban or agricultural areas.	25	Climate stress	216	10	0
Impact of land use changes designed to mitigate against climate change by sequestering carbon or reducing dependence on fossil fuels	Strategies designed to mitigate greenhouse gases, such as creating large wind farms, plowing new cropland for biofuel production, or planting trees as carbon sinks have the potential to affect large tracts of land and the species that use those areas in both positive and negative ways.	17, 10, 8	Climate stress	216	96	0

Species sensitivity factors						
Dispersal ability	Species with poor dispersal abilities may not be able to track fast-moving, favorable climates.	6, 23, 38, 16	Climate stress	215	78	90
Historical thermal niche	Species that have not experienced much temperature variation in recent historical times (the last 50 years) may not be able to adapt to future change.	31, 35, 37, 9, 5, 12, 20	Temperature change	216	5	74
Physiological thermal niche	Species requiring specific temperature regimes may be less likely to find similar areas as climates change and previously associated temperature and precipitation patterns uncouple.	31, 35, 37, 9, 12, 20	Temperature change	216	14	6
Historical hydrological niche	Species that have not experienced much variation in precipitation during recent historical times (the last 50 years) may not be able to adapt to future change.	31, 35, 37, 9, 12, 20	Precipitation and temperature, weighting precipitation three times as much as temperature	216	159	11
Physiological hydrological niche	Species requiring specific precipitation, hydrological conditions, or moisture regimes may be less likely to find similar areas as climates change and previously associated temperature and precipitation patterns uncouple.	31, 35, 37, 9, 12, 20	Precipitation and temperature, weighting precipitation three times as much as temperature	216	67	1

(*Continued*)

Table 7.1. (*Continued*)

	Factor information			Nevada pilot species		
Factor	Description	References[1]	Exposure weighting	No. of species with adequate knowledge to assess	No. of species for which factor increased vulnerability	No. of species for which factor decreased vulnerability
Dependence on ice, ice edge, or snow-cover habitats	The extent of oceanic ice sheets and mountain snow fields is decreasing as temperatures increase, thus imperiling species dependent on these habitats.	34, 15, 20	Climate stress	215	5	N.A.
Physical habitat specificity	Species requiring specific substrates, soils, or physical features such as caves, cliffs, or sand dunes may become vulnerable to climate change if their favored climate conditions shift to areas without these habitat elements.	12	Climate stress	215	20	96
Reliance on interspecific interactions: (a) Dependence on other species to generate habitat	Because species will react idiosyncratically to climate change, those with tight relationships with other species may be threatened.	4, 11, 12	Climate stress	216	21	N.A.
(b) Pollinator versatility (plants)	See above.	12	Climate stress	N./A.	N.A.	N.A.
(c) Dependence on other species for propagule dispersal	See above.	12	Climate stress	216	0	N.A.

(d) Dietary versatility (animals)	See above.	33, 20	Climate stress	216	12	0
(e) Forms part of some other mutualism	See above.	4	Climate stress	212	0	N.A.
Migrations (animals)	Species with very specific migratory destinations are vulnerable, whereas those with broad destinations are less vulnerable to climate change.	19, 16	Climate stress	216	147	60
Measured genetic variation	A species' ability to evolve adaptations to environmental conditions brought about by climate change is largely dependent on its existing genetic variation.	13, 1	Climate stress	0	0	0
Occurrence of bottlenecks in recent evolutionary history	See above.	13, 1	Climate stress	0	0	N.A.
Phenological response to changing seasonal temperature and precipitation regimes	Some species are declining due to their inability to respond to changing annual temperature dynamics (e.g., earlier onset of spring, longer growing season), including European bird species that have not advanced their migration times, and some temperate-zone plants that have not moved their flowering times.	24, 39	Climate stress	0	0	0
Documented or modeled responses to climate change						
Documented change in distribution or abundance attributable to recent climate change	Although conclusively linking species declines to climate change is difficult, convincing evidence relating declines to recent climate patterns has begun to accumulate in a variety of species groups.	25, 26, 30, 7	—	0	0	0

(*Continued*)

Table 7.1. (*Continued*)

