

# Relative vulnerability to climate change of trees in western North America

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**Abstract** Many recent changes in tree species distributions, mortality, and growth rates have been linked to changes in climate. Managing forests in the face of climate change will require a basic understanding of which tree species will be most vulnerable to climate change and in what ways they will be vulnerable. We assessed the relative vulnerability to climate change of 11 tree species in western North America using a multivariate approach to quantify elements of sensitivity to climate change, exposure to climate change, and the capacity to adapt to climate change. Our assessment was based on a combination of expert knowledge, published studies, and projected changes in climate. Of the 11 species, Garry oak (*Quercus garryana*) was determined to be the most vulnerable, largely because of its relatively high sensitivity. Garry oak occupies some of the driest low woodland and savanna sites from British Columbia to California and is highly dependent on disturbances, such as periodic, low intensity fire. Big leaf maple (*Acer macrophyllum*) was determined to be the least vulnerable, largely because of its adaptive capacity. Big leaf maple can reproduce quickly after disturbances and its seeds can disperse long distances potentially allowing it to move in response to a changing climate. Our analyses provide a framework for assessing vulnerability and for determining why some species will likely be more vulnerable than others. Such information will be critical as natural resource managers and conservation practitioners strive to address the impacts of climate change with limited funds.

## 1 Introduction

Managing forests in the face of climate change will require an understanding of which species will be most vulnerable to future climate change and what factors will lead to increased

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vulnerability or resilience. Vulnerability can be seen as being a function of sensitivity, exposure, and adaptive capacity (IPCC 2001, Turner et al. 2003, Schröter et al. 2005). The sensitivity of an individual species is generally characterized by its ability to withstand changes in climate and is largely a product of a species' natural history including life history traits, interspecific relationships, physiological factors, dependencies on sensitive habitats, and relationships with disturbance regimes. Exposure can be defined as the degree of climatic change or climate-induced change likely to be experienced by a species and is determined by the character, magnitude, rate, and variability of climate change (Dawson et al. 2011). Estimates of potential future exposure can be derived from projected changes in climate and climate-driven changes in fire regimes, hydrology, invasive species, and land–use. Although initial definitions of vulnerability considered adaptive capacity in terms of human-related responses, we recognize a variation of this definition that characterizes adaptive capacity as the ability of a species to cope with climate change by persisting in situ or moving to more suitable locations (Dawson et al. 2011). This ability to respond physiologically or behaviorally to the effects of climate change is influenced by both intrinsic and extrinsic factors such as: reproductive strategy, genetic variability, phenotypic plasticity, dispersal distance and barriers, and landscape permeability (how easy it is to move through the landscape in question). Several of these factors could also be used to describe the acclimation of species to climate change.

Using sensitivity, exposure, and adaptive capacity, vulnerability assessments can identify 1) which species are most vulnerable, 2) why those species are vulnerable, and 3) which factors can potentially be leveraged to reduce vulnerability (Williams et al. 2008, Foden et al. 2013). Several recent studies have assessed vulnerability to climate–change for trees species (e.g., Coops and Waring 2011, Devine et al. 2012, Booth 2013, Vieilledent et al. 2013). However, these studies have focused largely only the most common and economically important species and most have assessed one or two components of vulnerability, but not all three—sensitivity, exposure, and adaptive capacity.

Here, we assess the vulnerability to climate change of 11 ecologically diverse tree species in western North America. We conducted a series of workshops throughout the region to synthesize knowledge and insight on species' sensitivities and adaptive capacities from experts and groups of experts. Combining this information with climate-change projections and information gleaned from the literature, we assessed vulnerability using a four–step approach. First, we compiled expert knowledge of the 11 tree species to produce estimates of the sensitivity of each. Second, we assessed potential exposure by quantifying the magnitude of climate change projected across the range of each species. Third, we assessed each species' adaptive capacity using information on species' reproductive strategies, dispersal abilities, and climatic breadths derived from the literature and expert knowledge. Finally, we quantified the multivariate dissimilarity between each species and a reference species with low vulnerability to assess relative vulnerability.

