

Modeling Contemporary Climate Profiles of Whitebark Pine (*Pinus albicaulis*) and Predicting Responses to Global Warming

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The Random Forests multiple regression tree was used to develop an empirically-based bioclimate model for the distribution of *Pinus albicaulis* (whitebark pine) in western North America, latitudes 31° to 51° N and longitudes 102° to 125° W. Independent variables included 35 simple expressions of temperature and precipitation and their interactions. These climate variables were derived from a spline climate model that provides point estimates (latitude, longitude, and altitude). The analysis used presence-absence data from more than 119,000 plot locations largely from USDA Forest Inventory and Analysis. Of these plots, 2738 contained whitebark pine. Climate estimates were made for each plot location and assembled into 10 data sets containing all of the plots where whitebark pine was present at a proportion of 40%. The remaining 60% were randomly selected from the database.

The Random Forest regression tree analysis was then applied to each of the 10 data sets to develop a model for predicting the occurrence of whitebark pine from climate, using the general approach described in detail in Rehfeldt et al. (2006). The analyses consisted of constructing 10 forests each with 100 trees. The most parsimonious model was determined through an iterative process of removing variables and repeating the analysis until an increase in out-of-bag error was observed. Output from the analyses included statistics useful for evaluating the importance of input variables. We used importance scores from the Gini index to determine variable importance. To produce mapped projections of the bioclimate model, the estimated climate for 5.9 million pixels of 1 km resolution representing the terrestrial area of western USA were run down the regression tree. Each tree of the 10 forests provided a vote on whether or not the climate of the pixel was within the profile of the species.

The most parsimonious had 9 variables and had an overall error of classification of 2.47%. Among the 9 variables, the 3 most important were degree-days > 5 °C, mean temperature of the warmest month, and Julian date when degree-days > 5 °C reaches 100. When run independently, these 3 variables classified the species occurrence with an overall error of only 4.91%. The mapped prediction for the occurrence of *P. albicaulis* using its climate profile was more accurate than its published range map (Fig 1).

This model was then used to predict responses to global warming. The Hadley and Canadian General Circulation Models (1% increase GGa/yr) were used to estimate the climate of each pixel for the area of analysis. The future climate expected in each pixel was then run down the regression tree to predict the future geographic distribution of *P. albicaulis*' contemporary climate profile. Projections were made for climates expected for the decades beginning in 2030, 2060, and 2090 (Fig 2)

Results indicated a rapid and large scale decline in the total area occupied by the species' contemporary climate profile throughout the century. For the decade beginning in 2030, *P. albicaulis*' contemporary climate profile is projected to decline 70 % while moving upward in altitude by 333 m on average. By the end of the century, its contemporary climate profile is projected to diminish to an area equivalent to less than 3% of its current distribution.

This bioclimate model for *P. albicaulis* provides a tool of high statistical precision that predicts the location of sites having a suitable climate. It can be used by resource managers as a range map and for identify geographic locations climatically suited for establishment and growth of the species. The model may also be used in conjunction with climate change scenarios to identifying populations at risk and future locations climatically suited for conservation efforts.

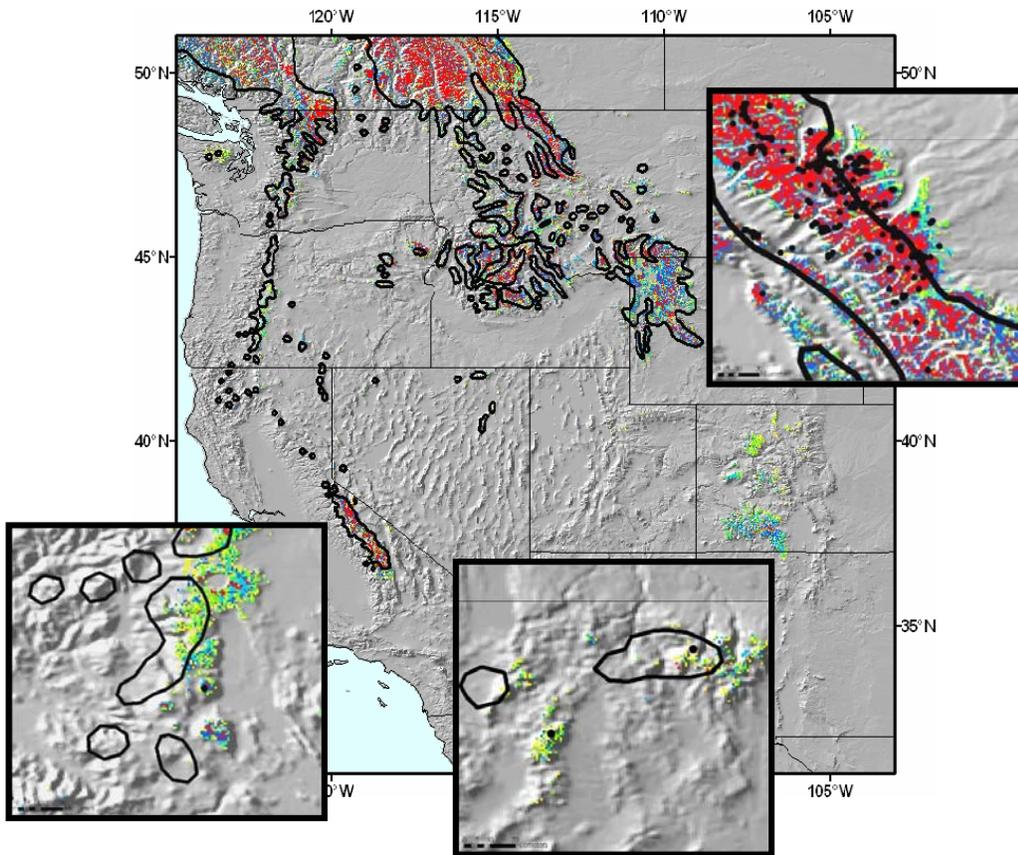


Fig. 1 Modeled bioclimate profile of *Pinus albicaulis* overlaid with the digitized range map of Little (1971). Colors code the proportions of votes received by a pixel in favor of being within the climate profile: 0%–50% no color; yellow 50%–60%; green 60%–70%; light blue 70%–80%; dark blue 80%–