	Factor information			Nevada pilot species		
Factor	Description	References[1]	Exposure weighting	No. of species with adequate knowledge to assess	No. of species for which factor increased vulnerability	No. of species for which factor decreased vulnerability
Modeled future change in range size	Change in the area of the predicted future range relative to the cu)rrent range is a useful indicator of the species' vulnerability to climate change.	23, 36	—	0	0	0
Overlap of modeled future range with current range	A spatially disjunct predicted future range indicates that the species will need to disperse in order to occupy the newly favored area, and geographical barriers or slow dispersal rates could prevent the species from getting there.	27, 32	—	0	0	N.A.
Occurrence of protected areas in modeled future distribution	If future ranges fall outside of protected areas, long-term viability of populations may be compromised.	38	—	0	0	N.A.

[1] References: 1. Aitken et al. 2008. 2. Archer and Predick 2008. 3. Benito Garzón et al. 2008. 4. Bruno et al. 2003. 5. Calosi et al. 2008. 6. Dyer 1995. 7. Enquist and Gori 2008. 8. Fargione et al. 2009 9. Gran Canaria Declaration 2006. 10. Groom et al. 2008. 11. Hampe 2004. 12. Hawkins et al. 2008. 13. Huntley 2005. 14. IPCC 2002. 15. IPCC 2007. 16. Jiguet et al. 2007. 17. Johnson et al. 2003. 18. Koerner 2005. 19. Laidre and Heide-Jørgensen 2005. 20 Laidre et al. 2008. 21. Lenoir et al. 2008. 22. Loarie et al. 2008. 23. Midgley et al. 2003. 24 Møller et al. 2008. 25. Parmesan 1996. 26. Parmesan and Yohe 2003. 27. Peterson et al. 2002. 28. Pfeffer et al. 2008. 29. Price 2008. 30. Root et al. 2003. 31. Saetersdal and Birks 1997. 32. Schwartz et al. 2006. 33. Simmons et al. 2004. 34. Stirling and Parkinson 2006. 35. Thomas 2005. 36. Thomas et al. 2004. 37. Thuiller et al. 2005. 38. Williams et al. 2005. 39. Willis et al. 2008.

Computing an Index Score

To calculate an overall score, the index first combines information on exposure and sensitivity to produce a numerical sum, calculated by adding subscores for each of the extrinsic and intrinsic species sensitivity factors. Factors receive values (3.0, 2.0, 1.0, 0, –1.0, and –2.0), depending on the degree to which vulnerability is increased or decreased. If a factor is scored in multiple levels, the index uses an average.

The value for each factor is weighted by exposure to calculate a subscore. Climate influences vulnerability factors in different ways. For most factors, the exposure weighting is a climate stress value that combines data on projected change in both temperature and precipitation. In these cases, the weighting factor is the product of weightings for temperature (0.5, 1.0, 1.5, or 2.0, depending on the temperature increase) and precipitation (0.5, 1.0, 1.5, or 2.0, depending on change in precipitation). Table 7.1 summarizes the weighting used for each factor.

The exposure/sensitivity sum is therefore calculated as

$$\Sigma f_i w_i \qquad \text{[eq.1]}$$

where f is the value assigned to each factor according to how it influences sensitivity, and w is the specific exposure weighting for each factor i. The thresholds for the index scores of extremely vulnerable, highly vulnerable, moderately vulnerable, not vulnerable/presumed stable, and not vulnerable/increase likely are 10.0, 7.0, 4.0, and –2.0. The thresholds correspond with possible scenarios of exposure and sensitivity. For example, the “extremely vulnerable” threshold is reached for species with high exposure and at least two indirect exposure/sensitivity factors scored as greatly increase vulnerability, or with high exposure and three factors scored as increase vulnerability.

The documented/modeled response factors are scored identically to the exposure/sensitivity factors and are summed independently with no weighting, because exposure has already been incorporated in the studies upon which the factors are based. The thresholds for the index scores are 6.0, 4.0, 2.0, and –1.0, using the same logic as is used for exposure/sensitivity while accounting for the fewer documented/modeled response factors.

The overall index score is either the exposure/sensitivity score, if there is no documented/modeled response information, or an average of the exposure/sensitivity and documented/modeled response scores. In the case of adjacent scores, such as moderately vulnerable and presumed stable, the average is defined as the score higher on the vulnerability scale. If fewer than 3 indirect exposure or 10 species sensitivity factors are scored, the index score is insufficient evidence.