## 2 Methods

### 2.1 Tree species

We assessed the vulnerability to climate change of 11 tree species in western North America: Pacific silver fir (*Abies amabilis*), grand fir (*Abies grandis*), noble fir (*Abies procera*), big leaf maple (*Acer macrophyllum*), subalpine larch (*Larix lyallii*), western larch (*Larix occidentalis*),

whitebark pine (*Pinus albicaulis*), western white pine (*Pinus monticola*), Garry oak (*Quercus garryana*), Pacific yew (*Taxus brevifolia*), and western redcedar (*Thuja plicata*). We chose these species based on input from 10 regional natural resource managers who requested that we focus on a diverse set of regional tree species that are ecologically and economically important but less well-studied and that represent a wide range of life–history traits, climate sensitivities, and adaptive capacities.

## 2.2 Experts and working groups

We identified approximately 50 individuals as being experts on the 11 tree species and invited them to participate in five workshops (held between 2011 and 2012) or to work independently to record information about relative sensitivity and adaptive capacity of the species. Workshops were focused on assessing sensitivity and adaptive capacity and we did not present climate change projections. Experts had a diversity of backgrounds and experience but all held advanced graduate degrees in ecology, forestry, and/or biology. Experts were selected based on their experience and were employed by U.S. Forest Service, U.S. National Park Service, University of Washington, Washington Department of Natural Resources, and a number of regional tribes. In some cases, we approached higher-level managers in the agencies and they identified the experts for us.

The goal of expert workshops was to identify the sensitivity of species to climate change by going through a series of questions related to each of the sensitivity factors below, details of which can be found online (Case et al. 2015). To counter some of the inherent biases of expert judgment, we formalized our workshop procedure by employing an expert-elicitation approach (Martin et al. 2012). To demonstrate the use of the database and calibrate the expert scoring system, we required everyone to work methodically through one of the predetermined species. Collecting information on the sensitivity of species in such a way also creates more consistency and transparency with the use of expert opinion. In all workshops, there were a number of relevant questions that spurred further discussion and therefore this portion took about 2 hours to complete. The procedure of working through an example species as a group provided the experts with training on assessing sensitivity as well as an opportunity to ask questions and get clarification, and ensured that participants were interpreting the questions in the same way. After the example species was completed, experts either broke into groups or worked independently to assess the sensitivity of additional species. In some cases, individual experts were invited to work independently to assess the sensitivity of species and relied heavily on scientific literature. However, these individuals were also trained and calibrated to assess sensitivity by working through an example species.

For each of the sensitivity factors listed below, experts provided both a sensitivity score ranging from one (low sensitivity) to seven (high sensitivity) and a confidence score ranging from one (low confidence) to five (high confidence). Although we explored qualitative assessments earlier in the project, these scales were identified as being relevant and appropriate by experts. Individual scores were averaged when more than one expert assessed a species. In the case of conflicting reference materials or opinions, experts were asked to apply their knowledge and seek resolution, which all did, eventually. Experts also provided additional information, including more detailed comments as to why a species might be more or less sensitive and citations when applicable.

## 2.3 Sensitivity

We assessed six aspects of sensitivity: 1) the degree to which the species is a generalist or specialist, 2) how physiologically sensitive the species is to changes in temperature, precipitation and carbon dioxide, 3) whether the species depends on sensitive habitats, 4) dependence on disturbance regimes, 5) climate-dependent ecological relationships, and 6) interacting non-climatic stressors (see Supplementary Material (SM) Table S-1). After these sensitivity factors were assessed, we calculated an overall climate change sensitivity score based on the Euclidean distance between the sensitivity scores for each species and a hypothetical reference species with low sensitivity. This hypothetical reference species had very low sensitivity scores for each of the six sensitivity factors – each factor was given a score of 1, thereby making it less sensitive than any of the species in the data set. The hypothetical reference species represents a species that was a generalist, was not physiologically sensitive to changes in temperature, precipitation, or carbon dioxide, did not depend on sensitive habitats, was not dependent on disturbance regimes, did not have climate-dependent ecological relationships, and had little to no relationships with interacting non-climatic stressors.

This type of analysis – measuring the multivariate distance between a given observation and a hypothetical reference observation – has been used in other regional vulnerability assessments and has been shown to provide unique results compared to other assessment techniques and account for the covariance substructure of the data (Smith et al. 2003). We used a hypothetical reference species with low scores because we wanted high sensitivity scores (larger Euclidean distances) to represent higher levels of sensitivity, which would correspond to higher vulnerability. Because different approaches to combining diverse metrics into a single measure often produce different results and can be more or less sensitive to changes in the inputs, we conducted a sensitivity analysis on our multivariate measure of sensitivity (SM).

