Department of Defense
Legacy Resource Management Program

PROJECT 09-433

A TOOL TO ASSESS THE VULNERABILITY OF TERRESTRIAL VERTEBRATE SPECIES TO CLIMATE CHANGE

KAREN E. BAGNE, MEGAN M. FRIGGENS, AND DEBORAH FINCH
USDA FOREST SERVICE, ROCKY MOUNTAIN RESEARCH STATION

AUGUST 2010

Table of Contents

SUGGESTED CITATION

Bagne, Karen E., Megan M. Friggens, and Deborah M. Finch. 2010. A Tool to Assess the Vulnerability of Terrestrial Vertebrate Species to Climate Change. DoD Legacy Program Report. 37 pp.

Introduction

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 (Root et al. 2003, Enquist and Gori 2008). How ecosystems will be altered is unclear, because climate predictions are uncertain, global carbon and nitrogen cycling is complex, and our knowledge of ecological relationships is incomplete. Natural selection provides a mechanism whereby species can adapt to changes in their environments (Skelly et al. 2007), but the speed with which the climate is currently changing may preclude adaptation in many species (Janzen 1994, Visser 2008). The magnitude of the problem constitutes a major challenge for conservation practitioners. Despite these challenges, the potential impact on global biodiversity makes this task critically important.

Species assessments of vulnerability or extinction risk are management tools used to prioritize conservation needs so that actions can be directed in an effective and efficient manner (Glick and Stein 2010). Efforts have been made to integrate climate change into species' assessments (Enquist and Gori 2008, Foden et al. 2008, Young et al. 2010). We present a simple and flexible tool for assessing the relative risk of individual species to population declines or increases associated with projected changes in climate and related phenomena.

Assessment Strategy

This assessment synthesizes complex information related to projected climate changes into a simple predictive tool, which can then be used to inform management planning. We avoided complex modeling or analysis to create a system that could be easily implemented and that was flexible to additional information. It was also our intention that managers would use the tool and apply their local knowledge to species of interest. Detailed Guidelines for tool application are provided at the end of this document. This vulnerability assessment tool focuses solely on the effects of climate change rather than integrating threats from other sources or addressing all factors involved in management decisions, because current management or conservation plans generally cover these topics. We also limited this tool to terrestrial vertebrate species.

We used basic ecological principles and published studies linking survival or reproduction to climate or related phenomena (e.g., fire, floods) to select criteria predictive of climate change response. We included anticipated vulnerability, but also resilience as not all species will respond negatively to climate change (Araújo et al. 2006). We focused on those variables known to affect the reproduction and survival of individual species that are influenced by climate. During our selection of scoring variables, we considered repeatability, relation to quantitative values, and independence from other scoring variables (Beissinger et al. 2000). We lacked information on response to climate change for most individual species, but we were able to use published information related to species' response to climatic fluctuations, such as drought or snowpack levels, to make predictions.

Climate projections vary regionally and effective strategies for conserving species during climate change need to integrate biogeography and ecology (Hannah et al. 2002, Seavy et al. 2008). We expect assessments to be applied at the scale of a management unit and the scoring tool is designed to only accommodate a single climate zone (i.e., a uniform set of climate projections), which will be adequate for most applications. Climate projections for the targeted region are used to score individual species and we recommend obtaining these from published studies, reports, or other analyses.

Scoring Variables

We based variables on published species' responses, observed or modeled, that could be used to predict direction, rather than magnitude, of climate change response. We selected a wide range of variables representing both the direct and indirect responses to changes in temperature and precipitation, as well as to extreme events, which are important in driving population dynamics and natural selection (Boag and Grant 1984, Easterling et al. 2008, Parmesan et al 2000). We identified variables related to climate change effects on species from four broad categories or factors: habitat, physiology, phenology, and biotic interactions.

Habitat

Predicted changes to climate will alter global temperature and precipitation patterns resulting in alterations to habitats (McCarty 2001, Hitch and Leberg 2007, Sekercioglu et al. 2008). We identified 5 variables predictive of population change as climate affects habitats: changes in habitat area or location, effects on habitat elements, changes in habitat quality, dispersal ability, and reliance on additional habitats during migration.

Reductions or increases in available habitat area will affect resources and, thus, populations. A good example is the observed shift of species to higher latitudes and higher elevations with warmer temperatures (Parmesan 2006). A major shift in distribution of a vegetation type will almost certainly affect resources, because of the expected species-specific plant responses as well as differences of the new site such as soils, previous vegetation, topography, and land use. In addition to association with broad vegetation types, additional features components are essential to survival or reproduction for some species. Timing and duration of key ephemeral resources, such as for the hydroperiod of amphibian breeding ponds, are one important example of a critical component that will be affected by changes in precipitation patterns (Paton and Crouch 2002). We consider breeding and non-breeding habitats separately in this assessment, because requirements or locations for these activities differ for many species.

Structure or composition of habitat can be altered by climate, which is important when these features affect survival or reproduction (i.e., habitat quality). For example, precipitation is closely associated with plant biomass and, thus, habitat quality for herbivores (Chase et al. 2000). Changes in disturbance events, such as fire, flooding, or freeze events, further affect vegetation and habitat quality (Westerling et al. 2006, Hamlet and Lettenmaeir 2007). Breeding success of Humboldt penguins, which nest in burrows or on the ground, is negatively impacted flooding caused by events such as the heavy rains associated with El Niño events (Simeone et al. 2002). Habitat changes related to snowpack and ice formation as well as sea level rise have consequences for species. Deeper snow pack is expected to hinder grazing animals in winter (Post and Stenseth 1999). Conversely, a smaller snow pack is expected to negatively affect species, such as lemmings and pikas that rely on snow for protection (Lindström 1994, Coulson et al. 2008).

When habitats change, dispersal strategies and mobility of organisms help a species to cope with shifting habitats (Thomas et al. 2004, Araújo et al. 2006, Jiguet et al. 2007). Although not limited by dispersal ability, species that regularly disperse between habitats, such as long-distance migrants, will be subject to greater variability because climate change effects vary with time and location leading to greater likelihood of mistiming (Visser et al. 2004).

PHYSIOLOGY

Species exhibit physiological requirements and limitations related to temperature and moisture (McCain 2007), which can help predict future impacts (Helmuth et al. 2005). We identified 6 predictive variables related to physiology: physiological thresholds, temperature-dependent sex ratios, exposure to extreme climate or disturbance events, energetics related to activity patterns, adaptations to cope with resource fluctuations, and capacity to moderate metabolic expenditure.

The range of temperature and moisture tolerances exhibited by species are important in predicting direct impacts of climate (Beever et al. 2003, Humphries et al. 2004, Bernardo and Spotila 2006). For birds in France, species that had a lower tolerance for high temperatures were more likely to have experienced recent declines (Jiguet at al. 2007). Additionally, nocturnal reptiles and small mammals generally have lower tolerances for high temperatures than diurnal species (Cowles 1940). A comparison of metabolic stress in montane salamanders along an elevational gradient indicated that species adapted to cool temperatures were physiologically intolerant of increasing temperatures (Bernardo and Spotila 2006). Conversely, species that tolerate extremely warm or dry conditions were not necessarily more tolerant of climate change, but rather may be vulnerable to temperature increases if they are already near their physiological limits (Hargrove 2010).

Some reptiles have temperature-sensitive sex determination and will be vulnerable to skewed sex ratios that ultimately affect population viability (Janzen 1994, Mitchell et al. 2008). Mean temperature increases of 4°C are projected to eliminate males in painted turtle populations (Janzen 1994).

