Forest Ecology and Management 354 (2015) 104–118

Contents lists available at ScienceDirect

Forest Ecology and Management

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

A forest reconstruction model to assess changes to Sierra Nevada mixed-conifer forest during the fire suppression era

Molly A.F. Barth [a],*, Andrew J. Larson [a], James A. Lutz [b]

[a] Department of Forest Management, College of Forestry and Conservation, University of Montana, Missoula, MT 59812, USA
[b] Wildland Resources Department, Quinney College of Natural Resources, Utah State University, Logan, UT 84322, USA

ARTICLE INFO

Article history:
Received 17 May 2015
Received in revised form 24 June 2015
Accepted 25 June 2015
Available online 30 June 2015

Keywords:
Tree growth
Fire history
Restoration
Sugar pine
Tree decay
Pinus lambertiana

ABSTRACT

Fire suppression has resulted in dramatic changes to species composition and structural diversity in the Sierra Nevada mixed-conifer forests. We need a better understanding of how these forests have changed during the fire suppression era, but empirical historical datasets are rare and methodologies for developing new historical reference information are subject to limitations. We sought to develop historical reference information for the Yosemite Forest Dynamics Plot (YFDP), a research plot located in an old-growth mixed-conifer forest in Yosemite National Park. We performed a dendrochronologial fire history analysis to characterize the historical fire regime of the YFDP, resulting in an estimated pre-1900 point fire return interval of 29.5 years. We then developed two different forest reconstruction models to estimate structural and compositional forest changes since 1900, the year the last widespread fire burned the YFDP, to the present. We explored the use of two different tree growth models—a regionally parameterized competition-dependent model and a parsimonious site-specific model—as well as a decay model based on published estimates of wood decay rates. The competition-dependent growth model predicted slightly higher stem densities (175 trees ha^{-1} vs. 112 trees ha^{-1} in 1900) and slightly lower basal area (20.9 m^2 ha^{-1} vs. 24.1 m^2 ha^{-1} in 1900) than the site-specific growth model. Predictions about dead trees, especially large diameter sugar pines, are potentially inaccurate, both in this study and other reconstruction studies in the Sierra Nevada, due to a lack of size-specific snag and log decay rate data. Our study highlights the need for more detailed decay data for Sierra Nevada mixed-conifer forests. While reconstruction models are constrained by the data used to parameterize them, they can still produce estimates of historical conditions that are useful for understanding the direction and magnitude of forest change, as well as for planning forest management. Our analysis demonstrates dramatic changes in forest conditions since fire-exclusion—a clear ecological basis for restoration. We encourage managers to focus on restoring key ecological processes that maintain ecosystem structure and function, in this case fire, rather than attempting tree-for-tree recreations of historical structure without reintroducing fire.

1. Introduction

Fire suppression has resulted in dramatic changes to species composition and structural diversity in dry coniferous forests across the western United States (Abella et al., 2007). The mixed-conifer forests of the Sierra Nevada in California, including those in Yosemite National Park (Yosemite), are no exception (Scholl and Taylor, 2010). Climate change may confound or intensify existing ecological problems, and could bring a continued increase in fire frequency and severity (Miller and Urban, 1999; Cansler and McKenzie, 2014, but see Lutz et al., 2011), tree species range shifts (Lutz et al., 2010), declines in forest productivity (Battles et al., 2008), drought-triggered tree mortality (Guarín and Taylor, 2005), and a loss of biological diversity (Stephenson and Parsons, 1993). Given the significant alteration of these forests and the uncertain ecological impacts of future climate change, it is imperative that we exercise timely adaptive management and restoration based on the best available science if we hope to sustain western dry forests and the ecological services they provide.

Forest reconstruction is a technique in which contemporary inventories of live and dead trees are used to estimate forest structure and composition at some point in the past (Fulé et al., 1997). When historical forest structure datasets (e.g., timber inventories, historical photos, and land surveys) are rare or lacking,

---

* Corresponding author.
E-mail addresses: molly.barth@umontana.edu (M.A.F. Barth), a.larson@umontana.edu (A.J. Larson), james.lutz@usu.edu (J.A. Lutz).

http://dx.doi.org/10.1016/j.foreco.2015.06.030
0378-1127/

reconstructions often represent the best available option for obtaining historical reference information. This information is important for guiding management and for investigating changes caused by the exclusion of fire or other past land uses, as well as for understanding the mechanisms of change in forest ecosystems. It is essential to have an understanding about the accuracy, limitations, and uncertainties of reconstruction models when using this approach to assess ecological change or guide management (Harmon et al., 2015).

Forest reconstructions are an invaluable research tool and are worth improving because they offer a way to obtain new information and can potentially provide more detailed, site-specific data than extant historical datasets. Reconstructions generally rely on several assumptions, including: (1) all evidence of historical forest structures is detectable during contemporary inventories; (2) the ages of snags and logs can be determined based on a field classification of tree decay; and (3) decay rates are consistent across size classes. There have been some efforts to investigate the impact of variable decay rates on reconstruction estimates through sensitivity analyses (Fulé et al., 1997; Scholl and Taylor, 2010; Taylor et al., 2014), but thorough investigations of uncertainties in decay and growth are rare despite the widespread use of reconstructions to investigate changes from historical conditions in frequent-fire forests (Arno et al., 1995; Harrod et al., 1999; North et al., 2007; Beaty and Taylor, 2007; Van de Water and North, 2011).