## 2.4 Exposure

We assessed exposure by quantifying the magnitude of change in multivariate climate space between historical climatic conditions and an ensemble of projected future climates across a species' current geographic range. Species' distributions were derived from digital representations of species range maps (USGS 1999). We used ClimateWNA to downscale historical data and future climate projections to a 1-km<sup>2</sup> grid. ClimateWNA is a program that generates both directly calculated and derived climate variables for specific locations across western North America (Wang et al. 2012) using Parameter–elevation Regressions on Independent Slopes Model (PRISM, Daly et al. 2002) and ANUSPLIN. ANUSPLIN is a smoothing approach that interpolates multi–point and multivariate data using thin plate smoothing splines (Hutchinson 1989). We generated values for mean annual, seasonal, and monthly climate for the period of 1961 to 1990.

We used climate projections from the IPCC Fourth Assessment Report run for the SRES A2 greenhouse–gas emissions scenario. The A2 emissions scenario represents a world with increasing population growth, regionally oriented economic development, slower development, and implementation of new technologies (Nakicenovic and Swart 2000). We used projections from each of the five following general circulation models (GCMs) averaged over the years 2070 to 2099: BCCR-BCM2.0, CCCma-CGCM3.1, CSIRO-MK3.0, INM-CM3.0, and MIROC-3.2MEDRES (IPCC 2007).

We chose 11 climate variables to represent exposure: mean annual temperature, mean temperature during the warmest month, mean temperature during the coldest month, the difference in temperature between the warmest and the coldest month, mean maximum temperature during spring, mean maximum temperature during winter, precipitation falling as snow, mean total precipitation for the driest month, mean total precipitation during the wettest month, mean total precipitation during autumn, and Hargreaves climatic moisture deficit. These variables represent the spatial variability of climate across the study area and are biologically important controls of tree growth (McKenzie et al. 2003). We normalized each climate variable by subtracting the mean and dividing by the standard deviation from both the historical and future climate datasets. This was done to ensure that all variables would be equally weighted and so that future climate–change trends would be emphasized over historical inter–annual climate variability (Williams et al. 2007).

We calculated the Euclidean distance between historical climate and each of the five future climate projections for each grid cell and all 11 climate variables. We then averaged these Euclidean distance values in each cell and calculated the mean value of all cells across an individual species' distribution. Because we did not apply sensitivity and adaptive capacity spatially across individual species' distributions, we represented exposure with one number for each species (i.e., the mean of the Euclidean distance of all grid cells across the species' distribution). We calculated an overall exposure score using the Euclidean distance between the mean Euclidean distance scores for each species and a hypothetical low Euclidean distance reference score of 0.1. We used a reference score of 0.1 because it is less than the calculated Euclidean distance scores between historical climate and each of the five future climate projections for the 11 climate variables (see Figure S-1). We also calculated the exposure score using Euclidean distance to be consistent with the sensitivity score. And, again, we chose a low reference score so that our metric of exposure would increase with increasing exposure, which would correspond to increasing vulnerability.

## 2.5 Adaptive capacity

To quantify adaptive capacity for each tree species, we assessed reproductive strategy, dispersal ability, and climatic breadth. We included reproductive strategy as an aspect of adaptive capacity because species that can recover from low numbers rapidly are more likely to be able to withstand rapidly changing climates (Pianka 1970). Rapid population growth can also help maintain genetic variability in some populations (Lande 1988). These same species may also be able to colonize new suitable locations following climatic change. We included dispersal ability as a factor of adaptive capacity because species that are poor dispersers will be less likely to be able to move from areas that climate change renders unsuitable or into areas that become newly climatically suitable. We defined dispersal ability as a function of maximum annual dispersal distance and the relative influence of dispersal barriers. Barriers, such as mountains, arid lands, clearcuts, and agriculture, will reduce the ability of some tree species to disperse. Reproductive strategies and dispersal abilities were quantified and separately ranked on a scale of one (high reproductive strategy and dispersal ability greater than 100 km) to seven (low reproductive strategy and dispersal ability of less than 1 km) by experts for each of the 11 tree species. As with sensitivity, the experts quantified these scores and more detailed information, including references. We assessed climatic breadth as the range of climates that each species occupies. Species that occupy a wider range of climates are likely to be able to better adapt to climate change as they are likely to either have relatively high levels of

phenotypic plasticity or they have relatively high genetic diversity (Brown 1995). We used the USGS Climate-Vegetation Atlas of North America (Thompson et al. 1999) to estimate the climatic breadth of each of the 11 species (SM).