Disturbance and extreme conditions have been known to shape species' distributions and to drive natural selection (Boag and Grant 1984, Parmesan et al. 2000). Response to disturbance events, however, varies by species (Pike and Stiner 2007). For example, some bird species are adapted to take advantage of post-fire habitats, while others favor habitats in later stages of succession (Hutto 2008, Bagne and Purcell 2009). Some bird species are exposed to storms and hurricanes during migration and could be affected if these events intensify or become more frequent (Butler 2000, Frederiksen et al. 2008). Other disturbance events expected to change include intense rainfall events, droughts, and spring freezes, all with various impacts on species.

In addition to physiological thresholds, energetic constraints can be linked with climate and will play an important role in species' response. Population variations and reproductive output are often associated with energetic tradeoffs related to climate (Franklin et al. 2000). Extreme conditions may limit periods when individuals can be active ultimately restricting food intake, access to mates, or avoidance of predators (Lueth 1941, Walsberg 2000, Sinervo et al. 2010).

Life history traits will be important in predicting a species' ability to endure and recover from periods of drought, excessive heat, or other interannual periods that may be limiting. Some species have specific adaptations or strategies that can cope with fluctuating resources. For example, alternative morphology and diet in spadefoot tadpoles can maximize recruitment during dry periods that generally restrict tadpole development as well as during wet periods when development can be slower (Phennig 1992).

Ectothermic animals also have lower resting metabolic rates than birds or mammals, which is generally considered to be an advantage for surviving periods when resources are restricted (Bennett and Ruben 1979). Greater variability in climate is expected to similarly increase variability in resources, thus species that can survive periods of low resources availability will be at an advantage over species that are favored by stable resource levels.

PHENOLOGY

Effects of climate change on phenology are among the best known (McCarty 2001). Because resources and conditions vary over time, species can often improve survival and reproduction through timing of their activities. Initiation of these activities is often in response to a cue that directly, or indirectly, signals availability of favorable resource events or environmental conditions. We predicted phenological response through expected changes to timing of cues or favorable events and traits that may favor synchrony of cues and events.

Changes in temperature and precipitation can alter the timing of life history events either through altering cues or altering the benefits associated with the cue (Beebee 1995, Dunn and Winkler 1999). When those cues become disassociated from their benefits, reductions in populations can occur (Both et al. 2006). Earlier flowering (Bowers 2007), earlier breeding (Millar and Herdman 2004, Parmesan 2007), and earlier migration (Bradley et al. 1999) are generally associated with climate change. For Nearctic-Neotropical birds, timing of departure is thought to be primarily endogenous (Hagan et al. 1991), thus increasing the potential for mismatches in timing with temperature sensitive resources on the breeding grounds. In addition, conditions during important activities can be important. A change in the timing of favorable climate conditions for breeding has already been found to affect some mountain populations (Inouye 2008). We assumed vulnerability would increase for timing shifts in cues or associated events, but we acknowledge that synchrony may be attained if timing shifts in interacting elements match.

Synchrony, to some extent, can be predicted through species' traits. Opportunistic or eruptive breeders respond rapidly to irregular events and may be less prone to mistiming effects (Visser et al. 2004). Species with more than a single breeding attempt per year or that have similarly extended breeding periods may also be expected to experience synchrony with critical resources or conditions during at least some portion of this period (Jiguet et al. 2007).

Biotic Interactions

All species interact with others to some degree, but when species are closely associated there is potential for indirect effects at multiple trophic levels (Memmott 2007). We selected food, predation, symbiosis, disease, and competition as the most important interactions that will potentially affect climate change response. Species that depend on a single other species for survival or reproduction will be subject to that species response to climate change regardless of its own response. Disease exposure may increase if climate becomes more favorable to vectors (Benning et al. 2002, Freed et al. 2005). A species competitive advantage may be lost or gained due to climate change and non-native invasive species are a particular concern (Carroll 2007).

Tool Application

Scoring

Scoring needs to include both the predicted climate-related change (e.g., increased burning) and the predicted response of the species (e.g., fire increases preferred habitat). Thus, scoring is regional and species specific. We recommend first outlining current climate changes predicted for the region of interest including related phenomena such as snowpack, sea level, and disturbance. Refer to the scoring guidelines that follow for further guidance on obtaining climate projections and applying the scoring system.

Scoring indicates probable population decreases (vulnerability) or increases (resilience) associated with projected changes in climate. The scoring scale is based on a reference value of 0 as the neutral response to climate. When a species is expected to experience a more favorable condition or possesses a trait expected to prevent a climate change impact, it scores a -1 signifying resilience. When conditions are expected to be less favorable or the species does not possess a trait expected to prevent a climate change impact, it scores a 1 signifying vulnerability. Because the numbers of predictive criteria were unequal among the four factors or categories, adjustments were made to equalize factor scores as well as the maximum and minimum scores. For the overall score, all criteria were treated as equal predictors and ignored factors. An uncertainty score also accompanies each criterion or question for assessing the percentage of criteria that posed difficulties. Worksheets for vulnerability and uncertainty calculations as well as for keeping track of scores are provided following the tool.

INTERPRETING SCORES

Balanced across the scoring criteria, positive scores indicate vulnerability to negative impacts of climate change, and negative scores indicate resilience. The magnitude of the factor or overall scores reflects the balance of the number of vulnerable and resilient traits possessed by the species for that set of criteria. Because some criteria were included that only apply to some vertebrate species and some traits can incur both resilience and vulnerability, obtaining a maximum or minimum score is unlikely.

Although the scale is linear, we do not expect that this translates to a linear biological effect of the predictors, but allows for comparison based on the same metric. With this caveat in mind, scores can be used to rank vulnerability for a group of species within the same regional climate projections and, along with other considerations, can aid in prioritization and planning. Use of scores will depend on the target(s) of the user. If the focal scoring region is smaller than the species range, it should be noted that the scoring applies to the species in that region and not the entire species.

Factor scores, as well as vulnerabilities and resiliencies identified during scoring, contain information on what attributes could be important for species' response to climate change. Identified areas of vulnerability or resilience can be used to target the most effective management actions (i.e., creation of corridors, land acquisition, captive breeding). This can also be a starting point for discussion and identification of areas that need more complex analysis.

Limitations

To include climate change in a vulnerability assessment is a challenging task, because the strongest climate change effects are not yet manifest, global carbon and nitrogen cycling are complex, and direct effects on relatively few species have been identified. The complexity of ecological communities also means that some changes simply will not be foreseen such as those arising from new species assemblages (Brown et al. 1997) or novel ecosystems (Harris et al. 2006).

The inclusion of uncertainty scores helps identify those species that lacked information and where scoring was more difficult. Uncertainty indicates that the prediction of effects was more uncertain and that neutral scores may indicate lack of information rather than a neutral effect of climate change. Species that receive high uncertainty scores may also be good candidates for further research and monitoring.

Despite uncertainties and because climate change impacts are likely to intensify over time, we recommend identifying vulnerable species and instituting effective management actions and planning proactively. With high likelihood of increasing intensity of warming, even low vulnerability species may be in need of intervention. Although the process and the product are inherently imprecise, this is a first step towards anticipating and responding to climate change and provides a framework for integrating new research and information.

Acknowledgments

Funding for this project was provided by the DoD Legacy Program (Project 09-433). Additional funding was provided by the USDA Forest Service. Sharon Coe, University of Arizona and Rocky Mountain Research Station, provided review and discussion that improved this tool. Collaborators that inspired tool development include Carolyn Enquist and David Gori of The Nature Conservancy, Lisa Graumlich at the University of Arizona, and Heather Bateman at Arizona State University Polytechnic. Further support and advice was provided by Jack Triepke and Bryce Rickels of USDA Forest Service, Region 3.

Literature Cited

Araujo, M., W. Thuiller, and R. Pearson. 2006. Climate warming and the decline of amphibians and reptiles in Europe. Journal of Biogeography 33:1712-1728.

