Department of Defense
Legacy Resource Management Program

PROJECT 09-433

A TOOL TO ASSESS VULNERABILITY OF PLANT SPECIES TO CLIMATE CHANGE

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

AUGUST 2010

INTRODUCTION

Rapid climate change is likely to overwhelm dispersal and adaptive ability in plants resulting in increased extinction risk for many species (Jump and Peñuelas 2005). Anticipating changes in species distribution and abundance will be important for identifying effective management actions and taking a proactive approach to preserving biodiversity. Species assessments of vulnerability or extinction risk are management tools used to help prioritize conservation needs so that actions can be directed in an effective and efficient manner (Glick and Stein 2010). We approached vulnerability by identifying traits that may be more vulnerable or resilient to projected changes in climate. Vulnerability or resilience was predicted from expectations of decreased or increased reproduction or survival under projected climate conditions.

Despite lack of information on plant species response to climate change, some simple predictions can be made regarding plant traits likely to be associated with lesser or greater vulnerability to declines with projected future climate. We developed a simple scoring system based on a few readily identifiable and predictive plant traits to assess vulnerability of individual plant species to climate change. We primarily focused on predictors related to plant survival and reproduction as we had taken a similar approach with assessing vertebrate species. Scoring criteria were selected to be simple predictors and be flexible to new information. Because plant species vary so widely, we chose to tailor the scoring system to the desert Southwest of North America. In general, this region is predicted to become hotter and drier (Seager et al. 2007) and scoring is based on this projection. Details of the criteria incorporated into the tool are provided below and the tool follows.

TOOL COMPONENTS

Habitat

Various aspects of the environment, including temperature, rainfall, topography, and soils, affect plant distributions. As a simple starting point for considering climate change effects, increased temperatures will increase evaporation and decrease water availability. Although water limitation affects all plants, those species that have high water needs will be the most vulnerable in regions where water is already limiting such as the Southwest. We expect that annual streamflows will be reduced and wetlands will be prone to drying (Garfin and Lenart 2007), and, therefore, we predict increasing stress for species that require mesic habitats.

Basic climate variables may not capture a species' specific habitat requirements, but will further restrict distribution and ability to survive with changing conditions. Specialization of a species to a limited set of localized environmental conditions (i.e, microsite, microhabitat, microenvironment) will also increase vulnerability to environmental stress and population declines as conditions change (Broennimann et al. 2006), thus greater specialization or habitat specificity increases vulnerability.

Dispersal will be important as locations of suitable environmental conditions shift spatially. Climate change scenarios usually consider migration of species with their associated climate envelope to be complete or they assume no dispersal occurs, but dispersal will vary with species traits and geography (Broennimann et al. 2006). Seeds are most commonly dispersed by animals, but animal species will also be subject to changes associated with changing climate. Declines in the rate of animal dispersal could be related to decreases in local disperser populations, or changes in timing of animal activities that can potentially result in a mismatch between seed readiness and animal presence. Thus, we consider animal-dispersed plant species at greater risk for adverse effects under future climate scenarios. We further predict that water dispersal may be limited as rainfall inputs and snowpack decrease (Seager et al. 2007), but wind dispersal should be relatively unchanged.

Seedlings requirements may differ from those of mature individuals, thus we differentiated predictions between seedlings and other age groups. A well known example of disparate requirements is the association of seedlings with nurse plants in many cacti. In other species, seedlings may require a narrower range of environmental conditions than mature plants and changes that affect those conditions will be limiting to recruitment and populations in the longterm. Climate change response will, in part, depend on the resilience of these nurse plant species or trends for favorable climatic conditions.

Physiology

Climate variables also influence disturbance patterns such as fires and floods that can affect survival and reproduction in some plant species. Warmer temperatures are expected to increase floods as snowpack melts more quickly and earlier. Greater flood risk from intense storms is also projected for the southwestern United States (Garfin and Lenart 2007, Seager et al. 2007). Wildfires are expected to become more frequent with projected increases in temperature (Rogers and Vint 1987, Swetnam and Betancourt 1990, Esser 1992, Westerling et al. 2006). Projected increases in climate variability will also increase fire occurrence as years of high rainfall are followed by dry/hot years creating conditions conducive both to ignition and fuel accumulation (McLaughlin and Bowers 1982). Some plants are resistant to fire mortality while others are favored by the altered soil and light conditions, although this relationship may depend on a number of other factors such as season or intensity. For this region, we expect species for which fire creates favorable conditions to be resilient, while those species that are prone to fire mortality or reduced recruitment will be more vulnerable.