We calculated an overall adaptive capacity score using the Euclidean distance between the adaptive capacity scores for each species and a hypothetical reference species with high adaptive capacity. This hypothetical reference species had scores of 1 for reproductive strategy and dispersal ability and a score of 8 for climatic breadth (which is the largest score possible), representing a species that is able to quickly reproduce, disperse long distances, and that occupies a large range of climates. We chose to use a reference species with high adaptive capacity so that larger Euclidean distances corresponded with low adaptive capacity, which would lead to higher vulnerability. Again, we conducted a sensitivity analysis to investigate the effects of removing each of the three adaptive capacity factors.

## 2.6 Calculating vulnerability

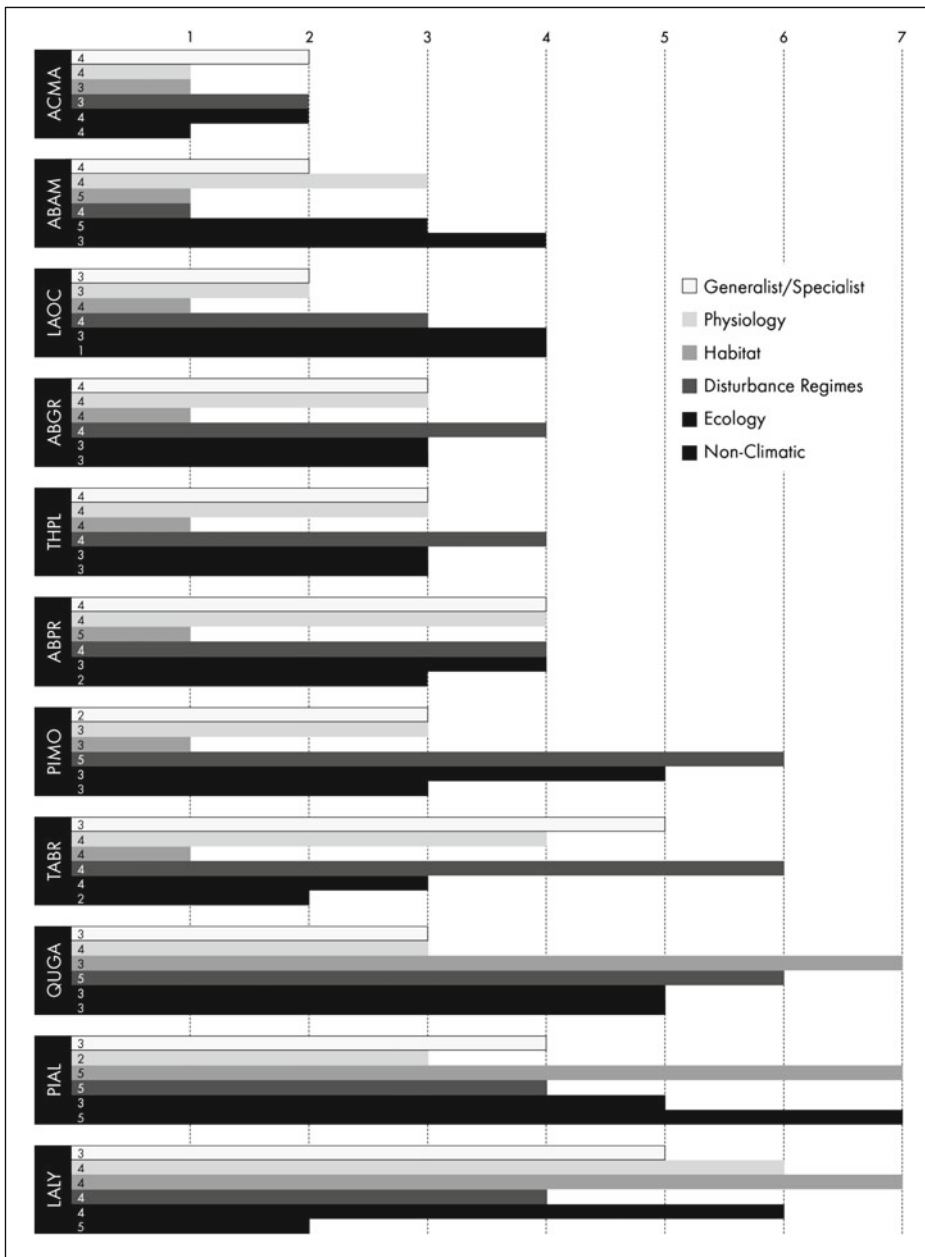
To quantify vulnerability, we calculated the Euclidean distance between the scores for sensitivity, exposure, and adaptive capacity for each species and a hypothetical reference species with low vulnerability. We chose to use a reference species that accentuated the differences between the 11 species and a species that would not be much affected by climate change – that is a species with low sensitivity, low amounts of expected exposure, and a strong ability to adapt. Our hypothetical reference species had scores of 1 for sensitivity (low sensitivity), 0.1 for exposure (low exposure), and 1 for adaptive capacity (high adaptive capacity). We explored the sensitivity of our results to the factors included in our vulnerability calculation by systematically removing each of the three vulnerability components and recalculated the Euclidean distance score for each species. We also explored two alternative approaches for combining the three vulnerability components (SM).