Bagne, K. E. and K. L. Purcell. 2009. Lessons learned from prescribed fire in ponderosa pine forests of the southern Sierra Nevada. Proceedings of the Fourth International Partners in Flight Conference: Tundra to Tropics:679–690.

Beebee, T. J. C. and R. A. Griffiths. 2005. The amphibian decline crisis: A watershed for conservation biology? Biological Conservation 125:271-285

Beever, Erik A., Peter F. Brussard, and Joel Berger. 2003. Patterns of apparent extirpation among isolated populations of pikas (*Oncotona princeps*) in the Great Basin. Journal of Mammalogy 84:37-54.

Beissinger, Steven R., J. Michael Reed, Joseph M. Wunderle, Jr., Scott K. Robinson, and Deborah M. Finch. 2000. Report of the AOU Conservation Committee on the Partners In Flight species prioritization plan. Auk 117:549-561.

Bennett, A. F. and Ruben, J. A. 1979. Endothermy and activity in vertebrates. Science 206:649-654.

Benning, T. L., D. LaPointe, C. T. Atkinson, and P. M. Vitousek. 2002. Interactions of climate change with biological invasions and land use in the Hawaiian Islands: Modeling the fate of endemic birds using a geographic information system. Proceedings of the National Academy of Sciences of the United States of America 99:14246-14249.

Bernardo, J., and J. Spotila. 2006. Physiological constraints on organismal response to global warming: mechanistic insights from clinally varying populations and implications for assessing endangerment. Biology Letters 2:135-139.

Boag, P., and P. Grant. 1984. The classical case of character release- Darwin's finches (*Geospiza*) on Isla Daphne Major. Galapagos Biological Journal of the Linnean Society 22:243-287.

Both, Christiaan , Sandra Bouwhuis, C. M. Lessells and Marcel E. Visser. 2006.

Climate change and population declines in a long-distance migratory bird. Nature 441:81-83.

Bowers, J. E. 2007. Has climatic warming altered spring flowering date of Sonoran desert shrubs? The Southwestern Naturalist 52:347-355.

Bradley, N. L., A. C. Leopold, J. Ross, and W. Huffaker. 1999. Phenological changes reflect climate change in Wisconsin. Proceedings of the National Academy of Sciences, USA 96:9701-9704.

Broenniman, O., W. Thuiller, G. Hughes, G. Midgley, J. Alkemade, and A. Guisan. 2006. Do geographic distribution, niche property and life form explain plants' vulnerability to global change? Global Change Biology 12:1079-1093.

Brown, James H., Thomas J. Valone, and Charles G. Curtin. 1997. Reorganization of an arid ecosystem in response to recent climate change. Proceedings of the Natural Academy of Sciences 94:9729.

Butler, R. W. 2000. Stormy seas for some North American songbirds: Are declines related to severe storms during migration? Auk 117:518-522.

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

Chase, T. N., R. A. Pielke Sr., T. G. F. Kittel, R. R. Nemani and S. W. Running. 2000. Simulated impacts of historical land cover changes on global climate in northern winter. Climate Dynamics 16:93-10.

Coulson, Tim and Aurelio Malo. 2008. Population biology: Case of the absent lemmings. Nature 456:43-44.

Cowles, R. B. 1940. Additional Implications of Reptilian Sensitivity to High Temperatures. The American Naturalist 74:542-561.

Ditto, Amy M., and Jennifer K. Frey. 2007. Effects of ecogeographic variables on genetic variation in montane mammals: implications for conservation in a global warming scenario Journal of Biogeography 34:1136 – 1149.

Dunn, P. O. and D. W. Winkler. 1999. Climate change has affected the breeding date of tree swallows throughout North America. Proceedings of the Royal Society Biological Sciences 266: 2487–2490.

Easterling, D. 2002. Recent changes in frost days and the frost-free season in the United States. Bulletin of the American Meteorological Society 83:1327-1332.

Easterling, D., G. Meehl, C. Parmesan, S. Changnon, T. Karl, and L. Mearns. 2000. Climate extremes: Observations, modeling, and impacts. Science 289:2068-2074.

Enquist, C., and D. Gori. 2008. Implications of recent climate change on conservation priorities in New Mexico. Climate Change Ecology and Adaptation Program, The Nature Conservancy, New Mexico.

Foden, W., G. Mace, J.-C. Vie, A. Angulo, S. Butchart, L. DeVantier, H. Dublin, A. Gutsche, S. Stuart, and E. Turak. 2008. Species susceptibility to climate change impacts. In: J.-C. Vie, C. Hilton-Taylor, and S. Stuart (eds.). The 2008 Review of the IUCN Red List of Threatened Species. IUCN Gland, Switzerland.

Franklin, Alan B., David R. Anderson, R. J. Gutierrez and Kenneth P. Burnham. 2000. Climate, Habitat Quality, and Fitness in Northern Spotted Owl Populations in Northwestern California. Ecological Monographs 70:539-590.

Frederiksen, M., F. Daunt, M. Harris, and S. Wanless. 2008. The demographic impact of extreme events: stochastic weather drives survival and population dynamics in a long-lived seabird. Journal of Animal Ecology 77:1020-1029.

Freed, L. A., R. L. Cann, M. L. Goff, W. A. Kuntz, and G. R. Bodner. 2005. Increase in avian malaria at upper elevation in Hawai'i. Condor 107:753-764.

Glick, P. and B. A. Stein, editors. 2010. Scanning the Conservation Horizon: A Guide to Climate Change Vulnerability Assessment. Draft. National Wildlife Federation, Washington, D.C. Available online.

Hagan, John M., Trevor L. Lloyd-Evans and Jonathan L. Atwood. 1991. The Relationship between Latitude and the Timing of Spring Migration of North American Landbirds. Ornis Scandinavica 22:129-136.

Hamlet, A., and D. Lettenmaier. 2007. Effects of 20th century warming and climate variability on flood risk in the western U.S. water resources research 43:-.

Hannah, L., G. Midgley, and D. Millar. 2002. Climate change-integrated conservation strategies. Global ecology and biogeography 11:485-495.

Hargrove, L. J. 2010. Limits to species' distributions: Spatial structure and dynamics of breeding bird populations along an ecological gradient. PhD Dissertation. University of California, Riverside, California.

Harris, James A., Richard J. Hobbs, Eric Higgs, and James Aronson. 2006. Ecological Restoration and Global Climate Change. Restoration Ecology 14:170-176.

Helmuth B., J. G. Kingsolver, and E. Carrington. 2005. Biophysics, physiological ecology, and climate change: does mechanism matter? Annual Review of Physiology 67:177-201.

Hitch, A., and P. Leberg. 2007. Breeding distributions of North American bird species moving north as a result of climate change. Conservation Biology 21:534-539.

Humphries, Murray M., James Umbanhowar and Kevin S. McCann. 2004. Bioenergetic Prediction of Climate Change Impacts on Northern Mammals. Integrative and Comparative Biology 44:152-162.

Hutto, R. L. The ecological importance of severe wildfires: some like it hot. Ecological Applications 18:1827–1834.

Inouye, D. 2008. Effects of climate change on phenology, frost damage, and floral abundance of montane wildflowers. Ecology 89:353-362.

IPCC. 2007. Climate change 2007: the physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Soloman, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, and H. L. Miller (eds.). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. 996 pp.

Janzen, Fredric J. 1994. Climate Change and Temperature-Dependent Sex Determination in Reptiles. Proceedings of the National Academy of Sciences USA91: 7487 -7490.

Jiguet, F., A. Gadot, R. Julliard, S. Newson, and D. Couvet. 2007. Climate envelope, life history traits and the resilience of birds facing global change. Global Change Biology 13:1672-1684.

Lueth, Francis X. 1941. Effects of Temperature on Snakes. Copeia 1941:125-132.

