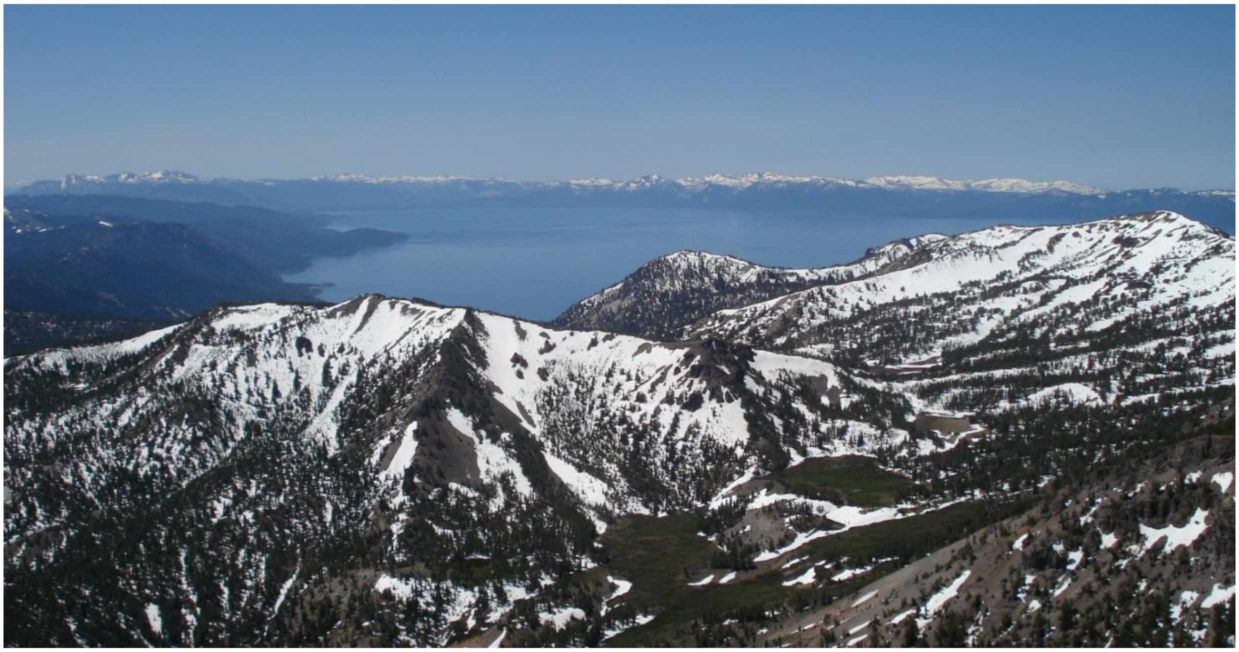

Identifying Spatially Explicit Reference Conditions for Forest Landscapes in the LTB, USA

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Abstract

The overall goal of this project was to develop spatially explicit reference conditions for pre-Comstock forest landscapes and associated fire regimes for the LTB that can be used by land managers in the ecosystem restoration planning and implementation process. An understanding of the spatial variability in pre-Comstock forest characteristics is essential for understanding if and how planned stand-level activities (mechanical fuel treatments, prescribed burning, etc.) scale up and contribute to restoration of functioning forest landscapes (i.e., wildlife habitat, forest health, hydrologic conditions, etc.). A mismatch between the cumulative effects of stand level treatments in contemporary forests and spatial variability in pre-Comstock vegetation patterns may fail to achieve the goal of restoring fire resilient functioning landscapes. This research builds on previous work on pre-Comstock forests conditions at the stand scale and fills a critical gap in knowledge on the spatial variability of pre-Comstock forest structure and fire regimes across the LTB. The specific objectives of this project were to: 1) identify the relationship between spatial variability in pre-Comstock forest structure (composition, density, basal area, size structure) and topographic variables in the lower and upper montane forest zones of the LTB; 2) identify the relationships between spatial variability in fire regimes (fire return interval, season of burn) and topographic variables in the montane and upper montane zone in the LTB; and 3) develop a spatially explicit reconstruction that distributes and visually represents pre-Comstock forest structure, forest fuels, and fire regimes for lower and upper montane forests in the LTB.