## 3 Results

### 3.1 Sensitivity

The 11 species varied greatly in the degree to which they were expected to be sensitive to climate change (Fig. 1). Big leaf maple was deemed to be the least sensitive, with scores of two or less across all six of the sensitivity factors. Subalpine larch, whitebark pine, and Garry oak, on the other hand, were determined to be highly sensitive to climate change. All three species were identified as being dependent on one or more sensitive habitats and as having ecological relationships that are sensitive to climate change, however, their sensitivities to the other factors differed. Subalpine larch was identified as being highly physiologically sensitive to changes in temperature, whereas Garry oak was seen to be highly sensitive to changes in disturbance regimes. Whitebark pine had the highest sensitivity to interacting non-climatic stressors.

The confidence that the experts put in their sensitivity assessments varied both by species and by sensitivity factor (Fig. 1). Their estimates of sensitivity for individual factors for a given species ranged from a low of one, for interacting non-climatic stressors for western larch to a high of five for four of the six different factors across the 11 species. The average confidence score across all species was four. Confidence was greatest on whether a species was dependent



**Fig. 1** Climate change sensitivity factors and confidence scores for 11 tree species. Confidence scores are numeric scores embedded on the left side of each horizontal bar and were assessed on a scale from one (low confidence) to five (high confidence). Sensitivity scores, represented by horizontal bars, were assessed on a scale from one (low relative sensitivity) to seven (high relative sensitivity). Overall sensitivity scores are summarized in Table 1 (A). Tree species codes are: ABAM – Pacific silver fir (*Abies amabilis*), ABGR – grand fir (*Abies grandis*), ABPR – noble fir (*Abies procera*), ACMA – big leaf maple (*Acer macrophylla*), LALY – subalpine larch (*Larix lyallii*), LAOC – western larch (*Larix occidentalis*), PIAL – whitebark pine (*Pinus albicaulis*), PIMO – western white pine (*Pinus monticola*), QUGA – Garry oak (*Quercus garryana*), TABR – Pacific yew (*Taxus brevifolia*), and THPL – western redcedar (*Thuja plicata*)



on disturbance regimes and lowest on whether there were interacting non-climatic stressors. Interacting non-climatic stressors also had the largest variance in confidence scores. Experts were most confident in the sensitivity scores for Pacific silver fir and least confident for western larch.

The overall ranking of sensitivity scores, as calculated by Euclidean distance, was relatively resilient to minor changes in which sensitivity factors were included. We found that removing any one of the six sensitivity factors produced relatively little change in the sensitivity rankings (Table S-2). We also calculated sensitivity with an additive algorithm, which resulted in a slight change in the ranking of some species; however, the ranking of the three most and three least sensitive species was unaffected (Table S-2).