Precipitation, both quantity and timing, will be important to plant species' response (Ehleringer et al. 1991, Patrick et al. 2009), but has not been projected in detail. Large megadroughts lasting >20 years have occurred in the past without large inputs to greenhouse gases (Cook et al. 2009). Although projections are uncertain, the Intergovernmental Panel on Climate Change (IPCC) and others (Seager et al. 2007) predict future conditions that are similar to those that produced the megadroughts (Cook et al. 2009). We used general predictions of increasing droughts and greater evaporation to predict drier conditions in the Southwest, although we expect rainfall to be variable on an annual basis. Although difficult to project, drought response as related to intensity or duration and plants that possess adaptations to endure dry conditions will clearly be at an advantage. Many desert plants possess these traits, but other species escape harsh conditions by remaining dormant, often as seeds, until conditions are more favorable.

Photosynthetic pathways that reduce water loss will also be favorable under conditions of greater water stress. Crassulacean Acid Metabolism or CAM allows plants to open stomata at night reducing water loss. Higher temperatures should also favor C4 relative to C3 plants. Although elevated CO_2 can favor C3 plants, we feel higher temperatures will be the overriding effect for the desert Southwest. Expansion of C4 over C3 plants in response to increased CO_2 levels has already been observed in some areas (Wittmer et al. 2009).

Interactions

Although some interactions with other species were involved in previous factors, we wanted to highlight a number of important interspecific relationships. Like seed dispersal, pollination is mostly through animal interactions, which are vulnerable to effects of climate change through various factors including phenology and population dynamics. Phenology is particularly of concern because of the potential mismatch in timing changes for pollinators and flowering (Stenseth and Mysterud 2002).

Disease, parasites, or insect pests that affect plant populations may be altered by changing climate conditions with subsequent impacts on plant populations. For example, a number of insect pests are also projected to increase with warmer temperatures although conditions may become less favorable for other pests. Outbreaks of phytophagous insects are promoted by drought conditions although insects may be reduced when drought conditions are prolonged (Mattson and Haack 1987).

Distribution and abundance of plants is also regulated by interactions with other plant species. Of particular interest are climate effects on important competitors. Unfortunately, invasive plant species are often ones that respond to increased CO_2 with increase growth rates (Dukes and Mooney 1999, Smith et al. 2000), which will have important consequences for competitive interactions as well as ecosystem dynamics.

UNCERTAINTY

The uncertainty score that accompanies each factor quantifies the proportion of questions answered that were uncertain. This uncertainty arises from the lack of information on which to base scores or from mixed predictions within a single criterion. Uncertainty of climate projections or of how a plant species responds is important, but not part of this score.

Other sources of uncertainty or data gaps limited the development of the tool itself. We avoided traits that are not well known across a wide range of species, even though they will have clear effects on response, such as persistence of dormant seeds exposed to warmer temperatures. We did not consider direct effects of CO_2 increase on plants, as these effects are complicated by interactions with other factors such as nutrients and water. Elevated CO_2 may have some mitigating effects for drought, however, because stomata can stay closed longer, but this also varies among species (Korner et al. 2007).

SCORE APPLICATION

The purpose of scoring species is to compare vulnerability or resilience among a group of species. Scores can then be used for ranking or prioritization and to identify potential targets for management actions, although selecting management targets will involve integration of other factors that threaten species or that inform management decisions (e.g., legal requirements). Vulnerability was indicated by positive scores and resilience by negative scores relative to a neutral response to climate change of zero. Scores for each factor were adjusted to be equal to facilitate comparison among the factors. For overall scores, all criterion were weighted equally regardless of factor and, thus, are not the sum of the factor scores. Adjustments were also made so that maximum and minimum scores are equal despite fewer predictors of resilience (negative scores). Calculation details follow the scoring criteria.