McCain, Christy M. 2007. Area and mammalian elevational diversity. Ecology 88:76-86.

McCarty, J. 2001. Ecological consequences of recent climate change. Conservation Biology 15:320-331.

Memmott, Jane, Paul G. Craze, Nickolas M. Waser, and Mary V. Price. 2007. Global warming and the disruption of plant–pollinator interactions. Ecology Letters 10:710–717.

Midgley, G., L. Hannah, D. Millar, M. Rutherford, and L. Powrie. 2002. Assessing the vulnerability of species richness to anthropogenic climate change in a biodiversity hotspot. Global Ecology and Biogeography 11:445-451.

Millar, J., and E. Herdman. 2004. Climate change and the initiation of spring breeding by deer mice in the Kananaskis Valley, 1985-2003. Canadian Journal of Zoology 82:1444-1450.

Mitchell, N. J., M. R. Kearney, N. J. Nelson, and W. P. Porter. 2008. Predicting the fate of a living fossil: how will global warming affect sex determination and hatching phenology in tuatara? Proceedings of the Royal Society Biological Sciences 275:2185-2193.

Parmesan, C. 2006. Ecological and evolutionary responses to recent climate change. Annual Review of Ecology, Evolution, and Systematics 37:637-669.

Parmesan, C. 2007. Influences of species, latitudes and methodologies on estimates of phenological response to global warming. Global Change Biology 13:1860-1872.

Parmesan, C., T. Root, and M. Willig. 2000. Impacts of extreme weather and climate on terrestrial biota. Bulletin of the American Meteorological Society 81:443-450.

Paton, Peter W. C., William B. Crouch, III. 2002. Using the Phenology of Pond-Breeding Amphibians to Develop Conservation Strategies. Conservation Biology 16:194-204.

Phennig, D. W. 1992. Polyphenism in spadefoot toad tadpoles as a logically adjusted evolutionarily stable strategy. Evolution 46:1408-1420.

Pike, D., and J. Stiner. 2007. Sea turtle species vary in their susceptibility to tropical cyclones. Oecologia 153:471-478.

Post, Eric and Nils C. Stenseth. 1999. Climatic variability, plant phenology, and northern ungulates. Ecology 80:132-1339.

Preston, K., J. Rotenberry, R. Redak, and M. Allen. 2008. Habitat shifts of the endangered California gnatcatcher under altered climate conditions: importance of biotic interactions. Global Change Biology 14:2501-2515.

Root, Terry, Jeff T. Price, Kimberly R. Hall, Stephen H. Schneider, Cynthia Rosenzweig and J. Alan Pounds. 2003. Fingerprints of global warming on wild animals and plants Nature 421:57-60.

Seavy, N. E., K. E. Dybala, and M. A. Snyder. 2008. Climate models and ornithology. Auk 125:1-10.

Sekercioglu, C. H. S. H. Schneider, J. P. Fay, and S. R. Loarie. Climate Change, Elevational Range Shifts, and Bird Extinctions. Conservation Biology 22:140–150.

Sinervo, B., F. Méndez-de-la-Cruz, D. B. Miles, B. Heulin, E. Bastiaans, M. Villagrán-Santa Cruz, R. Lara-Resendiz, N. Martínez-Méndez, M. Lucía Calderón-Espinosa, R. N. Meza-Lázaro, H. Gadsden, L. J. Avila, M. Morando, I. J. De la Riva, P. V. Sepulveda, C. F. Duarte Rocha, N. Ibargüengoytía, C. Aguilar Puntriano, M. Massot, V. Lepetz, T. A. Oksanen, D. G. Chapple, A. M. Bauer, W. R. Branch, J. Clobert, J. W. Sites, Jr. 2010. Erosion of Lizard Diversity by Climate Change and Altered Thermal Niches. Science 328:894-899.

Skelly D. K., L. N. Joseph , H. P. Possingham , L. K. Freidenburg , T. J. Farrugia, M. T. Kinnison, and A. P. Hendry. 2007. Evolutionary responses to climate change. Conservation Biology 21:1353-1355.

Simeone, A., B. Araya, M. Bernal, E. N. Diebold, K. Grzybowski, M. Michaels, J. A. Teare, R. S. Wallace, and M. J. Willis. 2002. Oceanographic and climatic factors influencing breeding and colony attendance patterns of Humboldt penguins *Spheniscus humboldti* in central Chile. Marine Ecology Progress Series 227:43-50.

Smucker, K. M., R. L. Hutto, and B. M. Steele. 2005. Changes in bird abundance after wildfire: importance of fire severity and time since fire. Ecological Applications 15:1535–1549.

Thomas, C., A. Cameron, R. Green, M. Bakkenes, L. Beaumont, Y. Collingham, B.

Erasmus, M. de Siqueira, A. Grainger, L. Hannah, L. Hughes, B. Huntley, A. van Jaarsveld, G. Midgley, L. Miles, M. Ortega-Huerta, A. Peterson, O. Phillips, and S. Williams. 2004. Extinction risk from climate change. Nature 427:145-148.

Visser, M. E. 2008. Keeping up with a warming world; assessing the rate of adaptation to climate change. Proceedings of the Royal Society B-Biological Sciences 275:649-659.

Walsberg, G. 2000. Small Mammals in Hot Deserts: Some Generalizations Revisited. BioScience 50:109–120.

Walther, G., E. Post, P. Convey, A. Menzel, C. Parmesan, T. Beebee, J. Fromentin, O. Hoegh-Guldberg, and F. Bairlein. 2002. Ecological responses to recent climate change. Nature 416:389-395.

Westerling, A., H. Hidalgo, D. Cayan, and T. Swetnam. 2006. Warming and earlier spring increase western US forest wildfire activity. Science 313:940-943.

Young, B., E. Byers, K. Gravuer, K. Hall, G. Hammerson, and A. Redder. 2010. Guidelines for using NatureServe Climate Change Vulnerability Index, Release 2.0. NatureServe, Arlington, VA. Available online.

SPECIES' VULNERABILITY TO CLIMATE CHANGE:

Vertebrate scoring tool v.2.0

Habitat

H1. Area and distribution: breeding. Is the area or location of the associated vegetation type used for breeding activities by this species expected to change? Specific habitat elements and food resources are considered in other questions.
  a. Area used for breeding habitat expected to decline or shift from current location (SCORE = 1)
  b. Area used for breeding habitat expected to stay the same and in approximately the same location (SCORE = 0)
  c. Area used for breeding habitat expected to increase and include the current location (SCORE = -1)

H2. Area and distribution: non-breeding. Is the area or location of the associated vegetation type used for non-breeding activities by this species expected to change?
  a. Area used for non-breeding habitat expected to decline or shift from current location (SCORE = 1)
  b. Area used for non-breeding habitat expected to stay the same in approximately the same location (SCORE = 0)
  c. Area used for non-breeding habitat expected to increase and include the current location (SCORE = -1)

H3. Habitat components: breeding. Are specific habitat components required for breeding expected to change within the associated vegetation type?
  a. Required breeding habitat components expected to decrease (SCORE = 1)
  b. Required breeding habitat components unlikely to change OR habitat components required for breeding unknown (SCORE = 0)
  c. Required breeding habitat components expected to increase (SCORE = -1)

H4. Habitat components: non-breeding. Are other specific habitat components required for survival during non-breeding periods expected to change within the associated vegetation type?
  a. Required non-breeding habitat components expected to decrease (SCORE = 1)
  b. Required non-breeding habitat components unlikely to change OR habitat components required for breeding unknown (SCORE = 0)
  c. Required non-breeding habitat components expected to increase (SCORE = -1)