Sierra Nevada mixed-conifer forests present an opportunity for forest scientists to investigate how management interventions (e.g., fire exclusion and grazing) and shifts in climate (e.g., the end of the Little Ice Age) may have influenced forest structure, dynamics, and ecological functions and services over the past century. With this study, we seek to expand our ability to obtain new scientific evidence needed to both improve our ecological understanding as well as address specific research needs identified in contemporary Sierra Nevada mixed-conifer management frameworks (North et al., 2009; North, 2012). Specifically, our objectives are to: (1) develop a forest reconstruction model for Sierra Nevada mixed-conifer forests and evaluate the use of two alternative tree growth models; (2) systematically investigate the consequences of uncertainty in model components, including decay rates, on reconstructed estimates of historical forest structure and composition; (3) evaluate model performance by reconstructing historical forest structure and composition of a Sierra Nevada mixed-conifer forest at the time of the last widespread fire and comparing our results to existing historical datasets.

2. Methods

2.1. Study site

This study used field data from the Yosemite Forest Dynamics Plot (YFDP), a 25.6 ha (800 m × 320 m) permanent plot established in an old-growth, mixed-conifer forest near Crane Flat in Yosemite National Park (Yosemite), California (Gabrielson et al., 2012; Lutz et al., 2012, 2014). The YFDP is centered at 37.77°N, 119.82°W, with an elevation of 1774–1911 m. The climate is Mediterranean, with warm dry summers and cool, wet winters. Soils are primarily metasedimentary soils of the Clarkslodge-Ultic Palexeralfs complex (Lutz et al., 2012). Major tree species on the plot include sugar pine (*Pinus lambertiana*), white fir (*Abies concolor*), incense cedar (*Calocedrus decurrens*), California black oak (*Quercus kelloggii*) and Pacific dogwood (*Cornus nuttallii*). Canopy emergent trees, primarily sugar pine and white fir, reach 60–67 m in height and over 200 cm in diameter at breast height (1.37 m above ground level; dbh). The forest within the YFDP has never been subject to timber harvest.

2.2. Data collection

Baseline tree data in the YFDP have been collected following the protocols of the Smithsonian ForestGEO network (Anderson-Teixeira et al., 2015). All live trees $\geqslant$ 1 cm dbh, all snags $\geqslant$ 10 cm dbh and $\geqslant$ 1.8 m in height, and all logs $\geqslant$ 50 cm in their largest diameter were identified and mapped (for details, see Lutz et al., 2012). We augmented the existing measurements with additional data on logs <50 cm in diameter and snags <1.8 m tall. To avoid over-sampling these dead trees, we used estimates of species-specific tree growth rates developed from local Forest Inventory and Analysis data, species-specific log decay rates (Harmon et al., 1986), as well as allometric equations relating dbh to diameter at stump height (dsh) (Walters and Hann, 1986; Weigel and Johnson, 1997) to estimate the minimum dsh that stumps and logs would have to be in the present to have been alive in 1900. For each log and short snag that met minimum dsh requirements (white fir: 30 cm; sugar pine: all; incense cedar: 10 cm; black oak: 15 cm), we recorded the species and decay class (Thomas et al., 1979), and estimated dbh prior to decay using structural clues (Fig. 1). We mapped the original rooting locations of all logs. The YFDP contemporary tree inventory includes 35,498 live trees, 2734 snags, and 696 logs.

We collected tree increment cores around the perimeter of the YFDP to estimate local species-specific growth rates (sampling within plot boundaries was not permitted). We sampled individual trees from the principal species present on the plot (white fir: $n = 27$, sugar pine: $n = 34$, incense cedar: $n = 35$, black oak: $n = 11$) and sampled throughout the diameter distribution, although we could not core trees <10 cm or >130 cm dbh.

Although fire suppression began regionally as early as 1891 (Rothman, 2007; van Wagtendonk, 2007), we needed to know the year of the last widespread fires on the YFDP to set an appropriate year for the reconstruction. To assess YFDP fire history, we removed cross-sections from dead fire scarred trees ($n = 10$ sugar pine and $n = 2$ incense cedar) within and immediately adjacent to the plot (see Barth, 2014 for maps detailing sample locations and study area). Cross-sections were prepared using standard dendrochronological techniques (Stokes and Smiley, 1968) and growth rings were measured using CooRecorder version 7.5 (Cybis Elektronik & Data AB, Sweden). Fire scars identified by their characteristic ring disruption (McBride, 1983). Cross-sections were cross-dated by establishing marker years using locally developed tree-ring chronologies (King and Graumlich, 1990; Barth et al., 2014)

Fig. 1. Field assistant Erin Costello estimates a dead tree's original dbh, using structural clues to account for bole loss due to decay since tree death. Photo by M. Barth.