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Model-based scenario planning to develop climate change adaptation strategies for rare plant populations in grassland reserves

Laura Phillips-Mao [a,*], Susan M. Galatowitsch [a], Stephanie A. Snyder [b], Robert G. Haight [b]

[a] Department of Fisheries, Wildlife and Conservation Biology, University of Minnesota, 135 Skok Hall, 2003 Upper Buford Circle, Saint Paul, MN 55108, USA
[b] USDA Forest Service, Northern Research Station, 1992 Folwell Avenue, St. Paul, MN 55108, USA

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ABSTRACT

Incorporating climate change into conservation decision-making at site and population scales is challenging due to uncertainties associated with localized climate change impacts and population responses to multiple interacting impacts and adaptation strategies. We explore the use of spatially explicit population models to facilitate scenario analysis, a conservation planning approach for situations of high uncertainty. We developed dynamic, linked habitat suitability and metapopulation models using RAMAS GIS to consider management and monitoring options for a grassland reserve in Minnesota (USA) in order to support a hydrologically sensitive rare orchid (*Cypripedium candidum*). We evaluated 54 future scenarios combining changes in drought frequency, increased depth to water table, and multiple configurations of increased invasive species cover and management. Simulation results allowed us to prioritize adaptation strategies and monitoring guidelines to inform adaptive management for our model system. For example, preventing further spread of invasive species into the current *C. candidum* population is an important low-risk resilience strategy for this site. However, under more serious climate change scenarios, higher-risk strategies, such as protecting critical recharge areas, become essential. Additionally, allocating limited monitoring resources toward detecting changes in depth to water table and assessing *C. candidum* population responses to severe drought will more efficiently inform decisions about when to shift from low-risk resilience approaches to higher-risk resistance and facilitation strategies. Applying this scenario-based modeling approach to other high-priority populations will enable conservation decision-makers to develop sound, cost-effective, site-specific management and monitoring protocols despite the uncertainties of climate change.

1. Introduction

Climate change adaptation is an increasingly important component of conservation decision-making at multiple scales. Recently, adaptation has gained traction in conservation planning at national and regional scales (IPCC, 2014; Stein et al., 2013) in response to readily observed impacts, recognition of the inevitability of climate change regardless of mitigation efforts (Meehl et al., 2006), and growing awareness that existing reserves may fail to sustain vulnerable populations and plant communities into the future (Monzón et al., 2011). However, a significant gap remains between incorporating adaptation strategies into regional- and agency-level planning versus site-specific decision-making and implementation (Bierbaum et al., 2013). This gap is problematic because much of conservation decision-making necessarily occurs at the scale of individual sites and populations, whether it be land acquisition to protect and buffer conservation areas, vegetation management plans that address local threats, or monitoring programs to assess population viability and the need for possible rescue strategies (Loss et al., 2011; McLachlan et al., 2007). Research that increases understanding of how climate change impacts manifest at the site and population level is therefore important for facilitating conservation decision-making and prioritizing adaptation strategies across the full range of critical scales.

Greater availability of informational tools, resources, and frameworks for decision-making has helped overcome some of the previous barriers to incorporating climate change into conservation policy and practice. Downscaled climate projections and associated vulnerability assessments effectively inform regional planning by identifying risks to species and ecosystems (Galatowitsch et al., 2009; Groves et al., 2012; Hole et al., 2011; Williams et al., 2008). Additionally, decision-making frameworks such as scenario planning and structured decision-making can facilitate conservation planning in the face of uncertainty (Ogden and Innes, 2009; Peterson et al., 2003). However, incorporating climate change information into site-scale planning and management remains somewhat superficial, due – in part – to several key knowledge gaps: What localized impacts may result from the interaction of regional climate change with site features? What are the likely net effects of multiple interacting climate change impacts experienced by a given site or population? What adaptation strategies are likely to

* Corresponding author.
E-mail address: phil0308@umn.edu (L. Phillips-Mao).

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be most effective for a given site or population? And how (and when) can specific populations be expected to respond to climate change impacts and adaptation actions?

The question of localized climate change impacts has, thus far, received relatively little attention beyond the rather coarse bioclimatic envelope approach which can be used to explore potential ecological outcomes of regional climate change through comparison to a geographic analog (e.g. Galatowitsch et al., 2009, Hole et al., 2011). Truly localized impacts will result from the interaction between regional climate change and site features, such as topography, hydrology, and species composition. For example, regional climate change projections may indicate higher temperature and more variable precipitation, but resulting changes in soil water availability will depend on local features, including soil texture and drainage class, vegetative cover, topography and resulting hydrology (e.g. areas of recharge vs. discharge). Thus, on a site scale, climate change impacts may not manifest uniformly, and areas of currently suitable habitat for a given species may vary in their vulnerability to climate change. The ability to predict the most pressing local impacts, as well as identify both vulnerable habitat and potential on-site refuges, would not only enable more targeted management, but could also inform decisions about when – and where – to apply resistance, resilience or facilitation strategies (Galatowitsch et al., 2009).