H5. Habitat quality. Within habitats occupied, are features of the habitat associated with better reproductive success or survival expected to change?
  a. Projected changes are likely to negatively affect habitat features associated with improved reproductive success or survival. (SCORE = 1)
  b. Projected changes are unlikely to affect habitat features associated with improved reproductive success or survival.(SCORE = 0)
  c. Projected changes are likely to positively affect habitat features associated with improved reproductive success or survival.(SCORE = -1)

H6. Ability to colonize new areas. What is the potential for this species to disperse?
  a. Low ability to disperse (SCORE = 1)

b. Mobile, but dispersal is sex-biased (only one sex disperses) (SCORE = 0)
c. Very mobile, both sexes disperse (SCORE = -1)

H7. Migratory or transitional habitats. Does this species require additional habitats during migration that are separated from breeding and non-breeding habitats?
a. Additional habitats required that are separated from breeding and non-breeding habitats (e.g. most migratory species) (SCORE = 1)
b. No additional habitats required that are separated from breeding and non-breeding habitats (e.g. most resident species and short-distance migrants) (SCORE = 0)

Maximum score = 7
Minimum score = -6

Physiology

PS1. Physiological thresholds. Are limiting physiological conditions expected to change?
a. Projected changes in temperature and moisture are likely to exceed upper physiological thresholds (e.g. activities occur in very hot climates, amphibians in drier climates, species with narrow thermal range) (SCORE = 1)
b. Projected changes in temperature or moisture will primarily remain within physiological thresholds OR species is inactive during limiting conditions (e.g. species with moderate thermal range, aestivators that avoid hot/dry conditions,) (SCORE = 0)
c. Projected changes in temperature or moisture will decrease current incidents where lower thresholds are exceeded (e.g. species active in very cold climates, amphibians in wetter climates, species with very broad thermal range) (SCORE = -1)

PS2. Sex ratio. Is sex ratio determined by temperature?
a. Yes. (SCORE = 1)
b. No. (SCORE = 0)

PS3. Exposure to weather-related disturbance. Are disturbance events (e.g. severe storms, fires, floods) that affect survival or reproduction expected to change?
a. Projected changes in disturbance events will likely decrease survival or reproduction (SCORE = 1)
b. Survival and reproduction are not strongly affected by disturbance events OR disturbance events are not expected to change (SCORE = 0)
c. Projected changes in disturbance events will likely increase survival or reproduction (SCORE = -1)

PS4. Limitations to daily activity period. Are projected temperature or precipitation regimes that influence activity period of species expected to change?
a. Duration of daily active periods likely to be reduced (e.g. heliotherms in hot climates, terrestrial amphibians in drier climates) (SCORE = 1)
b. Duration of daily active periods unchanged or not limited by climate (species in habitats buffered from extremes, nocturnal species, primarily aquatic amphibians) (SCORE = 0)
c. Duration of daily active periods likely to increase (e.g. heliotherms in cool climates, terrestrial amphibians in wetter climates) (SCORE = -1)

PS5. Survival during resource fluctuation. Does this species have flexible strategies to cope with variation in resources across multiple years?
    a. Species has no flexible strategies to cope with variable resources across multiple years (SCORE = 1)
    b. Species has flexible strategies to cope with variable resources across multiple years (e.g. alternative life forms, irruptive, explosive breeding, cooperative breeding) (SCORE = -1)

6. Energy requirements. What is this species metabolic rate?
    a. Very high metabolic rates (e.g. shrews, hummingbirds) (SCORE = 1)
    b. Moderate (e.g. most endotherms) (SCORE = 0)
    c. Low (i.e. ectotherms) (SCORE = -1)

Maximum score = 6
Minimum score = -5

Phenology

PH1. Mismatch potential: Cues. Does this species use temperature or moisture cues to initiate activities related to fecundity or survival (e.g. hibernation, migration, breeding)?
    a. Species primarily uses temperature or moisture cues to initiate activities (e.g. some hibernators, aestivators, rainfall breeders) (SCORE = 1)
    b. Species does not primarily use temperature or moisture cues OR no cues to predict or initiate activities (e.g. photoperiod or circadian rhythms, resource levels) (SCORE = 0)

PH2. Mismatch potential: Event timing. Are activities related to species' fecundity or survival tied to discrete resource peaks (e.g. food, breeding sites) that are expected to change?
    a. Species' fitness is tied to discrete resource peaks that are expected to change (SCORE = 1)
    b. Species' fitness is tied to discrete resource peaks that are NOT expected to change (SCORE = 0)
    c. No temporal variation in resources or breeds year round (SCORE = -1)

PH3. Mismatch potential: Proximity. What is the separation in time or space between cues that initiate activities related to survival or fecundity and discrete events that provide critical resources?
    a. Critical resource occurs far in advance or in distant locations from cues or initiation of activity (SCORE = 1)
    b. Critical resource does NOT occur far in advance or in distant locations from cues or initiation of activity (SCORE =0)
    c. Species initiates activities directly from critical resource availability (e.g. opportunistic breeders) (SCORE = -1)

PH4. Resilience to timing mismatch. Does this species have more than one opportunity to time reproduction to important events?
    a. Species reproduces once per year or less. (SCORE = 1)
    b. Species reproduces more than once per year (SCORE = -1)

Maximum score = 4
Minimum score = -3

Biotic Interactions

I1. Food resources. Are important food resources for this species expected to change?
   a. Primary food source(s) are expected to be negatively impacted by projected changes (SCORE = 1)
   b. Species consumes variety of prey/forage species OR primary food resource(s) not expected to be impacted by projected changes (SCORE =0)
   c. Primary food resource(s) expected to be positively impacted by projected changes (SCORE = -1)

I2. Predators. Are important predator populations for this species expected to change?
   a. Primary predator(s) are expected to be positively impacted by projected changes (SCORE = 1)
   b. Preyed upon by a suite of predators OR the primary predator is not expected to be impacted by projected changes (SCORE = 0)
   c. Species has no predators (SCORE = 0)
   d. Primary predator(s) expected to be negatively impacted by projected changes (SCORE = -1)

I3. Symbionts. Are populations of symbiotic species expected to change?
   a. Symbiotic species populations expected to be negatively impacted by projected changes (SCORE = 1)
   b. Symbiotic species populations not expected to be impacted by projected changes (SCORE = 0)
   c. No symbionts (SCORE =0)
   d. Symbiotic species populations expected to be positively impacted by projected changes (SCORE = -1)

I4. Disease. Is prevalence of diseases known to cause widespread mortality or reproductive failure in this species expected to change?
   a. Disease prevalence is expected increase with projected changes (SCORE = 1)
   b. No known effects of expected changes on disease prevalence (SCORE = 0)
   c. Disease prevalence is expected to decrease with projected changes (SCORE = -1)

I5. Competitors. Are populations of important competing species expected to change?
   a. Major competitor species are expected to be positively impacted by projected changes (SCORE = 1)
   b. Species has a variety of competitive relationships OR no expected impacts of projected changes in major competitor species (SCORE = 0)
   c. Competing species are expected to be negatively impacted by projected changes (SCORE = -1)

Maximum score = 5
Minimum score = -5

Computing Scores

VULNERABILITY

Positive values indicate vulnerability to climate change and negative scores indicate resilience. Factors are adjusted for max score per factor = 5 or -5 to aid comparison among factors. Overall scores are computed from all predictive criteria (i.e., the 25 questions) regardless of factor and adjusted for maximum score of 20 or a minimum score of -20. Use caution in interpreting total score as any one factor may be limiting a species survival. Calculate scores as shown or enter raw totals of positive and negative values into the unfilled cells of the table below. Include the minus sign with negative totals and update fields after adding or changing values.

