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Land ownership and 20th century changes to forest structure in California

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ABSTRACT

Forests in California have changed dramatically during the 20th century. Shifts in forest structure including densification, declines in large trees and tree basal area have altered the function, productivity, and resilience of modern day forests. Attributing these changes to specific drivers is increasingly important for effective management of healthy and productive forests. Previous studies focus on climatic (temperature, precipitation, climatic water deficit), disturbance (fire), geomorphological (topography, soil types), and anthropogenic (logging, fire suppression) drivers, but few studies evaluate large scale change in forest structure across land ownership type. In this paper, we investigate 20th century changes to forest structure across six land ownership classes in California. We compare historical and contemporary forest structural data and find that declines in large trees and increases in forest density are consistent across the state. This pattern is most pronounced on private timberlands, which experience up to 400% regional increases in small tree (< 10.2 cm) density since 1930. All land ownership classes experience declines in large trees, while private timberlands, national parks and wilderness areas experience the most extreme change with an average loss of over 83% and 71% respectively. We conclude that understanding patterns of change across land ownership is essential for targeting federal, state, and locally specific policies that foster healthy and resilient forests for the future.

1. Introduction

Present-day forests in California are markedly different from their early 20th century counterparts. Numerous studies show changes in the structure and composition of California's forests by documenting shifts towards more small and fewer large trees (Dolanc et al., 2013a; Lutz et al., 2009; McIntyre et al., 2015); more structurally homogenous stands (Maxwell et al., 2014); and changes in species composition (McIntyre et al., 2015; Minnich et al., 1995; Taylor, 2000; van Mantgem et al., 2013). These changes vary over space and time due to the interaction of biophysical and socio-ecological drivers. In California, large tree decline has been attributed to increased temperatures, variable precipitation, and water deficit (Das et al., 2013; McIntyre et al., 2015; van Mantgem et al., 2013, 2009), as well as historical and contemporary legacies of logging (Knapp et al., 2013; Laudenslayer and Darr, 1990; McKelvey and Johnston, 1992; Beesley, 1996). Large scale forest densification, in part, is the result of nearly a century of widespread fire suppression efforts (Dolanc et al., 2014; 2013b; Lutz et al., 2010; Minnich et al., 1995), with previously logged lands showing greater densities than surrounding landscapes (Naficy et al., 2010). The lack of natural fire and increasing forest density positively correlate with a shift in species composition favoring shade-tolerant species (Miller et al., 2012; Taylor and Skinner, 2003). Such legacies of logging and forest fire suppression have profound impacts that can persist for decades after cessation, altering both the state of contemporary landscapes and influencing future trajectories of change (Perring et al., 2016). These legacies are often specific to the land management practices of a given land owner at a specific time. Given the difficulty in disentangling regional biophysical and socio-ecological drivers, an understanding of forest structure change across land ownership is needed. Additionally, determining how long-term patterns of change vary across ownerships is necessary to help target federal, state, and locally specific management policies that foster healthier more resilient forests for the future.

Land ownership has been used to understand the long-term effects of and variation in land management practices; especially when spatially explicit data on management practices are unavailable or incomplete. In agricultural landscapes for example, Lunt and Spooner (2005) showed that land ownership is predictive of disturbance and therefore can be used to better understand past, current, and future

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patterns of biodiversity in fragmented areas. In forested landscapes, Turner et al. (1996) showed that property boundaries create quantifiable patterns of land use change and that the similarities in these changes across ownerships are reflective of specific management goals. They showed that while forests on private lands were more fragmented than those on public lands, when areas had a common management goal (e.g. active timber harvesting) forests displayed similar spatial patterns.

Studies documenting changes in forest structure across land ownership at a large scale in California are rare. In this paper, we compared historical 1930s Vegetation Type Mapping project (VTM) forest survey plots with modern 2000s Forest Inventory and Analysis program (FIA) forest inventory plots and examined changes in measures of forest structure: stems per ha per size class (small, medium, large, and total) and total basal area (m^2/ha).

We assessed change over time in these variables across six California land ownership classes: (1) Private Timberland (PT), (2) Non-Wilderness National Forest (NWNF), (3) Non-Wilderness Bureau of Land Management and Tribal Lands (NWBT), (4) Private Protected lands (PP), (5) State and Regional Parks (SR), and (6) National Parks and Wilderness areas (NPW). We distinguished changes in stand density and size class distributions across land ownership and investigated differences in these measures between the six land ownership classes. We address the following questions: (1) have the numbers and sizes of trees changed significantly over time across all six land ownership classes; (2) how do changes in the number of trees per size class and forest densification vary by land ownership; and (3) do these patterns suggest differing land use legacies across ownership classes.

2. Methods

2.1. Study area

Our study area includes the forests of the California floristic province including the Northwestern, Sierra Nevada, Central, and South regions. This area has a Mediterranean climate of dry summers and wet winters. Regional differences in climate and soil characteristics are captured by geomorphic regions that are largely determined by the mountain ranges that divide them. The six land ownership classes investigated cover a range of ecoregions and vegetation types and are also representative of regional characteristics that correspond with spatial patterns of ownership.

