Forest Ecology and Management 399 (2017) 132–142

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Recent and future climate suitability for whitebark pine mortality from mountain pine beetles varies across the western US

Polly C. Buotte [a,b,*], Jeffrey A. Hicke [b], Haiganoush K. Preisler [c], John T. Abatzoglou [b], Kenneth F. Raffa [d], Jesse A. Logan [e]

[a] Environmental Science Program, University of Idaho, Moscow, ID 83844, United States
[b] Department of Geography, University of Idaho, Moscow, ID 83844, United States
[c] Pacific Southwest Research Station, USDA Forest Service, Albany, CA 94710, United States
[d] Department of Entomology, University of Wisconsin, Madison, WI 53706, United States
[e] USDA Forest Service (retired), Emigrant, MT 59027, United States

ARTICLE INFO

Article history:
Received 1 March 2017
Received in revised form 16 May 2017
Accepted 19 May 2017

Keywords:
Whitebark pine (*Pinus albicaulis*)
Mountain pine beetle (*Dendroctonus ponderosae*)
Climate suitability

ABSTRACT

Recent mountain pine beetle outbreaks in whitebark pine forests have been extensive and severe. Understanding the climate influences on these outbreaks is essential for developing management plans that account for potential future mountain pine beetle outbreaks, among other threats, and informing listing decisions under the Endangered Species Act. Prior research has focused on one geographic region, but geographic variability in beetle and tree physiological responses to climate conditions have been documented. Here we evaluate geographic variability in climate influences on recent beetle outbreaks in whitebark pine and estimate future climate suitability for outbreaks across much of the range of whitebark pine in the western US. To accomplish these objectives, we developed and analyzed statistical models for three different geographic regions as well as a Westwide model, then applied the Westwide model to a suite of climate projections. The general patterns of climate-tree mortality relationships were similar across the three regions of our study. However, the relative importance of individual climate metrics preceding and during the recent outbreaks varied geographically because of the different climates in the regions. Winter minimum temperatures appeared to be limiting prior to outbreaks in the colder regions. All regions experienced low summer precipitation prior to or during outbreak initiation. Future climate suitability for beetle outbreaks is estimated to increase or remain stable in the coldest regions and decline slightly in the warmest region by the end of this century. Across the study area, projections of higher winter temperatures and decreased summer precipitation (with lower confidence than for temperatures) contribute to increased climate suitability for outbreaks, while projected higher fall/spring/summer temperatures contribute to decreased suitability. Some regional variability exists; in particular, the effect of winter warming is muted in the warmest region (Cascades) where winter temperatures appear to be less limiting. However, all regions are projected to experience fewer years with very low suitability, which commonly occurred prior to the recent outbreaks and may have limited beetle populations. Given the inherent uncertainty in climate projections and ecological responses to novel climates, management plans that incorporate sites that are expected to experience a range of expected future climate conditions might increase the chances of whitebark pine persistence in a warmer future.

1. Introduction

Understanding changing disturbance regimes is important for developing a portfolio of management tactics to reduce the impacts of disturbances (Turner, 2010). Expansions in the geographic range of mountain pine beetle (*Dendroctonus ponderosae*) outbreaks (Carroll et al., 2004; Logan et al., 2010) indicate that disturbance regimes due to tree mortality from mountain pine beetle attack are changing. Climate change is likely to have an important influence on mountain pine beetle outbreaks (Bentz et al., 2010; Logan et al., 2010; Buotte et al., 2016), as it has in other instances of tree mortality documented globally (Allen et al., 2010), such as piñon pine dieoff in the southwestern US in the early 2000s (Breshears et al., 2005). Therefore, understanding climate influences on future mountain pine beetle outbreaks is one prerequisite

* Corresponding author.
E-mail address: pcbuotte@gmail.com (P.C. Buotte).

http://dx.doi.org/10.1016/j.foreco.2017.05.032
0378-1127/

for developing comprehensive forest management plans in areas with the potential for beetle outbreaks.

Historically, mountain pine beetle outbreaks affected limited areas of whitebark pine (*Pinus albicaulis*) forest, and for limited periods (Perkins and Swetnam, 1996; Logan et al., 2010), because temperatures were typically too low to allow successful mountain pine beetle development and survival (Amman, 1973). Accordingly, whitebark pine management plans have been primarily focused on mitigating the effects of fire exclusion and infection from white pine blister rust (*Cronartium ribicola*) (Keane et al., 2012). Recent beetle outbreaks, however, have been severe and extensive (Logan and Powell, 2001; Meddens et al., 2012; Macfarlane et al., 2013), and are a contributing reason whitebark pine has been listed as warranting Endangered Species protection by the US Fish and Wildlife Service (USFWS, 2011). Understanding climate influences on beetle outbreaks in whitebark pine is therefore crucial for developing rangewide management plans and informing future Endangered Species Act listing decisions for whitebark pine.