ACKNOWLEDGMENTS

Funding was provided by the Department of Defense Legacy Program (Project 09-433). We thank Christopher Bickford for his advice and input on this project. Megan Friggens also provided comments that improved this document.

LITERATURE CITED

Broennimann, O., W. Thuiller, G. Hughes, G. F. Midgley, J. M. R. Alkemades, and A. Guisan. 2006. Do geographic distribution, niche property and life form explain plants' vulnerability to global change? Global Change Biology 12:1079–1093.

Cook, E. R., Seager, R., Heim Jr., R. R., Vose, R. S., Herweijer, C. and Woodhouse, C. 2009. Megadroughts in North America: placing IPCC projections of hydroclimatic change in a long-term palaeoclimate context. Journal of Quaternary Science. Published online, ISSN 0267-8179.

Dukes, J. S. and H. A. Mooney. 1999. Does global change increase the success of biological invaders? Trends in Ecology and Evolution 14:135-139.

Ehleringer, James R., Susan L. Phillips, William S. F. Schuster, and Darren R. Sandquist. 1991. Differential utilization of summer rains by desert plants. Oecologia 88:430434.

Esser, Gerd. 1992. Implications of Climate Change for Production and Decomposition in Grasslands and Coniferous Forests. Ecological Applications 2:47-54.

Garfin, G. and M. Lenart. 2007. Climate Change Effects on Southwest Water Resources. Southwest Hydrology 6:16-17.

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

Ibanez, I., J. S. Clark, and M. C. Dietze. 2008. Evaluating the sourcesof potential migrant species: implications under climate change. Ecological Applications, 18:1664–1678.

Jump, A. S. and J. Peñuelas. 2005. Running to stand still: adaptation and the response of plants to rapid climate change. Ecology Letters 8:1010–1020.

Korner, C., J. Morgan, and R. Norby. 2007. CO_2 fertilization: when, where, how much? Pages 9-21 *in* Terrestrial Ecosystems in a Changing World (J. Canadell, D. Pataki, and L. Pitelka, eds). Springer-Verlag, Berlin.

Mattson, William J. and Robert A. Haack. 1987. The Role of Drought in Outbreaks of Plant-Eating Insects. BioScience 37:110-118.

McLaughlin, S. E. and J. P. Bowers. 1982. Effects of wildfire on a Sonoran Desert plant community. Ecology 63:246-248.

Patrick, L. D., K. Ogle, C. Bell, J. Zak and D. Tissue. 2009. Physiological responses of two contrasting desert plant species to precipitation variability are differentially regulated by soil moisture and nitrogen dynamics. Global Change Biology 15:1214–1229.

Rogers, G. F. and M. K. Vint. 1987. Winter precipitation and fire in the Sonoran Desert. Journal of Arid Environments 13:47-52.

Seager, R., et al. 2007. Model projections of an imminent transition to a more arid climate in southwestern North America. Science 316:1181–1184.

Smith, Stanley D., Travis E. Huxman, Stephen F. Zitzer, Therese N. Charlet, David C. Housman, James S. Coleman, Lynn K. Fenstermaker, Jeffrey R. Seemann and

Robert S. Nowak. 2000. Elevated CO_2 increases productivity and invasive species success in an arid ecosystem. Nature 408:79-82.
Stenseth, N. C. and A. Mysterud. 2002. Climate, changing phenology, and other life history traits: Nonlinearity and match–mismatch to the environment. Proceedings of the National Academy of Sciences 99:13379–13381.
Swetnam, T. W. and Betancourt, J. L. 1990. Fire-Southern Oscillation relations in the southwestern United States. Science 249: 1017-1021.
Westerling, A. L., H. G. Hidalgo, D. R. Cayan, and T. W. Swetnam. 2006. Warming and Earlier Spring Increase Western U.S. Forest Wildfire Activity. Science 313:940-943.
Wittmer, M. H. O. M., K. Auerswald, Y. Bai, R. Schaufele, and H. Schnyder. 2009. Changes in the abundance of C3/C4 species of Inner Mongolia grassland: evidence from isotopic composition of soil and vegetation. Global Change Biology doi: 10.1111/j.1365-2486.2009.02033.x

RMRS Vulnerability Scoring Tool for Plant Species in the Southwestern United States, v.1.0