### 3.2 Exposure

Among the 11 species, western larch and Pacific silver fir are projected to experience the most climatic change across their distributions followed by noble fir (Figure S-1). These relatively high exposure scores are largely explained by the substantial projected decrease in precipitation that falls as snow, changes in precipitation during the driest and wettest months, and an increase in the mean temperature of the warmest month (Table S-3). These species also have large proportions of their distributions in the Cascade Mountains in Washington and Oregon, areas projected to lose a substantial amount of snow pack in the future.

### 3.3 Adaptive capacity

Garry oak, subalpine larch, whitebark pine, and noble fir had the lowest adaptive capacity scores among the 11 species. Garry oak and whitebark pine were determined to have very limited dispersal abilities, in part because of barriers to dispersal. Garry oak was identified as being limited by land-use change, whereas whitebark pine was identified as being limited by mountains. Garry oak was also determined to have a relatively short maximum annual dispersal distance and a limited reproductive strategy. Noble fir and subalpine larch were determined to have low adaptive capacity scores largely because of their narrow climatic breadths.

The overall ranking of adaptive capacity scores was moderately sensitive to changes in which of the three adaptive capacity factors are included. Although the rankings did change somewhat (Table S-4), the species with the most and least adaptive capacity generally retained their rankings when individual factors were removed. Adaptive capacity scores calculated using an additive algorithm result in similar ranking as the multivariate analysis, with most of the changes occurring within the intermediately-ranked species (Table S-4).

### 3.4 Relative vulnerability

Of the 11 tree species analyzed, Garry oak, subalpine larch, and whitebark pine were determined to be the most vulnerable to climate change (Table 1). Their vulnerability stems from their relatively high sensitivity and their relatively low adaptive capacity. By contrast, big leaf maple was determined to be the least vulnerable due to a relatively low sensitivity to climate change and relatively high adaptive capacity. This relatively low vulnerability is anticipated despite the fact that big leaf maple was also projected to experience a relatively moderate to high degree of climate change.



The multivariate vulnerability analysis was moderately sensitive to changes in which of the three vulnerability components were included. The vulnerability rankings changed only slightly when exposure or adaptive capacity scores were excluded but changed more when sensitivity scores were excluded (Table S-5). Combining the three components of vulnerability additively or multiplicatively produced similar rankings as did the multivariate analysis with slight changes in the middle-ranked species (Table S-5).

## 4 Discussion

Our results highlight just how variable species' vulnerabilities to climate change are likely to be. Granted, the 11 species in our study were chosen in part because they likely spanned a range of sensitivities and adaptive capacities, but nonetheless, they demonstrate a striking range of vulnerability. Understanding this variability, and particularly which species are likely to be more and less vulnerable, will be an essential first step in developing climate adaptation strategies and management actions to address climate change (Stein et al. 2014). In addition to resulting in a ranking, vulnerability assessments, like the one presented here, have the potential

**Table 1** Euclidean distance scores of sensitivity, exposure, adaptive capacity, and vulnerability for 11 tree species in western North America

Species	Common name	Species code	A) Sensitivity Euclidean distance score	B) Exposure Euclidean distance score	C) Adaptive capacity Euclidean distance score	D) Vulnerability Euclidean distance score
<i>Quercus garryana</i>	Garry oak	QUGA	10.0	0.46	7.7	11.3
<i>Larix lyallii</i>	Subalpine larch	LALY	10.6	0.47	6.8	11.2
<i>Pinus albicaulis</i>	Whitebark pine	PIAL	10.5	0.44	6.5	11.0
<i>Abies procera</i>	Noble fir	ABPR	7.4	0.72	6.5	8.5
<i>Taxus brevifolia</i>	Pacific yew	TABR	7.3	0.66	6.1	8.1
<i>Pinus monticola</i>	Western white pine	PIMO	6.3	0.56	5.3	6.8
<i>Abies grandis</i>	Grand fir	ABGR	5.0	0.49	5.6	6.1
<i>Thuja plicata</i>	Western redcedar	THPL	5.0	0.61	5.1	5.8
<i>Abies amabilis</i>	Pacific silver fir	ABAM	4.2	0.86	5.6	5.7
<i>Larix occidentalis</i>	Western larch	LAOC	4.2	0.86	5.6	5.7
<i>Acer macrophylla</i>	Big leaf maple	ACMA	1.7	0.69	2.6	1.9

Euclidean distance scores were calculated between each species and a reference species with 1) low sensitivity, 2) low exposure, 3) high adaptive capacity, and 4) low vulnerability. Larger scores represent 1) higher sensitivity, 2) higher exposure, 3) lower adaptive capacity, and 4) higher vulnerability

to provide information about why species are more or less vulnerable to climate change and thus to inform the development of species-specific adaptation strategies (Glick et al. 2011).