Uncertainty

Predicting vulnerability to climate change involves uncertainty about future greenhouse gas emissions, how the climate system will respond to these emissions, how species will respond to climate change, and how indirect effects will influence species (Patt et al. 2005, Lawler et al. 2009a). Developing a user-friendly tool requires compromise, and the sheer complexity of exhaustively incorporating uncertainty is beyond the scope of this project. Because our target audience is resource professionals with knowledge of species' natural history, we have allowed users to evaluate the results when more than one level of vulnerability is plausible for one or more factors. The index runs 1,000 Monte Carlo simulations, randomly selecting a single vulnerability level for each factor in which more than one level has been entered. The index calculates a measure of confidence in species information as very high, high, or moderate if more than 90%, 80%, or 60% of the simulation runs, respectively, yield the same score as the original index score. In cases with less than 60% concordance, the confidence is low.

Application of the Climate Vulnerability Index

Nevada Case Study

In 2008, Nevada set out to revise its state wildlife action plan to better address climate change. The Nevada Natural Heritage Program assessed the relative vulnerability of 263 species of "conservation priority," explaining why some species were more vulnerable than others. Although these species are of conservation concern in Nevada, they have rangewide conservation statuses varying from highly threatened to common and secure. Because so many species are involved, Nevada Heritage has used the climate change vulnerability index as a rapid and cost-efficient tool. The project is ongoing, but here we present results for the 216 priority vertebrates and mollusk taxa.

The mid-century climate predictions for Nevada suggest warming of approximately 2.6° C to 3.2° C and variable precipitation scenarios in different parts of the state (figure 7.2). The index sorted taxa into differing levels of vulnerability to climate change (table 7.2, figure 7.3). The majority of taxa fell in the moderately vulnerable and not vulnerable/presumed stable categories. Across taxa, 100% of mollusks, 80% of fish, 38% of amphibians, 30% of reptiles, 35% of mammals, and 4% of birds are at least moderately vulnerable. Natural history and distribution knowledge was

Table 7.2. Taxa scored preliminarily as "extremely vulnerable," "highly vulnerable," and "increase likely" by the climate change vulnerability index applied for distributions within Nevada

Taxon[1]	Group	Conservation status[1]
Extremely vulnerable		
Pygmy rabbit, *Brachylagus idahoensis*	Mammal	G4, S3
Preston White River springfish, *Crenichthys baileyi albivallis*	Fish	T1, S1
Desert dace, *Eremichthys acros*	Fish	G1, S1
Monitor Valley speckled dace, *Rhinichthys osculus* ssp. 5	Fish	T1, S1
Bull trout, *Salvelinus confluentus* pop. 4	Fish	T2, S1
Duckwater springsnail, *Pyrgulopsis aloba*	Snail	G1, S1
Southern Duckwater springsnail, *Pyrgulopsis anatina*	Snail	G1, S1
Elongate Cain Spring springsnail, *Pyrgulopsis augustae*	Snail	G1, S1
Pleasant Valley springsnail, *Pyrgulopsis aurata*	Snail	G1, S1
Fly Ranch springsnail, *Pyrgulopsis bruesi*	Snail	G1, S1
Northern Soldier Meadow pyrg, *Pyrgulopsis militaris*	Snail	G1, S1
Bifid duct springsnail, *Pyrgulopsis peculiaris*	Snail	G2, S1
Antelope Valley springsnail, *Pyrgulopsis pellita*	Snail	G1, S1
Highly vulnerable		
Sierra Nevada mountain beaver, *Aplodontia rufa californica*	Mammal	T3, S1
Sagebrush vole, *Lemmiscus curtatus*	Mammal	G5, S3
Pale kangaroo mouse, *Microdipodops pallidus*	Mammal	G3, S2
Humboldt yellow-pine chipmunk, *Neotamias amoenus celeris*	Mammal	T2, S2
American pika, *Ochotona princeps*	Mammal	G5, S2
California bighorn sheep, *Ovis canadensis californiana*	Mammal	T4, S3
Columbia spotted frog, *Rana luteiventris* (Toiyabe subpopulation)	Amphibian	Not assessed at subpopulation level
Wall Canyon sucker, *Catostomus* sp. 1	Fish	G1, S1
Railroad Valley springfish, *Crenichthys nevadae*	Fish	G2, S2
Fish Lake Valley tui chub, *Gila bicolor* ssp. 4	Fish	T1, S1
Railroad Valley tui chub, *Gila bicolor* ssp. 7	Fish	T1, S1
Big Smoky Valley tui chub, *Gila bicolor* ssp. 8	Fish	T1, S1
Pahranagat roundtail chub, *Gila robusta jordani*	Fish	T1, S1
White River spinedace, *Lepidomeda albivallis*	Fish	G1, S1

