Demographic status, trajectory, and stressors of the demography of *Pinus lambertiana*

# Introduction

Sugar pine (*Pinus lambertiana*) is the largest Pinus species, an important timber species, and a component of several dry western conifer forest types, in particular the extensive Sierra Nevada Mixed Conifer forest where it typically composes 5-25% of basal area (Kinloch and Scheuner 1990, Safford and Stevens 2017). Its range extends through much of the North American Mediterranean zone throughout mountain ranges in California and central Oregon (Safford and Stevens 2017), with most of the growing stock located in California (Kinloch and Scheuner 1990). Like many other plant and animal species, Sugar pine faces numerous challenges in the Anthropocene, and managers and policymakers are concerned about the future status of the species.

First, there is evidence that modern densified forest structure poses a threat to the ability of sugar pine to successfully reproduce. Sugar pine is a fire-tolerant species with moderate shade intolerance (Yeaton 1984) and persisted in frequent fire forest types with mean fire return intervals of 11-16 years. Effective fire suppression, which was instituted across much of sugar pine’s range in the 20th century, has resulted in an overall densification of these forests and shifted species composition (especially of younger cohorts) towards shade-tolerant firs and incense-cedar (Stephens et al. 2015, Levine et al. 2016, Ansley and Battles 1998). Historical logging practices tended to target large and valuable sugar pines, further altering forest composition and structure (Cermak 1996, Safford and Stevens 2017).

Second, one result of densification and a warming climate has been an increase in the annual area burned by high severity wildfire throughout the range of sugar pine (Parks et al. 2020). Sugar pine is not serotinous and has adaptations for large adults to survive wildfire (Schwilk & Ackerly 2001). However, the novel fire regime is creating large swaths of landscape with no surviving reproductive adults, and thus no seed source for the next generation (North et al. 2020, Stevens SDC paper).

Third, the changing climate may increase the duration and severity of droughts and associated bark beetle epidemics, which are already causing mass mortality events in sugar pine’s range (Fettig et al. 2019). Once these epidemics are underway, bark beetles tend to preferentially target large and reproductively-valuable sugar pines, independent of individuals’ stress (Stephenson 2019).

Finally, an invasive fungal pathogen, *Cronartium ribicola* (white pine blister rust; WPBR) has spread across much of sugar pine’s range since its introduction and has caused substantial mortality (van Mantgem et al. 2004, Dudney et al. 2020). Maloney et al. 2014 found that some subpopulations of sugar pine in the Lake Tahoe basin exhibited negative population growth rates and high levels of WPBR infection. Sugar pine may have been facing these challenges for some time: some subpopulations of sugar pine showed evidence of inbreeding, potentially caused by population bottlenecks which may the result of historical logging, fire suppression, and/or more recent white pine blister rust outbreaks (Maloney et al. 2011).

Given these numerous challenges, there are widespread concerns about the future of the species (Kinloch et al. 1996). Management options to benefit sugar pine are available, ranging from restoration thinning and prescribed fire to restore forest structure (Restaino et al. 2019) to outplanting seedlings with genetic resistance to WPBR (Kinloch et al. 1996, Aitken 2013, North et al. 2020). However, many of these options are expensive. In a context where natural resource management funding is constrained, it is important to understand the status and demographic outlook for sugar pine as a species. This study seeks to inform decisions about when and where to prioritize management actions to conserve sugar pine. To that end, I address two questions:

1. What is the current status and trajectory of the ensemble of sugar pine populations across its range?
2. What is the relative importance of the various stressors acting on sugar pine?

# Methods

## Study Area

The area of interest for this study is that part of the range of sugar pine which is within the contiguous United States (Figure 1), which is the vast majority of the species’ range. The range of sugar pine extends from LATITUDE to LATITUDE throughout much of the Sierra Nevada and Klamath mountains, and parts of the Transverse and Southern Cascades ranges in the US states of California and Oregon. Sugar pine is widely distributed throughout this range as an important element of the mixed conifer forest belt at elevations ranging from LOWER MCF ELEVATION to UPPER MCF ELEVATION. The climate throughout this range is Mediterranean, with a cool-wet season extending from MONTH through MONTH and a warm-dry season extending from MONTH through MONTH.

The range delineation used for this study was generated using the raster files provided by (Wilson et al. 2013). The USFS RMRS Live Tree Species Basal Area of the Contiguous United States 2000-2009 (CITE) provides species-specific rasters of predicted basal area at 250m resolution across the contiguous US, with each raster cell giving a predicted value for the basal area (ft2/acre) of the selected species. The abundance predictions are generated using k-nearest neighbors and canonical correspondence analysis on MODIS imagery, raster data describing relevant environmental parameters, and Forest Inventory and Analysis (FIA) field plot data. This continuous raster was converted to a discrete polygon by first aggregating the resolution from 250m to 3km and filtering to cells where predicted sugar pine basal area was greater than 0.46 m2/ha. This level of aggregation and filtering provided the best combination of sensitivity and specificity when comparing the resulting range polygon against the presence of sugar pine on FIA plots (at their nominal locations).

## Inventory Data

The FIA plots are part of a US Forest Service-run nationwide inventory network operating in its current form since 2001 (Bechtold 2005). Here, we use data from California, Oregon, and Nevada clipped to the processed sugar pine range map. The geographic coordinates listed for the FIA plots are not exact; to preserve plot integrity, the plot coordinates are randomly perturbed, and some plot locations are swapped. Most perturbations are to a random location within 0.8km of the true location, and all perturbations are to within 1.6 km of the actual location. Between 0 and 10 percent of plot locations are swapped with a similar plot in the same county. FIA plots are placed on a hexagonal grid with a density of approximately 1 plot per 2429 ha. Each plot is revisited once every 10 years. On each FIA plot, trees >= 12.7 cm diameter at breast height (1.37 m, DBH) are inventoried on four 168 m2 permanent subplots. Small trees from 2.54-12.7 cm DBH are inventoried on a 13.5 m2 microplot, and large trees on an optional 1012 m2 macroplot. Data inventoried for each individual stem include the species, live/dead status, DBH, and a “damage agent” code indicating whether some agent (e.g. white pine blister rust) is visibly affecting the individual’s health. The smallest stems surveyed (height >= 0.15 m and DBH < 2.54 cm) are not inventoried as individuals but tallied by species.

In addition to the tree-level data collected, the FIA program also records information about forest conditions, including the presence of significant disturbances (e.g., fire) and the ecological subsection (CITE) the plot is located within, and the nominal GPS coordinates of the plot center. For this study I selected only the subset of FIA plots whose nominal centers were within the sugar pine range polygon described above. The range polygon was used, rather than simply using all plots where sugar pine was actually present, in order to better capture the range of environmental conditions existing within sugar pine’s range.

## Climate Data

To

## Vital Rates Model

## Model Validation

## Integral Projection Model

# Results

# Discussion

* Talk about potential interactions among stressors
  + Warming climate -> more fire, changes to wpbr range
  + Warming climate -> regeneration failures, incl. potentially of planted seedlings
  + Fire and drought effects on forest composition / densification
* Weigh potential management responses