Habitat

1. Increased droughts and warming. Is this species associated with wetlands, riparian areas, or other mesic environments that are expected to decline?
    a. Species occurs exclusively in mesic environments (SCORE = 1)
    b. Species does not occur exclusively in mesic environments (SCORE = 0)
2. Habitat specificity. Is this species widespread throughout its range or does it occur only at particular microsites or microhabitats?
    a. Limited occurrence in specialized microsites/microhabitats (SCORE = 1)
    b. Unknown (SCORE = 0)
    c. Occurs in multiple microsites/microhabitats (SCORE = -1)
3. Ability to colonize new areas. What is this species dispersal mechanism?
    a. Seeds are animal or water dispersed (SCORE = 1)
    b. No seed dispersal agent (SCORE = 0)
    c. Seeds are wind dispersed (SCORE = -1)
4. Seedling conditions. Do seedlings require different conditions from mature individuals (e.g., shade, moisture, fires, nurse plants, etc.)?
    a. Conditions for successful seedling survival likely to decrease with projected changes (SCORE = 1)
    b. Conditions for successful seedling survival likely unchanged or are similar to conditions for adult survival OR unknown conditions (SCORE = 0)
    c. Conditions for successful seedling survival likely to increase with projected changes (SCORE = -1)

Physiology

5. Exposure to disturbance. Do disturbance events such as the floods or fires that are expected to increase under future conditions affect survival or reproduction in this species?
    a. Floods, fires or other disturbance events that are expected to increase are detrimental to this species (SCORE = 1)
    b. No expected effect of increasing disturbance events on survival or reproduction (SCORE = 0)
    a. Floods, fires or other disturbance events that are expected to increase are beneficial to this species (SCORE = -1)
6. Adaptations to survive water limitations. Does this species possess adaptations to increase survival during droughts? (e.g., waxy leaves, water storage, drought deciduous)
    a. Species does not possess drought-resistant traits (SCORE = 1)
    b. Species avoids drought conditions through annual life cycle (SCORE = 0)
    c. Species possesses drought-resistant traits (SCORE = -1)
7. Photosynthetic pathway. Which photosynthetic pathway does this species use?

  a. Obligate C3 (SCORE = 1)
  b. Obligate C4 (SCORE = -1)
  c. C3 or C4 (facultative) (SCORE = -1)
  d. CAM (SCORE = -1)

Interactions

8. Pollination. What is the pollination vector?
   a. Wind or self pollination (SCORE = -1)
   b. Animal or insect pollinators (SCORE = 1)
9. Disease. Are any diseases or insect pests known to result in mass mortality related to temperature or precipitation?
   a. Mortality from disease or pests is expected to increase with climate projections (SCORE = 1)
   b. No known disease or pests related to temperature or precipitation OR disease and pests are not known to cause mass mortality (SCORE = 0)
   c. Mortality from disease or pests is expected to decrease with climate projections (SCORE = -1)
10. Competition. Are populations of important competing species expected to change?
    a. Competing species are expected to benefit with projected changes (SCORE = 1)
    b. No expected changes in competing species OR no known competing species (SCORE = 0)
    c. Competing species are expected to decrease with projected changes (SCORE = -1)

Score Calculations

Use the following formulas to compute scores or enter in the table below. Use F9 or right click and select "update" to update formulas in shaded boxes. Maximum for each Factor is 3 and minimum is -3. The maximum overall score is 10 and minimum is -10.

Habitat: Add the positive scores for Questions (1 + 2 + 3 + 4) x 0.75. Add the negative scores for Questions 2 + 3 + 4. Add Positive + Negative for Habitat Score.

Physiology: Add Questions 5 + 6 + 7

Interactions: Add Questions 8 + 9 +10

Overall: Add all of the positive scores (Questions1 through 10). Add all of the negative scores for Questions (2 through 10) x 1.1. Add Positive + Negative for Overall Score.

	Sum of positive scores	Sum of negative scores	SCORE
Habitat			0.0
Physiology			0
Interactions			0
Overall	0	0.0	0

Uncertainty

For each question note if the criterion was unknown for the species or conflicting predictions within a criterion made scoring difficult. Calculate % uncertainty by counting the number of these questions and divide by total number of criteria for each factor and for overall (i.e., 10).