(*Continued*)

Table 7.2. (*Continued*)

Taxon[1]	Group	Conservation status[1]
Lahontan cutthroat trout, *Oncorhynchus clarki henshawi*	Fish	T3, S3
Big Smoky Valley speckled dace, *Rhinichthys osculus lariversi*	Fish	T1, S1
Diamond Valley speckled dace, *Rhinichthys osculus* ssp. 10	Fish	TH, SH
Oasis Valley speckled dace, *Rhinichthys osculus* ssp. 6	Fish	T1, S1
White River speckled dace, *Rhinichthys osculus* ssp. 7	Fish	T2, S2
Steptoe hydrobe, *Eremopyrgus eganensis*	Snail	G1, S1
Turban pebblesnail, *Fluminicola turbiniformis*	Snail	G3, S–
Smooth juga, *Juga interioris*	Snail	G1, S1
Elko pyrg, *Pyrgulopsis leporina*	Snail	G1, S1
Wong's pyrg, *Pyrgulopsis wongi*	Snail	G2, S1
Increase likely		
Clark's grebe, *Aechmophorus clarkii*	Bird	G5, S4
Western grebe, *Aechmophorus occidentalis*	Bird	G5, S4
Cinnamon teal, *Anas cyanoptera*	Bird	G5, S5
Bald eagle, *Haliaeetus leucocephalu*	Bird	G5, S1
Least sandpiper, *Calidris minutilla*	Bird	G5, S4
Short-eared owl, *Asio flammeus*	Bird	G5, S4
Costa's hummingbird, *Calypte costae*	Bird	G5, S3
Lewis's woodpecker, *Melanerpes lewis*	Bird	G4, S3
Olive-sided flycatcher, *Contopus cooperi*	Bird	G4, S2
Mountain willow flycatcher, *Empidonax traillii brewsteri*	Bird	T3, S2
Black phoebe, *Sayornis nigricans*	Bird	G5, S4
Loggerhead shrike, *Lanius ludovicianus*	Bird	G4, S4
Phainopepla, *Phainopepla nitens*	Bird	G5, S2
Virginia's warbler, *Vermivora virginiae*	Bird	G5, S4
Tricolored blackbird, *Agelaius tricolor*	Bird	G2, S1
Hoary bat, *Lasiurus cinereus*	Mammal	G5, S3
Long-eared myotis, *Myotis evotis*	Mammal	G5, S4
Little brown bat, *Myotis lucifugus*	Mammal	G5, S3
Northern river otter, *Lontra canadensis*	Mammal	G5, S2
Brush mouse, *Peromyscus boylii*	Mammal	G5, S3

[1] NatureServe conservation status ranking in which G indicates status for entire global range of a species (T is substituted for G in subspecies), and S indicates status within the state of Nevada. Conservation status scores range from 1 (critically imperiled) to 5 (secure); H indicates species known only from historical records but possibly still extant. A dash (–) indicates that a rank is not applicable. See Master et al. 2000 for more details.