90%; and 90%–100% red. Areas outlined in black depict species boundaries defined by Little (1971). Dots in the panels indicate sites known to be inhabited.

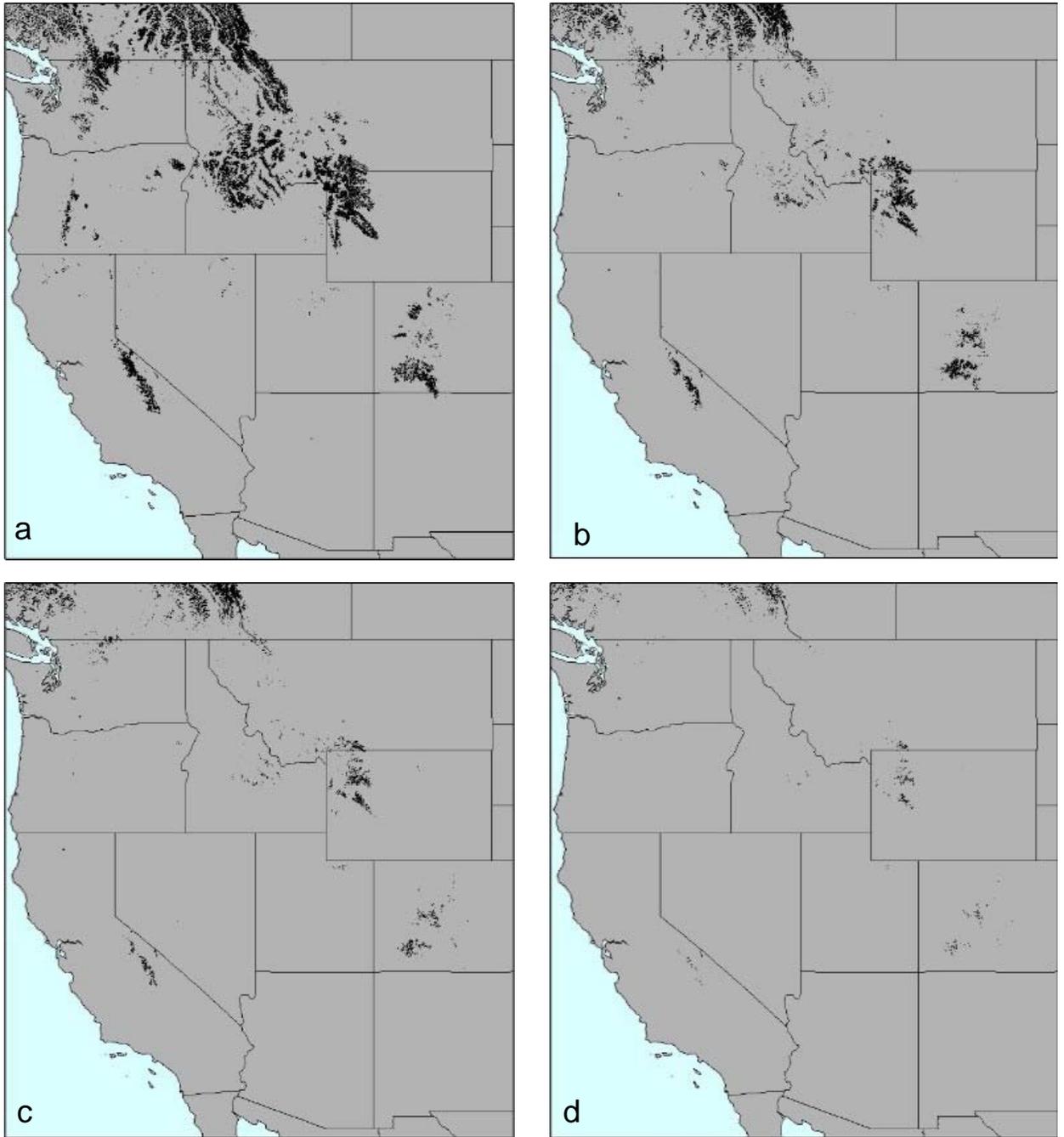


Fig. 2 Modeled bioclimate profile of *Pinus albicaulis* for the present (a) and predicted climate for decades 2030 (b), 2060 (c) and 2090 (d) under climate change scenario using an average of Hadley and CCMA GCM scenarios of 1% per year increase GPa. Black indicates location of pixels receiving $\geq 50\%$ proportion of votes in favor of being within the climate profile.

References

- Little, E. L., Jr., 1971, *Atlas of United States trees, volume 1, conifers and important hardwoods*. Washington DC: U.S. Department of Agriculture Miscellaneous Publication 1146, 9 p., 200 maps.
- Rehfeldt, G. E., N. L. Crookston, M. V. Warwell, and J. S. Evans. 2006. *Empirical analyses of plant-climate relationships for western United States*. International Journal of Plant Science 167: 1123-1150.