Additionally, a given site or population will inevitably be affected by multiple climate change impacts, including chronic, long-term trends (e.g. increasing mean temperatures), changing frequencies in extreme climatic events (e.g. floods and drought; Easterling et al., 2000), as well as indirect effects of climate change (e.g. increasing rates of invasion by non-native species; Bradley et al., 2010; Diez et al., 2012). Effects of climatic “events” versus trends and indirect effects mediated through biotic interactions are particularly difficult to predict with precision (Jentsch et al., 2007; Staudinger et al., 2013), yet failing to account for these effects will yield an overly narrow – and likely overly optimistic – range of potential future scenarios. Simply understanding the response of species and communities to a single climate change parameter in isolation of others is likely insufficient, as combinations of impacts may either exacerbate (Bradley et al., 2010; Staudt et al., 2013; Zedler, 2009) or mitigate (Wyckoff and Bowers, 2010) the realized effects. Lacking data on such interactions, it can be difficult to prioritize which potential impacts to address. Managers may opt to focus on impacts they perceive to have the greatest certainty (e.g. model agreement on increasing temperatures), or simply continue existing “low-risk” resilience strategies. While these are not inherently unreasonable approaches, a failure to address the most damaging of impacts or to account for exacerbating interactions may lead to costly inefficiencies and a failure to sustain targeted populations (Staudt et al., 2013).

These knowledge gaps pose the greatest risk to conservation of rare and endangered species because their inherent vulnerability contributes to a greater risk of population decline in response to climate change and leaves little room for error in decision-making. Fine-resolution spatial variability in climate change impacts will be particularly important to rare and endangered plant species, which may occur in only a single location within a site and lack the capacity to disperse into future habitat refuges. Moreover, when the risk of extinction is already so high, precise estimates of sensitivities to interacting climate change impacts–– and management strategies – become critical. Unfortunately, while the pressing need for data on species' responses to climate change is well recognized (Staudinger et al., 2013), opportunities to experimentally test responses of rare and endangered species are quite limited. Difficult decisions, such as when to abandon conservative approaches (e.g. resilience strategies) in favor of high-risk, high-reward strategies like assisted migration, must therefore be made with little guiding information.

Models that incorporate high-resolution spatial data and multiple climate change impacts can play an important role in informing management decisions at the site and population scale by allowing us to explore population responses under multiple future scenarios, identify the most important impacts and interactions between multiple impacts, and make decisions about when to shift between different management strategies (e.g. resistance, resilience, and facilitation approaches). Others have effectively applied similar modeling approaches to conservation and restoration planning at broader regional scales (Bonebrake et al., 2014; Conlisk et al., 2014; Franklin et al., 2014; Lawrence et al., 2014), but applying this approach to the site-scale allows for an even greater degree of specificity, making it a valuable tool for informing and accelerating adaptive management. Richer model output resulting from more nuanced and high-resolution model scenarios could inform planning and evaluation stages of adaptive management by facilitating the prioritization of management strategies, focusing monitoring efforts, and allowing for earlier detection of responses to climate change and management, which may be especially critical for sustaining rare, endangered, and highly vulnerable populations. In turn, monitoring results can be used to refine model parameters and scenarios, resulting in increasing accuracy and relevance with future cycles of adaptive management.

Our objective for this research was to develop a model that incorporated interactions between multiple climate change impacts, management strategies, and site features in order to inform conservation management at the site scale. To this end, we developed dynamic, spatially-explicit, linked habitat suitability and metapopulation models (Akçakaya, 2000; Keith et al., 2008) for a rare orchid species of wet grasslands and fens, incorporating species population biology, fine-resolution spatial data, and future scenarios based on combinations of regional projected climate change impacts and invasion management outcomes. We aimed to directly inform adaptation strategies and monitoring protocols for vulnerable plant species of wet grasslands, while also investigating more broadly the importance of considering multiple impacts and site features in climate change impact studies.

Our model species, *Cypripedium candidum* Muhl. ex Willd. (small white lady's slipper), is a rare orchid occurring in wet prairies, meadows, and calcareous fens of eastern North America (Bowles, 1983). Populations have declined dramatically in response to wide-scale habitat loss and conversion, and it is currently listed as globally vulnerable by the IUCN Red List (Rankou, 2014), federally endangered in Canada (Species at Risk Act, 2002) and as endangered, threatened, rare or extirpated in most U.S. states within its range (Bowles, 1983; USDA NRCS, 2014a). *C. candidum* is potentially a high risk species with respect to climate change, as its wet prairie habitat and required hydrologic conditions are considered vulnerable to regional climate change impacts such as water table drawdowns and increased frequency of severe drought (Galatowitsch et al., 2009). Although its ability to withstand environmental stress via dormancy may provide some buffer against the effects of climate change (Shefferson et al., 2005), *C. candidum* is long-lived, slow to mature, and has low recruitment—species' traits that increase its likely vulnerability (Staudinger et al., 2013). Furthermore, because *C. candidum* tends to occur in isolated populations within a highly fragmented landscape, opportunities for dispersal to new sites and inter-population genetic exchange are minimal, which may limit its capacity to adapt to climate change. Given strong statewide and regional interest in developing conservation and monitoring programs for *C. candidum* (Anderson and Ruby, 2012; Minnesota Prairie Plan Working Group, 2011; MN DNR, 2014), and its likely sensitivity to localized climate change impacts, particularly as mediated through impacts on local groundwater (for which specific projects are rarely available), this orchid is a suitable model species for exploring the applications of linked habitat suitability and population models to site- and population-level adaptation planning.

2. Methods

2.1. Study site

We modeled *C. candidum* populations within Expandere Wildlife Management Area (WMA) in Cottonwood County, southern Minnesota