Previous research has provided a strong understanding of climate influences on mountain pine beetle outbreaks in their primary host, lodgepole pine (*Pinus contorta*) (for reviews, see Raffa et al., 2008; Bentz et al., 2009, 2010). The limited research on climate drivers of outbreaks in whitebark pine forests indicates that the risk of mountain pine beetle attack is linked to higher temperatures (Logan et al., 2010; Buotte et al., 2016) and lower summer precipitation (Buotte et al., 2016). Past studies of mountain pine beetle outbreaks in whitebark pine have primarily focused on one geographic region, the Greater Yellowstone Ecosystem (Perkins and Roberts, 2003; Logan et al., 2010; Jewett et al., 2011; Buotte et al., 2016). However, substantial outbreaks have occurred outside this region: during 1997–2009, over 6000 km^2 of mortality occurred across the range of whitebark pine in the western US (Meddens et al., 2012).

Previous research in lodgepole pine systems indicates beetles' physiological responses to climate influences can vary geographically (Bentz et al., 2001, 2011, 2014; Weed et al., 2015). Beetle development rates are adapted to the local temperature regimes they experience (Bentz et al., 2001), and the importance of temperature to beetle-caused tree mortality can vary across geographic regions (Weed et al., 2015). Field measurements (Bentz et al., 2014) have shown that although the number of days required to complete a life cycle are similar, the thermal units required varies across latitudinal and elevational gradients.

Temperate forest tree species (Breda et al., 2006; Littell et al., 2008), including conifers (Graumlich and Brubaker, 1995; Littell et al., 2008), are also adapted to their local climate conditions. Whitebark pines exhibit genetic variation in their growth response to temperature (Millar et al., 2012) and cold-hardiness (Keane et al., 2012). Taken together, this previous research suggests the potential for geographic variability in climate influences on whitebark pine mortality from mountain pine beetle colonization.

Our objectives were to assess geographic variability in climate influences on whitebark pine mortality from mountain pine beetles across much of the western US by (1) evaluating the potential for geographic variability in climate-whitebark pine mortality relationships; (2) comparing climate influences on the recent beetle outbreaks; and (3) estimating future climate suitability for whitebark pine mortality from mountain pine beetles. To understand climate influences on whitebark pine mortality, we developed statistical models of whitebark pine mortality from mountain pine beetles with and without geographically variable effects of climate. We then applied our model without geographically variable effects of climate (Westwide model, see results) to 1979–2009 climate data to assess climate influences on the recent beetle outbreaks, and to climate projections to estimate future climate suitability for whitebark pine mortality from mountain pine beetles.

2. Methods

Our study area covered the range of whitebark pine in the US outside of California and Nevada (Fig. 1). Given variability in seasonal temperatures and precipitation across this range (Fig. S1), we divided the study area into three geographic regions: the Greater Yellowstone Ecosystem (GYE), Northern Rockies (NR), and Cascades (Fig. 1), generally following Level III ecoregion classifications of the Environmental Protection Agency (Omernick, 2004) which are defined based on similar areas of climate and vegetation type. Due to a lack of whitebark pine mortality data, we did not include locations in California and Nevada.

2.1. Input data

We assigned the presence of whitebark pine mortality from mountain pine beetles based on US Forest Service Aerial Detection Survey (ADS) data (USDA Forest Service, 2000) covering our study area. During surveys, observers in aircraft record tree mortality by host and mortality agent. These data were gridded to a 1-km resolution (Meddens et al., 2012). From this data set, we identified the voxels (grid cells by year) with whitebark pine killed by mountain pine beetle from 1996 to 2009. Because trees that are successfully attacked and killed turn red the following summer, the year of attack is the year prior to the year recorded in the ADS data. In the GYE region, ADS reports indicate no observed whitebark pine mortality from mountain pine beetles from 1986 to 1995 so we defined all voxels as having no mortality from 1986 to 1995. Reports from other regions indicate low levels of mortality prior to 1996; however, mortality absence could not be assumed and we did not extend the study period backward for these regions.

We defined the spatial distribution of whitebark pine in the NR and Cascades by combining the 1-km pixels where ADS data recorded whitebark pine and locations with a map of the potential for blister rust infection in whitebark pine (R. Keane, pers. com.). In the GYE, we selected those 1-km pixels that had at least 10% whitebark pine according to a 30-m map of whitebark pine distribution developed from Landsat data (Landenburger et al., 2008). In all

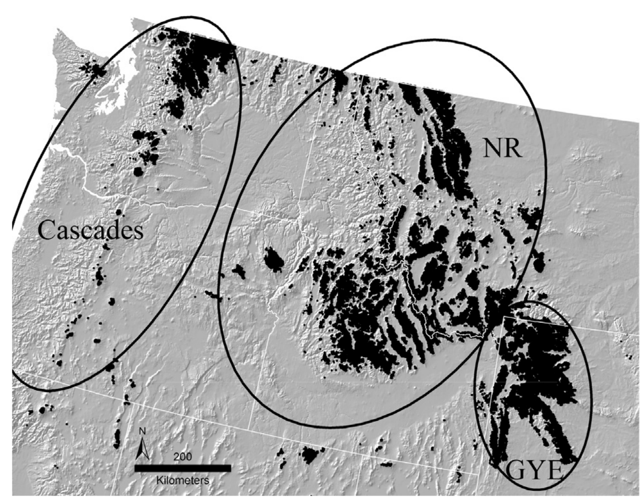

Fig. 1. Whitebark pine range in the western US and approximate boundaries of geographic regions for developing and applying models of the presence of whitebark pine mortality from mountain pine beetle (GYE = Greater Yellowstone Ecosystem, NR = Northern Rockies). Locations in California and Nevada were excluded due to a lack of tree mortality data.