Keywords: dendrochronology, forest reconstruction, fire behavior, fuels, pre-Comstock, spatial modeling

Conversions: Metric to English units

Conversion	Multiple by
cm to in	0.39
km to miles	0.62
m^2/ha to ft^2/ac	0.23
mg/ha to tons/ac	0.45
kg/m^3 to lb/ft^3	0.06
C° to F°	multiply by 9, then divide by 5, then add 32

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Introduction

Forest conditions at the time of Euro-American settlement and prior to the extensive Comstock logging era (hereafter pre-Comstock) are increasingly used as a point of reference for ecologists and managers in the Lake Tahoe Basin (LTB) for characterizing the range of variability in ecological processes and structures at a time when ecosystems were less affected by people (Kaufman et al., 1994; Swanson et al., 1994; Landres et al., 1999). During this period, the clarity of Lake Tahoe was high and much of the LTB is thought to have been covered by mainly mature and old-growth forest cover (Manley et al., 2000). Reference conditions are also used as an important source of information to identify restoration goals and restoration treatments in places where contemporary forest conditions are outside their historic range of variability (HRV; Morgan et al., 1994; Fule et al., 1997; White and Walker, 1997; Moore et al., 1999; Swetnam et al., 1999). Presumably, managing forests for conditions within the HRV would be consistent with maintaining high lake clarity and ecological conditions that reduce the risk of unexpected outcomes such as species extinction compared to conditions created by logging, grazing, and fire suppression management during the Euro-American land use period (Swanson et al., 1994; Landres et al., 1999; Moore et al., 1999). This ecosystem management perspective has been embraced by a wide range of stakeholders in the LTB. The desired condition for public forest lands is conceived as being similar to those in the pre-Comstock period (i.e., Christopherson et al., 1996). Consequently, identifying reference conditions is a key step in the ecosystem management-restoration planning process and it can be a particularly challenging task in forests that have been highly altered by human activity (USDA Forest Service, 2004).

Forests in the Sierra Nevada in general, and the LTB in particular, have been dramatically altered by Euro-American land use practices (Vankat and Major, 1978; McKelvey and Johnston, 1992; Sierra Nevada Ecosystem Project, 1996). The demise of the pre-Comstock forests in the LTB is well documented. Forests in large parts of the basin were nearly clearcut between ca. 1860 and 1920 to meet demand for wood in the silver mines in Virginia City, Nevada and areas served by rail from Truckee, California (Leiberg, 1902; Strong, 1984; Lindström, 2000). Forest has re-established on much of the cutover land, but the characteristics of these second growth forests differ markedly from pre-Comstock forests (Manley et al., 2000; Taylor, 2004; Beaty and Taylor, 2007, 2008). These second-growth forests have more trees, more basal area, and more pioneer species (e.g., lodgepole pine) that regenerate after severe disturbance than the original forests (Taylor, 2004). Fire was also a keystone disturbance agent in pre-Comstock forests that regulated forest dynamics and forest structure at stand and landscape scales, but fire is much less frequent in contemporary forests (Manley et al. 2000; Taylor, 2004; Taylor and Beaty, 2005; Beaty and Taylor, 2008). Moreover, the quantity of surface and aerial fuels in these highly altered forests is greater than in pre-Comstock forest, increasing the risk of stand-replacing fire (Weatherspoon and Skinner, 1996; Manley et al., 2000). The potential for high severity fire in the LTB poses a significant threat to water quality, life, property, and wildlife habitat in the LTB (Manley et al., 2000; Murphy and Knopp, 2000). The recent Gondola (2002) and Angora (2007) fires, which included significant areas of high severity fire, are an expression of this increased potential. Reducing the risk of high-severity fire, by treating fuels and changing the structure of forests so they are resilient to fire and more similar to reference forests, is a major thrust of forest and resource management in the LTB (Tahoe Regional Planning Agency, 2002; Lake Tahoe Basin Management Unit, 2012) and elsewhere in the Sierra Nevada (Christopherson et al., 1996; Manley et al., 2000; USDA Forest Service, 2004).

