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Which tree species and biome types are most vulnerable to climate change in the US Northern Rocky Mountains?

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ABSTRACT

The goal of this study was to assess components of vulnerability of tree species and biome types to projected future climate within the Great Northern Landscape Conservation Cooperative (GNLCC) in the US Northern Rockies and the ecosystems surrounding Glacier and Yellowstone/Grand Teton National Parks. We drew on the results of five published studies and analyzed current and projected future climate suitability for 11 tree species and 8 biome types under two IPCC emissions scenarios. We assessed components of vulnerability based on four metrics of current and projected future climate suitability. Results for biome types indicated largely a shift from climates suitable for alpine and subalpine conifer to climates suitable for desert scrub and grassland types. Results from the four studies of tree species indicated substantial loss of area of climate suitability for the four subalpine species by 2100. This was especially true for Whitebark pine (*Pinus albicaulis*). Suitable climate for this species dropped from just over 20% of the study area in the reference period to 0.5–7.0% by 2070–2100 under the A2 scenario. The studies agreed in projecting expansion of climate suitability for some montane tree species but disagreed on expansion of climate suitability of west-side mesic tree species to eastside locations such as Yellowstone National park. Importantly, the rankings of tree species vulnerability were similar among studies, scenarios, and geographic areas and indicated highest vulnerability for Whitebark pine and Mountain hemlock (*Tsuga mertensiana*). The results should help federal managers in the GNLCC prioritize tree species for climate adaptation strategies. Moreover, our methods for using published data as a basis for climate vulnerability assessment can be applied within other LCCs across the US and other management units internationally.

1. Introduction

Federal land managers are increasingly concerned about how climate change affects natural resources and ecosystem services within their jurisdictions. The rates and ecological impacts of climate change over past decades are known to vary geographically across the United States (Karl et al., 2009). Climate warming and drying have been particularly pronounced within western states, resulting in increased frequency of severe fires, widespread forest pest outbreaks, and drought-induced forest mortality (Westerling et al., 2006; Allen et al., 2010). These factors in combination have led to large scale forest die-off especially in the southwestern deserts, the Rocky Mountains, and the Sierra Nevada (Breshears et al., 2005) and include keystone tree species such as Whitebark pine (*Pinus albicaulis*) (Logan et al., 2010) and Joshua tree (*Yucca brevifolia*) (Cole et al., 2011). In the coming decades, climate is expected to warm substantially across the western US, and is projected to expand the area suitable for some tree species but cause dramatic declines in climate suitability for other species (McKinney et al., 2011; Coops and Waring, 2011; Gray and Hamann, 2013; Bell et al., 2014). Understanding forest response to climate change within local and regional management jurisdictions is vital to designing locally relevant strategies to cope with pending changes.

Resource managers can best plan, orient research, and manage if they are able to anticipate which species and ecosystems are most vulnerable to possible future change (Colwell et al., 2012; Stein et al., 2014). Accordingly, the US Department of Interior (DOI) launched programs aimed at assessing and managing vulnerable species under climate change (U.S. Department of the Interior, 2009). Among these programs, Landscape Conservation Cooperatives (LCCs) aim to communicate climate science among federal agencies within ecologically similar regions and to devise adaptation strategies for best coping with projected future change. These efforts are guided by recently published conceptual

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frameworks for linking science and management for climate change adaptation (National Park Service, 2010). Glick et al. (2011) and Stein et al. (2014), for example, advocate that vulnerability assessments be done to determine which elements are most at risk so that management actions can be focused on these elements.

An increasing number of studies have projected the potential impacts of future climate change on plant species and communities. One approach, termed bioclimate envelope modeling, quantifies the climate conditions where a species is currently present and projects the locations of these climate conditions under future scenarios (Huntley et al., 1995; Guisan and Thuiller, 2005; Berry et al., 2002; Pearson and Dawson, 2003; Thomas et al., 2004; Thuiller et al., 2005; Beale et al., 2008; Loarie et al., 2008; Serra-Diaz et al., 2013). This approach describes the conditions under which populations of a species persist in the presence of other biota as well as climatic constraints. Possible future distributions are projected on the assumption that current envelopes reflect species' environmental preferences, which will be retained under climate change. While this approach does not necessarily predict where a species will occur in the future (Pearson and Dawson, 2003; Thomas et al., 2004), it does project one foundational filter of where a species could exist in the future: climate suitability (Thuiller et al., 2005; Serra-Diaz et al., 2013). Consequently, bioclimate envelope modeling approaches have been widely used to assess change in the location of suitable climates for species under future climate scenarios.