California is a complex mosaic of land ownership, with federal, state, tribal, and local entities protecting and managing land. Nearly 150,000 km^2 of forest are managed by distinct ownerships with varying degrees of protection, production, and conversion of forests. 48% of California's forested lands (63,130 km^2) are managed by the U.S. Forest Service as National Forests, 51,395 km^2 (39%) are managed as private timberland encompassing both industrial and non-industrial private forest land. Approximately 8095 km^2 (6%) is set aside as forest reserves and managed through Wilderness designation or as a National Park, while various other private and public entities manage the remaining ~8900 km^2 (7%) (McIver et al., 2015).

PT includes both industrial and non-industrial forest lands, however the majority of plots investigated in this study were on lands managed for industrial timber. Generally, PTs are located on mixed conifer forests in the Northern Sierras, Klamath, and Cascade Ranges, and in the Douglas Fir and Redwood forests of the North and Central Coasts (Stewart et al., 2016), and tend to occur at lower elevations. NWNF areas are also located extensively in mixed conifer forests, interspersed with pockets of Red Fir, Eastside Pine, and Ponderosa Pine and extending into the hardwood forests and woodlands of the Central and South Coast.

NWBT lands are distributed in the low elevations of the North Coast, Mojave, Sierra, Central, and South Coast regions, and in our study area, consist of primarily conifer forests and woodlands concentrated in the Eastern Sierra Nevada, Klamath Ranges, and South Coast Ranges. Very few of our study plots occur on tribal lands, therefore NWBT is primarily illustrative of BLM lands.

PP land is scattered in the matrix of federal, state, and private ownerships, generally representing hardwood woodlands and hardwood forests. SR lands in our study are primarily hardwood woodlands within the greater San Francisco Bay Area. NPW areas are representative of National Parks and all federal agency owned wilderness. These lands are primarily located in the Sierra Nevada region, as well as the Southern Sierra and Transverse Ranges. Forest types in NPW are primarily mixed conifer but also higher elevation Red Fir, Lodgepole Pine, Jeffery Pine, and hardwood forest types. The spatial distribution of ownership types expresses regional concentrations owing to California's complex land settlement history, therefore the patterns represented in this study are reflective of differences across ownership that are particular to the regions where the plots are located.

2.2. Data

2.2.1. Historical and contemporary forest inventory data

The Vegetation Type Mapping (VTM) project is a series of landscape surveys conducted by the US Forest Service that covered ~40% of California between 1928 and 1940 that resulted in a large collection of 350 vegetation maps, 18,000 vegetation plots, over 3000 photographs and ~20,000 herbarium specimens (Wieslander, 1935). These data are digitized and georeferenced (see Kelly et al., 2005; Kelly et al., 2016; Kelly et al., 2017) and available for download via an open API and for download (vtm.berkeley.edu). In this study, we use the vegetation plot data, including geolocated information on numbers, diameter, and species of trees as well as other ancillary environmental information (e.g. elevation) associated with the marked plot location (Fig. 1a). The VTM crews conducted complete inventories of all trees over 10.2 cm diameter at breast height (DBH) within 20 m by 40 m (800 m^2) rectangular plots. The trees were tallied by species into four individual size classes: 10.2–30.4 cm, (4–12 in), 30.5–60.9 cm (12–24 in), 61.0–91.3 cm (24–36 in), and > 91.4 cm (> 36 in) (Kelly et al., 2005).

The VTM survey began in 1928, just after the beginning of large scale forest fire suppression across the state and in most areas before the 1940s and 1950s peak in forest harvesting. Today, the VTM collection serves as one of the only comprehensive datasets describing the California landscape in the early 20th century. Working with historical datasets requires the acknowledgment and examination of challenges such as plot geolocation error and potential bias. In the VTM dataset for example, plot location is derived from original markings on historical topographic maps and positional error is estimated to be ~200 m (Kelly et al., 2005) per plot which can affect direct plot comparisons or plot resurveys, especially in highly heterogeneous regions (Keeley, 2004).

The protocols behind VTM methods have raised questions about biased sampling favoring undisturbed forests. However, there is no evidence of bias suggested in the original VTM manual (Wieslander et al., 1933), or in the sample plot distributions, yet there are competing patterns of change when comparing FIA and VTM estimates to other historical comparisons. Some studies using alternative comparison datasets or plot resurvey have shown similar patterns of declines in large trees (e.g. Lydersen et al., 2013; van Mantgem et al., 2009) as the VTM dataset, while other studies have shown declines in large trees on some ownership classes but not on others, and increases in basal area across types (Collins et al., 2017; Lydersen et al., 2013). These disparities are difficult to verify as the datasets in question are not directly comparable but do require a cautionary approach to interpreting changes in large trees and biomass. There is no record of intentional bias in the selection of VTM plot locations the locations were chosen as representative samples of vegetation types being mapped (Wieslander et al., 1933), and have been shown to have a similar sampling densities across elevation and latitude as FIA plots which are determined randomly using a grid system (Dolanc et al. 2013a). Despite these potential shortcomings,