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Regional climate change adaptation strategies for biodiversity conservation in a midcontinental region of North America

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ABSTRACT

Scenario planning should be an effective tool for developing responses to climate change but will depend on ecological assessments of broad enough scope to support decision-making. Using climate projections from an ensemble of 16 models, we conducted an assessment of a midcontinental area of North America (Minnesota) based on a resistance, resilience, and facilitation framework. We assessed likely impacts and proposed options for eight landscape regions within the planning area. Climate change projections suggest that by 2069, average annual temperatures will increase 3 °C with a slight increase in precipitation (6%). Analogous climate locales currently prevail 400–500 km SSW. Although the effects of climate change may be resisted through intensive management of invasive species, herbivores, and disturbance regimes, conservation practices need to shift to facilitation and resilience. Key resilience actions include providing buffers for small reserves, expanding reserves that lack adequate environmental heterogeneity, prioritizing protection of likely climate refuges, and managing forests for multi-species and multi-aged stands. Modifying restoration practices to rely on seeding (not plants), enlarge seed zones, and include common species from nearby southerly or drier locales is a logical low-risk facilitation strategy. Monitoring "trailing edge" populations of rare species should be a high conservation priority to support decision-making related to assisted colonization. Ecological assessments that consider resistance, resilience, and facilitation actions during scenario planning is a productive first step towards effective climate change planning for biodiversity with broad applicability to many regions of the world.

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1. Introduction

Climate change resulting from CO_2 emissions will continue over the next century regardless of the scope and magnitude of mitigation efforts (IPCC, 2007). The rapid rate of climate change, coupled with other anthropogenic stresses, will deplete species diversity in some regions if habitats become unsuitable and migration is insufficient. Although climate change predictions are derived from global models, strategies to minimize effects on biodiversity need to be formulated at local and regional scales to account for land-use differences, extent of natural ecosystems, and ecology of the indigenous flora and fauna. The adjustments humans make in response to climate change, or that natural systems make unassisted, has been called adaptation by IPCC (2001). Scenario planning will likely be a crucial tool for developing these climate adaptation strategies, given the high uncertainty of ecological responses to anticipated changes and the complexity of addressing multiple stressors (Peterson et al., 2003; Brooke, 2008). Scenarios are projections of plausible alternative futures for a specific purpose, developed deliberatively and based on a shared understanding of system dynamics and how actions may alter the future trajectory of ecosystems. The foundation for scenario planning is an assessment that identifies key drivers of system dynamics, uncertainties with potential to have large impacts, and external changes most likely to influence the system in the future (Peterson et al., 2003). The challenge of converting highly context- or case- specific research results into assessments has hindered the incorporation of ecological information into climate change adaptation conservation planning (Brooke, 2008).

Climate change adaptation conservation planning, using a variety of conservation tools, is underway for some countries (e.g., UK, South Africa, Australia), groups of countries (i.e., Small Island Developing States (SIDS), European Union (EU)), and states/provinces within countries (e.g., Queensland, Australia; Alaska and Florida, USA) (IPCC, 2002; Hannah et al., 2005; Ferris, 2006; Von Maltitz et al., 2006; Pew Center on Global Climate Change, 2007; QCCCE, 2008). Some of these efforts have identified key ecosystems

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or species likely to be most threatened by climate change and compare adaptation options, but most are more general; scoping impacts, identifying major barriers to action, and discussing key issues needed for decision-making. Even when highly vulnerable species and ecosystems have been identified, conservationists have been reluctant to commit to specific adaptation plans (Heller and Zavaleta, 2009). This reluctance often stems from a lack of climate change predictions for specific regions, uncertainty about how species will actually respond, and limited evidence that the proposed actions will have the desired effects. When these uncertainties are informally weighed against the risk of actions being counterproductive and the costs of implementation, plans stall (McLachlan et al., 2007). This inaction or "paralysis by analysis" is not new to conservation biology and is one of the primary reasons scenario planning has been used to approach other problems with high uncertainty and complexity (Peterson et al., 2003). Scenario planning has the advantage of explicitly incorporating different assumptions about specific policies and actions when envisioning alternative futures (Nassauer and Corry, 2004). Ecological assessments need to be developed that can effectively serve as a basis for scenario planning.