Habitat = **Positive total [5/7] + Negative total [5/6] = ___**

Physiology = Positive total [5/6] + Negative total [1] = ___

Phenology = Positive total [5/4] + Negative total [5/3] = **___**

Biotic Interactions = **Positive total [1] + Negative total [1]** = **___**

Total Score = Positive total [20/22] + Negative total [20/19] = ___

Higher scores indicate greater vulnerability.

	Enter total positive	Enter total negative	Positive score adjusted	Negative score adjusted	**SCORE**
Habitat			0.00	0.0	**0.00**
Physiology			0.00	0.00	**0.00**
Phenology			0.00	0.00	**0.00**
Interactions			0.00	0.00	**0.00**
Overall total	0	0	0.00	0.00	**0.00**

UNCERTAINTY

Assuming climate change projections are correct, note the amount of information available for each question for assigning scores. Chose one of the following for each question:

a. Adequate information available to assign score for this species. SCORE = 0
b. Information is not adequate to confidently assign score OR conflicting predictions or responses make scoring difficult. SCORE = 1

Calculations are the percentage of uncertain scores for each factor and for all criteria (i.e., overall). Use the worksheet below to aid calculation.

WORKSHEET 2. UNCERTAINTY SCORE WORKSHEET

	Sum Score	Divisor	Percent Uncertainty
Habitat		7	0%
Physiology		6	0%
Phenology		4	0%
Interactions		5	0%
TOTAL	0	22	0%

WORKSHEET 3. This worksheet can be used to track scores during assessment. Mark the corresponding boxes for the selected score and for uncertainty if information was inadequate or conflicting. Use these values to calculate scores using worksheets 1 and 2. Shaded cells are not valid scores.

HABITAT	Vulnerability option			Uncertainty option
	1	0	-1	Check if 1
1. Is the area or location of the general associated vegetation type used for breeding activities by this species expected to change?				
2. Is the area or location of the general associated vegetation type used for non-breeding activities by this species expected to change?				
3. Are specific habitat components required for breeding expected to change within associated vegetation type?				
4. Are specific habitat components required for survival expected to change within associated vegetation type?				
5. Within habitats occupied, are features of the habitat associated with better reproductive success or survival expected to change?				
6. What is the potential for this species to disperse?				
7. Does this species require additional habitats during migration that are separated from breeding and non-breeding habitats?				
	Total columns			Count above

PHYSIOLOGY	Vulnerability option			Uncertainty option
	1	0	-1	Check if 1
1. Are limiting physiological conditions expected to change?				
2. Is sex ratio determined by temperature?				
3. Are disturbance events that affect survival or reproduction expected to change?				
4. Are temperature or precipitation regimes affecting activity periods expected to change?				
5. Does this species have strategies to cope with variation in resources across multiple years?				
6. What is this species metabolic rate?				
	Total columns			Count above

WORKSHEET 3 (Cont)

PHENOLOGY	Vulnerability option			Uncertainty option
	1	0	-1	Check if 1
1. Does this species use temperature or moisture cues to initiate activities related to fecundity or survival?				
2. Are activities related to species' fecundity or survival tied to discrete resource peaks that are expected to change?				
3. What is the separation in time or space between cues that initiate activities and discrete events that provide critical resources?				
4. Does this species have more than one opportunity to time reproduction to important events?				
	Total columns			Count above

INTERACTIONS	Vulnerability option			Uncertainty option
	1	0	-1	Check if 1
1. Are important food resources for this species expected to change?				
2. Are important predator populations expected to change?				
3. Are populations of symbiotic species expected to change?				
4. Is prevalence of diseases known to cause widespread mortality or reproductive failure in this species expected to change?				
5. Are populations of important competing species expected to change?				
	Total columns			Count above

Scoring Guidelines

This is a guide to applying the scoring system developed by Rocky Mountain Research Station for assessing the vulnerability of individual vertebrate species to climate change (v.2.0). Specifically, these sections provide criteria for inclusion or exclusion of data from the decision making process. We also list suggested sources of information and the type of data that might be helpful for selecting an appropriate response. We recommend documenting sources of information used for scoring as well as explanation of specific score choices. This will aid future edits.

Information on projected climate changes for your area of interest should be gathered before scoring species. IPCC (Intergovernmental Panel on Climate Change) reports and Climate Wizard (www.climatewizard.org) are two good starting points for future climate projections. Also consider impacts beyond temperature and precipitation such as flooding, droughts, timing of frosts, wildfire frequency, and changes to snowpack that may affect target species.

HABITAT

1. Area and distribution: breeding. Is the area or location of the associated vegetation type used for breeding activities by this species expected to change?

Criteria: Change in area or distribution of suitable habitat has a direct impact on populations. Consider whether the overall area of the vegetation association for this species' breeding habitat is going to shrink, expand or move from your area of interest. We consider species vulnerable to climate change if projections indicate a loss or shift of associated vegetation and resilient to climate change where climate effects are likely to increase the area of a species' associated vegetation type. For geographical shifts we considered a shift of >50% from the former range to represent substantial effect. Some species may have a single habitat association, whereas others may utilize a variety of vegetation types. There are numerous vegetation classification systems, but most guides and species accounts will report broad biome classifications or biotic communities, which is the most appropriate resolution for this tool. More specific habitat components and resources are considered in other questions. This question does not require a comprehensive account of all documented locations for an individual species, but should consider all primary vegetation associations where more than one is used.

Relevant data and suggested sources: Information on vegetation associations along with species range is available from most field guides and online species accounts (e.g., NatureServe, BISON-M, Birds of North America Online, AmphibiaWeb). For endangered species, the USFWS recovery plans contain good review of available natural history information.

2. Area and distribution: non-breeding. Is the area or location of the associated vegetation type used for non-breeding activities by this species expected to change?

Criteria: Species are likely to be impacted by climate related changes in the area or a geographical shift in habitat. Consider vegetation types and habitat associations for the species outside of the breeding season, generally winter. For geographical shifts we considered a shift of >50% from the former range to represent substantial effect. For resident or sedentary species associations considered for this question may be identical to those scored in Question 1 and, in these situations, the species will receive identical scores. Stopover or other transitional habitats between breeding and non-breeding habitats are considered in Question 7.

Relevant data and suggested sources: Same as Question 1.

3. Habitat components: breeding. Are specific habitat components required for breeding expected to change within the associated vegetation type?

Criteria: Climate change may affect the availability of critical habitat components within primary vegetation types that are required for breeding. Species are vulnerable when climate effects will result in a loss of components and consequentially a loss in breeding opportunity. Only specific components or features of the habitat necessary for breeding should be considered (i.e., breeding does not occur without this component). Consider whether a required component will become more or less prevalent with changes in climate or related aspects such as disturbance, but note that not all habitat components required are affected by climate. Variation in breeding success associated with a component is covered in Question 5.

Relevant data and suggested sources: Field guides or natural history accounts should contain information on required components if present.

4. Habitat components: non-breeding. Are specific habitat components required for survival during non-breeding periods expected to change within the associated vegetation type?

Criteria: Climate change may affect the availability of critical habitat components that are required for survival rather than reproduction as in Question 3. Only specific components or features of the habitat necessary for survival during non-breeding periods should be considered. Components may be a physical feature, such as a cave for hibernation or may be directly related to climate, such as snowpack, but components are required rather than improve survival (Question 5). Consider whether a required component will become more or less prevalent with changes in climate or related aspects such as disturbance.

Relevant data and suggested sources: Information regarding habitat components, if present, is readily available in most species' natural history accounts.

5. Habitat quality. Within the habitats occupied, are features of the habitat associated with better reproductive success or survival expected to change?