Our results identified three highly vulnerable tree species—Garry oak, subalpine larch, and whitebark pine. There are a number of potential actions that can be taken in response to these vulnerabilities and they are largely dependent on management objectives, organizational capacity, and spatial and temporal scales (Peterson et al. 2011). In general, these adaptation strategies can include increasing the resistance and resilience of species and response options (Millar et al. 2007). For instance, recent warming and earlier spring snowmelt have led to more frequent large wildfires and longer wildfire seasons (Westerling et al. 2006), a trend that is projected to continue into the future (Littell et al. 2010, Westerling et al. 2011). In response, managers could apply silvicultural treatments to thin forests and reduce fire intensity, establish fire fuel breaks to protect high-value forest stands, or use prescribed burning to lower fuel loads (Spittlehouse and Stewart 2003, Millar et al. 2007, Stephens et al. 2012).

Following disturbances, managers have a number of possible options, such as facilitating a change in species composition. This can be accomplished by identifying and planting more resilient genotypes of a species (e.g., a more drought tolerant genotype) or perhaps even planting a different species. Assisted colonization, also referred to as managed relocation or assisted migration, is becoming an increasingly accepted adaptation strategy in response to climate change (Lawler and Olden 2011). Some are already experimenting with assisted migration of tree species in some areas of North America (Schmidting 2001, Erickson et al. 2012, Marris 2009), a trend that may increase in fragmented landscapes and with species that have limited dispersal abilities (Williams and Dumroese 2013). Some species may also have an intrinsic ability to tolerate climatic conditions that are different from those within their natural distributions (Booth et al. 2015).

There are uncertainties in any assessment of vulnerability to climate change. We used a variety of information in our assessment and each component has its own associated uncertainty. For example, expert knowledge can be susceptible to biases due to personal experiences and attitudes (Shrader-Frechette 1996, Camerer and Johnson 1997, Ludwig et al. 2001, Campbell 2002). However, capturing the confidence scores and following a formalized process of acquiring expert knowledge helps counter some of these biases. There are also known uncertainties in climate change projections. Here we present exposure estimates that are based on the average exposure as projected by five different GCMs run for a single greenhouse gas emissions scenario. We explored how exposure would vary if we used the minimum and maximum estimates of exposure resulting from the five GCM models and found that although the total exposure varied from one GCM model to another, the overall exposure ranking between species remained similar. We did not explore the impact of using climate-change projections that were based on different emissions scenarios. Although doing so would have altered our vulnerability scores, it is unlikely that using projections based on a different emissions scenario would alter the relative exposure of the different species.

Although we explored some of the ways in which our results are likely to be sensitive to methodological choices, there are other ways in which our choice of methods could have affected our results. For example, our approach of combining individual sensitivity, exposure, or adaptive capacity factors may obscure high individual scores when all other scores are low. It is possible that one high factor could greatly influence vulnerability. One way to correct for this is to replace the existing multivariate analysis with a rule-based index that assigns a high

score when certain conditions are met. In addition, we used 11 biologically important climate variables to calculate exposure for one future time period. Alternative variables, time periods, and climate models may lead to different exposure estimates. Although we weighted factors equally, we recognize that some variables may be more important than others and that the importance could vary over time and across species. Finally, there are other approaches to assess climate change vulnerability and potential adaptability, such as using sophisticated, process-based models, however many of these require detailed physiological or demographic data.

Climate change presents a particularly difficult challenge for natural resource managers who will need to make decisions about which species should receive the benefits of limited funding. Vulnerability assessments, such as the one demonstrated here, are one of the tools that resource managers have at their disposal to better prepare for this uncertain future. Our approach, of quantifying inherent sensitivity, projected climatic changes, and adaptive capacity can facilitate, not only the identification of species that are relatively more vulnerable, but it can also identify the key aspects of vulnerability, which if addressed, could promote resilience in the face of climate change.

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