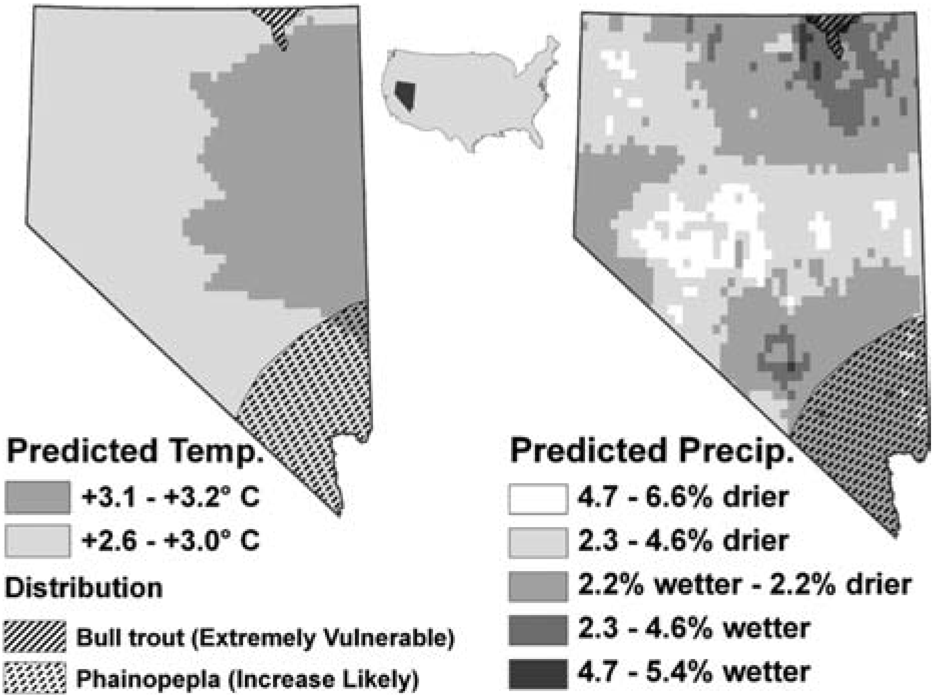

Figure 7.2. Predicted change in temperature and precipitation for Nevada in 2050, under a medium (A1B) emissions scenario

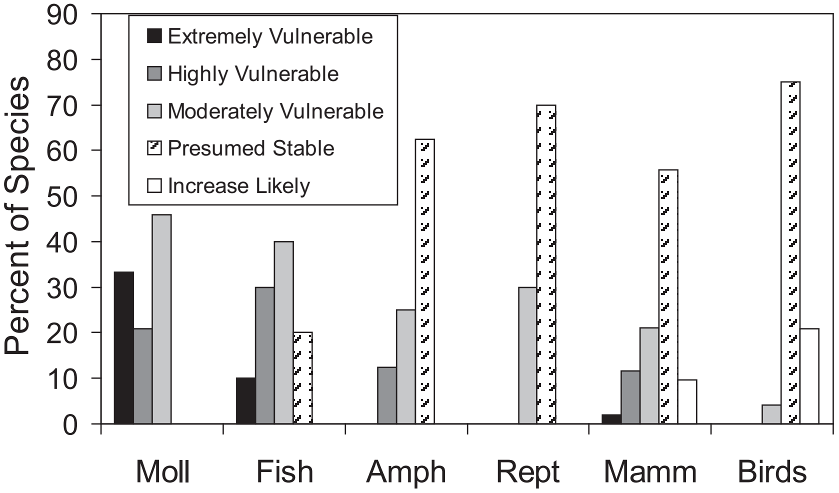

Figure 7.3. Vulnerability to climate change of selected Nevada mollusks (*n* = 24), fish (*n* = 40), amphibians (*n* = 8), reptiles (*n* = 20), mammals (*n* = 52), and birds (*n* = 72).

Table 7.3. Comparison between conservation status at both global (rangewide) and state level and climate change vulnerability. See table 7.2 and Master et al. (2000) for explanation of conservation status rankings.

	Climate change vulnerability				
Global conservation status	Extremely vulnerable	Highly vulnerable	Moderately vulnerable	Presumed stable	Increase likely
Possibly extinct (GH)	0	1	3	1	0
Critically imperiled (G1)	10	11	25	9	0
Imperiled (G2)	2	4	5	3	1
Vulnerable (G3)	0	4	3	11	1
Apparently secure (G4)	1	1	6	24	3
Secure (G5)	0	2	7	61	15
Nevada state conservation status					
Possibly extirpated (SH)	0	1	3	2	0
Critically imperiled (S1)	12	13	28	18	2
Imperiled (S2)	0	5	8	34	4
Vulnerable (S3)	1	3	2	32	5
Apparently secure (S4)	0	0	2	20	8
Secure (S5)	0	0	0	3	1

generally sufficient to allow assessment of all extrinsic factors and 14 of the 17 intrinsic species sensitivity factors (table 7.1).