Criteria: Habitat features associated with quality are those that incur variation in survival or reproduction. These can be aspects of the components required (Question 3 and 4). Consider aspects of the habitat (e.g., vegetative cover, snow depth), which directly lead to differential breeding or survival success in the focal species. Do not consider changes in overall habitat availability (area), distribution, or the presence or absence of critical habitat components, but aspects that are associated with variation in breeding success, which will ultimately affect populations Where relationship of habitat quality with climate projections is unclear, score as 0. Food resources should be considered under Biotic Interactions.

Relevant data and suggested sources: Habitat quality is often discussed in reference to locations with variable fitness or in reference to habitat selection. Additionally, references may refer to sources and sinks: locations where recruitment exceeds mortality are source populations and sinks are where recruitment does not exceed mortality. Information on quality of habitats is sometimes listed as part of natural history information, but more often needs to be checked within the wider scientific literature. Aspects related to quality may also be included as part of conservation strategies for the species. Try a query including "quality" or "habitat selection" and the species name in a scientific database (e.g., Google Scholar, BIOSIS). Also try a query using species name and "winter" or "mortality".

6. Ability to colonize new areas. What is the potential for this species to disperse?

Criteria: Species that are able to readily disperse are likely to be able to travel to new locations if needed and, thus, are considered more resilient to potential habitat changes. Consider species' capacity to move to new habitats or favorable microclimates both within the context of the time period of climate projections and the magnitude of the changes. Species that only move long distances over several generations may not have the capacity to respond to rapid climate-mediated changes in habitat. Sex-biased dispersal (i.e., dispersal by only one sex) or strong site fidelity will counter some of the benefits of mobility. Site fidelity or territoriality restricted to the breeding season would not constitute inability to disperse for this question as its effect is only temporary. Depending on the focal area of interest, you may be able to include barriers to dispersal when movement to alternative suitable habitats is potentially inhibited. When multiple barriers to dispersal are present, either behavioral or physical, use your best judgment as to whether together these are likely to incur vulnerability or resilience, or will not particularly hinder or help dispersal.

Relevant data and suggested sources: If species' mobility is not known, data on species range, average dispersal distances, presence of sex-biased dispersal, maximum known dispersal, or homing capacity are useful. Studies of the effect of habitat fragmentation may provide useful information regarding species capacity to move to new locations. Look for information in species accounts and life history papers. NatureServe also provides further discussion regarding dispersal abilities and barriers in its assessments of species. Knowledge of the geographic features of the focal scoring area are useful to judge whether geographic barriers may be an issue. Finally, information regarding the expected shift in habitat (e.g., 300 m upslope in 50 yrs) may be useful for providing a measure by which to assess species' dispersal capacity.

7. Migratory or transitional habitats. Does this species require additional habitats during migration that are separated from breeding and non-breeding habitats?

Criteria: Species which require additional habitats beyond breeding and non-breeding (e.g., wintering grounds) sites may be more vulnerable to climate effects, because we cannot expect parallel changes in all these habitats. Good examples of species with additional habitat requirements are long distance migratory birds that require stopover sites to replenish resources. Some mammal species also migrate across long distances through transitional habitats. Whenever additional habitats are geographically distinct and subject to different climatic changes or comprised of different vegetation types from breeding and non-breeding habitats a species should be considered vulnerable. Distance alone, however, may not determine whether a species uses transitional habitats. Species that move through transitional habitats without resource utilization such as long distance migratory birds that have non-stop flights or elevational migrants that shift flexibly over relatively short distances, are not considered vulnerable to this effect.

Relevant data and suggested sources: Basic natural history information should contain migratory information. Specific stopover information, which is often unknown, is not required for scoring. A basic climate projection map or vegetation map should indicate if transitional habitats are separate from breeding and non-breeding habitats.

Physiology

1. Physiological thresholds. Are limiting physiological conditions expected to change?

Criteria: Species often exist near their physiological limits with respect to temperature or moisture tolerances. If projected future conditions increase likelihood of that a species will experience limiting conditions (high heat, desiccation) then the species will be vulnerable to climate related population declines as habitat becomes unsuitable for species survival. Alternately, some species may benefit (exhibit increased resilience) when projected changes predict a move away from currently limiting thresholds as might be found for a cold sensitive species under a warming scenario. Consider both minimum and maximum thresholds of the focal species and, when both are likely to be influenced with distinct outcomes, select the variable that is most limiting for survival when scoring. For instance, in cases where a species may be limited by temperature maximums, but benefit by changes in temperature minima, base the score on the limiting effect; here the maximum temperature. Species that have moderate thermal range tolerances that are rarely exceeded under future scenarios or are able to avoid limiting conditions (e.g., aestivators) are not considered physiologically vulnerable climate changes and are given a neutral score (option b) unless that species is also expected to experience a decline in lower thresholds, in which case option c should be selected.

Relevant data and suggested sources: Information may be limited to laboratory experiments, which do not directly correspond to survival in the field. If not directly reported, a number of substitutes may be used to infer whether a species exists near its temperature or moisture threshold. Demonstrations of recent population shifts or records of die-offs during extreme weather may indicate physiological limits. Range boundaries available in basic species accounts often indicate a climatically driven limitation and thus species living along the boundary of their range are likely near their physiological limits. Also, location of species within its distribution may be informative (e.g., populations of interest at southern limit of range or only occur in moist microsites), or range of thermal conditions for species distribution (e.g., species that occupy areas of limited variability may have narrow tolerances). If no prediction can be made, score as 0 but also uncertain.

2. Is sex ratio determined by temperature?

Criteria: Only some reptile species are generally known to have temperature-determined sex ratios. Consider the effect of temperature on sex determination and whether future climate conditions may favor one sex over another. Although there have been some examples in other taxonomic groups with differential survival of embryos with temperature, this effect has generally not been well studied. If temperature has a sex-biased effect on survival of offspring, only consider situations where this effect is likely to result in strongly skewed sex ratios across populations.

Relevant data and suggested sources: This trait can usually be found in natural history profiles, field guides, or species accounts.

3. Exposure to weather related disturbance. Are disturbance events (e.g., severe storms, fires, floods, etc.) that affect survival or reproduction expected to change?

Criteria: This question regards mortalities caused by disturbances events. To be considered vulnerable, a species' population should experience significant mortality as a direct result of the disturbance event. Do not include indirect effects of these events on resources (see Biotic Interactions) or habitat (see Habitat). Do consider the frequency, timing and duration of these events when choosing a response. Consider the impact of extreme events for both breeding and non-breeding periods and again chose the most limiting condition when multiple effects are expected. For migrants, breeding and non-breeding may be in separate regions and have different projections. For non-migratory species, differences may simply be seasonal. Known response to extreme weather conditions (heat waves, drought) are more informative for thresholds (Question 1) than this question.

Relevant data and suggested sources: Gather information on species habitat from natural history accounts or field guides and consider in relation to your climate projection information. Population studies may be additionally helpful as they consider events related to mortality. Look for observed cases of mass mortality related to disturbances, as these are often unusual enough to inspire documentation.

4. Limitations to daily activity period. Are projected temperature or precipitation regimes that influence activity period of species expected to change?

Criteria: Activities important for survival or reproduction may be limited by environmental conditions and result in increased species vulnerability. Often limitations are associated with high temperatures or dry conditions, but can also be limited by cold or snow. Specifically consider whether the projected changes will lead to increases or decreases in activity periods that have the potential to affect survival or fecundity. Diurnal species may be exposed to greater extremes, but nocturnal species may be less tolerant of extremes.

Relevant data and suggested sources: Some useful information should be available in general natural history information. Look for information on limiting conditions for activity and timing of active periods and consider how these conditions may be altered. Most information on activity will be available on foraging or resting behaviors, but consider if these have the potential to affect fitness.

5. Survival during resource fluctuations. Does this species have alternative life history pathways to cope with variable resources or climate conditions?