For over 20 years, challenges to sustaining species and ecosystem diversity in remnant natural areas generated key conservation planning principles that are relevant to the new challenge we face with climate change. As with traditional conservation planning, a "coarse-filter approach" of prioritizing reserve selection of communities and ecosystems will provide more efficiency than attempting to build scenarios for every vulnerable species (Hunter et al., 1988). Connecting these reserves with corridor systems, stepping stone reserves, and buffer zones will be crucial to allow species' ranges to adjust to new climatic conditions (Halpin, 1997). However, as predictions of warming have become increasingly dire, there is recognition that these planning frameworks need to be supplemented to facilitate regional planning under a greater array of environmental and socio-economic situations (Halpin, 1997; Heller and Zavaleta, 2009). Millar et al. (2007) identified three kinds of adaptation actions for forest ecosystems: defensive actions intended to resist the influence of climate change; practices aimed at promoting resilient ecosystem responses to climate change; and active involvement in facilitating change to ecosystems or particular species. Distinguishing between resistance, resilience and facilitation options during ecological assessments and scenario planning is important for two reasons. First, conservation actions reflect assumptions about species and ecosystem responses to climate change and so recognizing these options can help ecologists comprehensively assemble the information needed for assessments. Second, developing scenarios that variably depend on resistance, resilience and facilitation actions allow regional conservation planning teams to compare the feasibility, risks, and potential outcomes without needing to reach consensus on aspects of climate change that are too uncertain to resolve. The resistance/resilience/facilitation framework is potentially applicable to many kinds of ecosystems and regional landscape contexts, although this has not yet been applied to systems other than forests.

We used the state of Minnesota (USA) as a case study for regional climate change adaptation ecological assessments using the resistance/resilience/facilitation framework. At the convergence of three major biomes—boreal forest, hardwood forest, and Great Plains grasslands—Minnesota is a good test case for this framework and for regional adaptation planning in general. In addition, approximately 50% of Minnesota's landscape has been converted for agriculture, industry and urbanization, but the state has an extensive protected areas network (Fig. 1), ranging from the 400,000 ha Boundary Waters Canoe Wilderness Area to small (<10 ha) remnant grasslands and wetlands surrounded by agriculture. Specifically, our objectives were to: (1) develop climate projections for different regions of the state, (2) assess likely impacts to wetland, forest and prairie ecosystems, and (3) propose a range of key adaptation strategies for each region based on the resistance/resilience/facilitation framework. How Minnesota's conservation practices need to change so its protected areas network continues to support the state's biodiversity should provide insights for many other midcontinental locales. As importantly, we report this ecological assessment as an example of information assembly that would ideally be part of scenario planning for climate change adaptation.

2. Regional projected climate change

To initiate the ecological assessment for Minnesota, we created climate change projection maps using the LLNL-Reclamation-SCU downscaled climate projections derived from the World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset, stored and served at the LLNL Green Data Oasis (LLNL et al., 2008). These simulations use general circulation models (GCMs) produced for the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4), scaled to a finer resolution (i.e., "downscaled") using bias-correction to eliminate discrepancies between the GCM and historical observations, and spatial interpolations to merge course-resolution (2° grid squares, or approximately 200 km by 200 km) GCM values with observed spatial patterns at a 1/8° grid square resolution (approximately 12 by 12 km).

Using averaged results from a single run of all 16 models in the CMIP3 archive, we produced projections of changes in annual and summer temperature and precipitation for two time periods, 2030–2039, and 2060–2069, relative to a baseline period (1970–1999) (data from Maurer et al., 2002; cited in LLNL et al., 2008), for the A2 (upper mid-range) emissions scenario (IPCC, 2001). Model ensemble averages are viewed with greater confidence than individual climate models, because they neutralize extreme results for given regions, and illustrate agreed-upon trends.

Climate change projections were evaluated for eight landscape regions in Minnesota (Fig. 2). These regions were based on Minnesota's Ecological Classification System (MN DNR, 2003), Forest Resources Council Regional Landscape Classification (MFRC, 2008), and Wetland Ecological Units (MN DNR, 1997) so that they reflect major differences in landform and natural vegetation and generally follow political boundaries. For each region, the minimum and maximum average annual temperature and precipitation was determined for the recent past, 2030–2039, and 2060–2069. To estimate current analogs for future conditions, the four coordinate pairs for each region and time were located on maps showing isopleth lines for the US 1961–1990 average annual temperature and precipitation (Owenby et al., 1992). Average summer (June–August) temperature and precipitation were also calculated for each region and time. However, climate maps for summer averages were not available, so we plotted potential analog locations using maps for July averages (High Plains Regional Climate Center, 2008).

Changes in average annual temperature and precipitation by 2069 suggest a shift in regional climates equivalent to current conditions approximately 400–500 km SSW (Fig. 3). Average annual and summer temperatures are projected to increase 3 °C (Tables 1 and 2). Average annual precipitation is predicted to increase slightly (4.8–7.8%) over this interval, although average summer precipitation is expected to decrease slightly, up to 4%. These trends are consistent with other published projections, which suggest that analogs are likely to exist for Minnesota's future climates (Williams et al., 2007) in more southerly midwestern US states (Kling et al., 2003).

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