Vulnerability to climate change was highly correlated with conservation status at both the global (rangewide) and state scale (global, Kendall's $\tau = 0.518$, $p < 0.001$; state, $\tau = 0.465$, $p < 0.001$; table 7.3). Although climate change vulnerability and conservation status are correlated, the relationship is not perfect. Four species ranked as apparently secure or secure (G4 or G5) also scored extremely or highly vulnerable to climate change. For example, the American pika (*Ochotona princeps*) is a widespread mountain inhabitant of western North America, but its dependence on declining snowpack and limited rocky talus slope habitat, together with its difficulty dispersing from one mountaintop to the next, renders it vulnerable to climate change in Nevada. Conversely, 34 (62%) of the 55 globally critically imperiled species examined with the index scored as presumed stable or only moderately vulnerable to climate change. For Nevada, conservation status is therefore an imperfect proxy for vulnerability to climate change.

The Monte Carlo simulations revealed that confidence in the index score was very high or high for 94 (61%) taxa, low for 19 (12%) taxa, and moderate for the rest. In most cases, a low confidence score resulted when the exposure/sensitivity sum was close to the threshold between two index categories.

Limited historical hydrological niches, anticipated impact from mitigation-related land use changes, migration to or through a few potentially vulnerable locations (see also Owen-Smith and Ogutu, this volume), lack of facultative distribution shifts in response to environmental conditions (such as the tracking by seed-eating birds of cone crops of conifers), and dependence on specific vulnerable aquatic/wetland habitats were the factors commonly contributing to vulnerability to climate change (table 7.1). Good dispersal ability, broad physical habitat requirements, migration to broad geographical areas, a tendency to shift distribution in response to environmental conditions, and adaptation to a broad range of temperatures were the factors that most commonly decreased vulnerability (table 7.1).

The climate change vulnerability index enables the state of Nevada to rapidly assess which of the wildlife species deemed of greatest concern are most imperiled by changing climate, and most deserving of more in-depth analysis and management. For each of the six taxonomic groups, the index succeeded in separating taxa into distinct classes of similar vulnerability, thus demonstrating that it is robust to taxonomic affinity for animals. Of course, only time will tell whether its predictions are borne out by range and population contractions or expansions. A more immediate, albeit weak, test of the index would be to compare historical population trends with index scores. Many factors influence population trends, but a preponderance of species scored as vulnerable that began or increased their rate of population decline in the 1970s, when temperatures began to increase sharply, would support the index's ability to identify threatened species.

The index has been a means to identify factors common to many Nevada vertebrates that increase their susceptibility to climate change. A noteworthy finding from this preliminary assessment is that two traits shared by many species in this state—limited historical hydrological niche and dependence on specific vulnerable aquatic/wetland habitats—relate to precipitation. This reflects the aridity of the Nevada climate as well as the dependence of many species of conservation concern on specific hydrological features, such as springs (WAPT 2006). Hence, it would be worthwhile to look more closely at how increasing temperatures will interact with moisture and wildlife habitats. A more surprising result was that anticipated climate-change-mitigation–related land use changes could contribute to several species' vulnerability. In response to the need to reduce emissions, Nevada officials anticipate the construction of solar, wind, and geothermal energy projects that could alter much wildlife habitat. These projects affect habitat used by nearly half of the species assessed, so management actions that mitigate detrimental effects to wildlife should be a priority. On a positive note, the results suggest that 20 species of priority birds and mammals may become more common in response to climate change.

Our results indicate the feasibility of a means to rapidly categorize species by their vulnerability to climate change using readily available natural-history and distribution information. Further testing is warranted. This index should be tested on larger scales to incorporate more spatial variation in climate-change predictions. At small spatial scales, exposure to climate change may be a constant for all species assessed, because they essentially all experience the same climate, so the differences in species' vulnerability would reflect differences in their intrinsic sensitivity. Finally, although we have developed the index using a variety of species as models, testing on larger samples of species that were underrepresented or not included in the Nevada case study, such as insects and plants, would show whether the index is as robust as desired. These results will allow for future refinement of this new resource for land managers.

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