Criteria: Some species have alternative life history pathways or employ strategies that allow them to maximize reproduction and survival under variable conditions, which is likely to confer resilience to expected climate changes. Species with irruptive or explosive breeding events, those that use cooperative breeding systems, or can employ alternate phenotypes (neotony, carnivorous phenotypes) are examples of animals that have such coping strategies. Conversely, the species may not have flexible strategies or the strategies it does possess are not expected to increase ability to survive during periods of low resource levels and it should be scored as vulnerable.

Relevant data and suggested sources: Life history/species accounts will generally list alternative life history pathways and often includes information related to the advantages of these strategies. Consider your regional projections and how these alternatives may or may not be advantageous.

6. Energy requirement. What is this species' metabolic rate?

Criteria: Mark as appropriate. Metabolism in endotherms is considered moderate for this purpose unless known to be particularly high relative to other vertebrates, such as in hummingbirds or shrews.

Phenology

1. Cues. Does this species use temperature or moisture cues to initiate activities related to fecundity or survival?

Criteria: Species that rely primarily on a temperature or precipitation cue to initiate activities will be more likely to experience impacts related to changes in timing. Species that rely on endogenous rhythms or cues (e.g., day length) are not subject to this risk and we also include those species that use a mix of cues in this group. Cues may initiate activities such as migration, ovulation or egg laying, or emergence from hibernation.

Relevant data and suggested sources: Life history/species accounts should list activities. How a species times activities is not always included in these accounts, but should be available from more general information on taxonomic groups or on the timed activity such as migration.

2. Event timing. Are activities related to species' fecundity or survival tied to the availability of discrete resource peaks (e.g., food, breeding sites) that are expected to change?

Criteria: Variation in the timing of critical resources due to climate change leaves species at an increased risk of mistiming their activities and therefore, species with such dependencies are considered more vulnerable. Assess if the species relies on a discrete resource event limited in time such as the emergence of insects or flowering plants. Certain weather conditions may also be discrete events that may be important such as calm weather for successful bird migration or onset of rainy season for spadefoot toad emergence. If these periods are likely to change, then the migrating species is likely to be negatively impacted. Not all resources or favorable conditions will be limited to discrete time periods or will be affected by projected climate change.

Relevant data and suggested sources: You first need information on what discrete events are important for your species and should be available in life history/species accounts. You will then need to consider if the timing of these events is affected by climate or climate-mediated variables. For this you may need additional information regarding resource pulses and/or biological properties of prey/forage species, which could be provided through accounts created for those species. You do not need to make estimate the magnitude of timing change to cues and resources or potential for synchrony.

3. Mismatch potential. What is the separation in time or space between cues that initiate activities and discrete events that provide critical resources?

Criteria: Consider the separation between the cues of Question 1 and the events of Question 2. Indicate whether a species initiates activities immediately in response to or in the immediate vicinity of a changing critical resource. In some instances, there could be a fairly constant level of critical resources that would make a timing mismatch unlikely. Opportunistic breeders and eruptive species are a good example of animals that respond directly to a resource pulse. Other species may not be able to respond within a short period of time to changes in resources, such as those whose activities are initiated in different latitude, time zone, elevation, or habitat type from critical resources.

Relevant data and suggested sources: Life history/species accounts and information gathered for the previous 2 questions is applicable here. You may need additional information regarding resource pulses and how they are affected by climate.

4. Resilience to timing mismatches during breeding. Does this species have more than one opportunity to time reproduction to important events?

Criteria: The ability to breed multiple times a year increases the chances that at least one of those attempts is optimally timed with resources. Indicate how species' reproductive period is distributed within a single year. Species need to breed and produce young more than once to qualify as resilient (i.e., a species that renests within a constrained period of time should not be considered to be resilient).

Relevant data and suggested sources: Life history/species accounts should have this information. Avoid using rare cases to determine score.

Biotic Interactions

The following questions require some knowledge of climate change effects on interacting species that have some demonstrable influence on the species under study. Strong interactions are relatively rare in most species and so the additional research required for this section will often be minimal. However, in the case where there is a notable or influential relationship between species, it is critical to assessing species vulnerability to understand how climate impacts will affect both parties. Indeed, such relationship may be one of the most important determinants of vulnerability.

1. Food resources. Are important food resources for this species expected to change?

Criteria: Consider important foods and especially any resources that are critical for species survival even if that resource is only required for a limited period. When an important resource has been identified, consider broadly how projected changes in climate are expected to impact this resource. If the species utilizes several food sources with variable potential responses to climate change projections, then (b) will be the most appropriate selection. Consider whether food resources may be limited during critical periods such as during reproduction or migration.

Relevant data and suggested sources: Diet is most commonly reported in natural history documents although it is not always well documented for individual species or across a species' range. A score of 0 is appropriate where information is absent. Most applications of this potential vulnerability will be those with more specialized diets, but some food resources may also be predicted to change even if comprised of multiple species. Life history and species accounts may provide information on potential direction of change for an animal species used as a resource. Additional information on a taxonomic group of interest may be found with online scholarly search engines such as Google Scholar or BIOSIS.

2. Predators. Are important predator populations for this species expected to change?

Criteria: Only predator species with a demonstrable impact on the species should be considered. If there are several predators with varying expected responses to climate change projections, then we assume that overall predation effects will remain unchanged. Similarly, no prediction is made if mortality from predation is low.

Relevant data and suggested sources: Life history/species accounts. A general understanding of the potential response of predator species to projected climate changes is required. This will likely involve reviewing the natural history of the predator or doing a literature search.

3. Symbionts. Are populations of symbiotic species expected to change?

Criteria: We define symbiotic relationships broadly here to identify any required relationships with other organisms. Consider species that are part of an obligatory mutualism (required for survival or breeding), commensalism, or parasitism (i.e., the focal species is parasitic). If the symbiotic species is only a food resource and already considered in Question 1, then use “none” here unless there is some additional aspect to the relationship that has not been addressed.

Relevant data and suggested sources: Life history/species accounts should list the presence of a symbiotic species. Knowledge of symbiont life history characteristics and potential response to climate change projections may be required (see Question 2). This question does not apply to hosts of parasites (see Question 4).

4. Disease prevalence. Is prevalence of diseases known to cause widespread mortality or reproductive failure expected to change?

Criteria: Consider only those pathogens or parasites that are known to cause substantial mortality or loss of fecundity. In addition to the disease-causing agent, consider how climate affects the incidence, spread, or virulence of the disease. Vector-borne diseases may be particularly prone to range expansions if climate projections alter range suitable for vector populations. Climate changes can additionally affect disease spread indirectly through increases in crowding if resources become more limited (e.g., shrinking water sources) or similarly if body condition is reduced. Consider crowding only when there is a demonstrable relationship between crowding and disease outbreak (e.g., many water borne pathogens for instance) as well as mechanism where crowding is expected to increase (e.g., concentration of limited water sources).

Relevant data and suggested sources: Life history/species accounts should provide information regarding disease susceptibility. USGS National Wildlife Health Center is a good source of wildlife disease information and a field manual of bird diseases is available online (http://www.nwhc.usgs.gov/publications/field_manual/). Literature searches of the species name or family and “mortality” may also be helpful. In addition some diseases may have detailed projections related to climate change, particularly if they affect human health as well (e.g., malaria). Primary literature search of the specific pathogen with reference to climate change or range expansions is recommended. For any significant diseases, follow up with a search for transmission risk factors.

5. Competitors. Are populations of important competing species expected to change?

Criteria: Consider the effects of climate changes on competing species that displace or negatively affect survival or reproduction in the species of interest. Specifically, note whether major competitors, those that are known to outcompete a species, will benefit or not by projected changes in climate. Consider introduced as well as native species.

Relevant data and suggested sources: Information on important competing species is often included with information on species conservation and suggested control measures may indicate if certain climate conditions favor these species.