We suggest that published bioclimate envelope studies of vegetation can serve as valuable contributions to the climate vulnerability assessments envisioned for DOI lands (Whittington et al., 2014). These studies are often done across sub-continental or larger areas, spatial extents much larger than LCCs or individual management jurisdictions. By analyzing results of these studies for the geographic areas of interest to managers, local patterns in current and projected future climate suitability can be revealed and used to craft management-relevant vulnerability assessments.

Synthesis of published studies of vegetation response to climate change can provide information both on which plant species and communities may have high potential impact under climate change, and the level of uncertainty in projected impacts based on level of agreement among studies. Vulnerability under climate change has been quantified based on area of suitable habitat in the current period and projected contraction, expansion, or shift in location of suitable habitat under future climate projections (Thomas et al., 2004; Thuiller et al., 2005; Loarie et al., 2008). Distance from current to newly suitable habitats is also considered because the pace of climate change may be faster than rates of population expansion to newly suitable habitats (Clark et al., 2003; Iverson et al., 2004; Zhu et al., 2012). In addition to changes in climate suitability, vulnerability assessments sometimes also include demographic, life history, and genetic factors (Thomas et al., 2011; Fordham et al., 2012; Pearson et al., 2014; Rehfeldt et al., 2014). We suggest, however, that consideration of climate suitability is an appropriate starting point for climate adaptation planning because knowledge of climate suitability is a critical filter for deciding where to use management actions to protect, restore, or establish species populations under climate change.

An assessment of vulnerability of vegetation to climate change is especially needed in the northern Rocky Mountains of the US. This region is within the Great Northern LCC, one of the first LCCs funded and a leader in building capacity for climate adaptation planning (http://greatnorthernlcc.org/). The Northern Rockies include the largest wilderness ecosystems in the 48 contiguous states, largely within and surrounding the iconic national parks of Yellowstone and Glacier (Baron, 2002). The harsh continental and montane climate strongly limits many species and the sharp gradients in climate imposed by topographic variability makes these relationships complex. Climate warming has been relatively rapid in this region over the past century (Karl et al., 2009) and is thought to have contributed to forest pest outbreaks and forest mortality in subalpine species such as Whitebark pine (Logan et al., 2010). Land allocation across the region is a mix of private and public lands with various levels of management flexibility or constraint. While there are few restrictions on management treatments on most private lands, human intervention in the form of active management is either dissuaded or illegal in national parks, roadless areas, and wilderness areas and management strategies need to be designed accordingly. In recent years, various studies have projected vegetation response to possible future climate change across western North America (see Table 1 for references). These studies generally project reductions in climate suitability for subalpine forests and expansion of grassland and shrubland communities in the coming century. The results of these studies have not been analyzed, however, within administrative units such as the GNLCC within which collaborative interagency management is being organized.

The goal of this paper was to assess components of vulnerability of tree species and biome types to projected future climate within the GNLCC and the ecosystems surrounding Glacier and Yellowstone/Grand Teton National Parks based on climate suitability. We do so using the projections of published studies of vegetation climate suitability under climate change across western North America. The results are expected to be useful for climate vulnerability assessments that the National Park Service is initiating (Whittington et al., 2014) and provide guidance to federal managers who are beginning to gauge the effectiveness of current management approaches under future climate change (GYCC, 2011). Beyond relevance to the GNLCC, this paper provides methods for harnessing existing bioclimate envelope studies to assess vulnerability within other LCCs across the US and other management units internationally.

2. Methods

2.1. Overview

We selected studies for inclusion in this synthesis that had projected tree or biome response to IPCC climate scenarios (IPCC, 2001, 2007) in the western U.S. at a resolution of 5 km or finer using methods based on the climate characteristics of field samples of vegetation. Uncertainty in the projections of bioclimate envelope studies includes that due to assumptions about future climate (e.g. climate scenario), global climate models (GCMs) used to project the climate scenario, and methods used to develop the bioclimate envelop models. In analyzing the results of the selected studies, we controlled to the extent possible for climate scenario and GCMs used, thus focusing on the extent of agreement among study results despite differences in statistical methods among them. Three of the selected studies allowed us to report results separately for the IPCC SRES A2 scenario (relatively high greenhouse gas emissions) and the B1 scenario (lowest emissions). The studies differed in some extent in GCMs used. One study used a single GCM, three other studies reported either individual results for multiple GCMS or a consensus result among several GCMS. We summarized the projections for each study, scenario, and tree species or biome type in terms of modeled climate suitability during the current period and for three future periods to 2090. The results were used to rank the vulnerability of tree species to future climate change. The vulnerability ranking was done separately for the results of each study and then ranks were averaged among studies. This allowed us to evaluate the extent to which the vulnerability rankings were robust to the differences in GCMs