A common approach for identifying reference conditions for ecosystem management and restoration of fire resilient forests is to quantify pre-Euro-American forest conditions (i.e., forest structure and composition) and fire regimes, and compare them to those of the contemporary forest (Fulé et al., 1997; Moore et al., 1999). Differences are then used to develop strategies and treatments to increase the resilience of forest stands or forested landscapes to fire (Weatherspoon and Skinner, 1996; Stephenson, 1999; Agee and Skinner, 2005; Schmidt et al., 2008). Quantitative descriptions of pre-Comstock reference conditions have been used to guide treatment design to reduce surface and canopy fuels, tree density, and basal area in small areas of forest in the LTB and in other fire-prone forests in the western USA (e.g., Covington et al., 1997). However, knowledge of reference conditions at the scale of forested landscapes is lacking and this information is needed to evaluate the ecological implications of implementing large areas of fuel treatments and for fuel treatment design on a landscape scale (Skinner and Chang, 1996). For example, more intensive fuel treatments may be appropriate on portions of landscapes that historically burned at higher severity (Weatherspoon and Skinner, 1996; Taylor and Skinner, 1998; Agee and Skinner, 2005; North et al., 2009).

Background and Problem Statement

Research on fire regimes and forest structure in fire-prone forests in California before the onset of fire suppression management demonstrate that there are important feedbacks between topographic setting, forest structure and composition, and the frequency, severity, and spread of fire (van Wagtendonk, 1995; Taylor and Skinner, 1998, 2003; Miller and Urban, 2000; Taylor, 2000a; Beaty and Taylor, 2001; Bekker and Taylor, 2001; North et al., 2009). These spatially explicit studies indicate that pre-Euro-American forest landscapes were more heterogeneous than the contemporary forest landscapes and that spatial variability in fire regimes and forest structure were key components contributing to higher heterogeneity (Vankat and Major, 1978; Taylor and Skinner, 1998, 2003; Beaty and Taylor, 2001, 2008; Gruell, 2001; Nagel and Taylor, 2005). Thus, reference conditions that are topographically distributed yield data on spatial variability in ecosystem elements that probably regulate landscape ecosystem structure and function. Much of this research was conducted in wilderness or areas where evidence of the pre-Euro-American forest had not been removed by burning or logging. Identifying reference conditions in highly altered forest ecosystems, where most evidence of the original forest was removed by 19th century logging as in the LTB is considerably more challenging.

Reference conditions for forest structure and fire regimes in the LTB that could be used as initial information to guide vegetation and fuels management have been estimated from small areas of forest. For example, Barbour et al. (2002) quantified the composition, density, and basal area of trees in 38 patches of old-growth forest scattered throughout the LTB. Barbour et al. (2002) used the composition, density and basal area of large live trees (>40 cm dbh) as a quantitative description for four widespread forest types: 1) Jeffrey pine forest; 2) mixed conifer forest; 3) white fir forest; and 4) red fir forest. Using an alternative approach, Taylor (2004) measured well-preserved cut tree stumps dating from the 19th century to estimate reference conditions for forest structure in 20 forest stands on the east shore of Lake Tahoe. The stumps yielded reference estimates of forest density, basal area, and spatial pattern for: 1) Jeffrey pine forest; 2) red fir forest; and 3) lodgepole pine forest. Fire scars preserved in the cut stumps, and in scattered live pre-Comstock trees, also provided estimates of the return interval, extent, and season of fire during the pre-Comstock period for Jeffrey pine and red fir forests (Taylor, 2004; Taylor and Beaty, 2005; Scholl and Taylor, 2010).

Although these studies provide detailed and useful information on pre-Comstock forest conditions for small areas of old-growth forest they provide little insight into the spatial heterogeneity of the pre-Comstock forest landscape in the LTB. Research on reference forest conditions elsewhere in northern California indicate that reference forest structure (i.e., density, basal area, tree size and age distributions), and fire regimes (i.e., frequency, severity, extent) vary with topographic characteristics. For example, fire return intervals and forest structure vary significantly with slope, aspect, and elevation in lower (Jeffrey pine/mixed conifer) and upper montane (red fir, lodgepole pine, mountain hemlock) forests in the southern Cascades and northern Sierra Nevada (e.g., Taylor, 2000a; Beaty and Taylor, 2001; Bekker and Taylor, 2001; North et al., 2009). Similarly, evidence of high-severity fire (even-aged forest, montane chaparral) is often concentrated on upper slope positions (e.g., Taylor and Skinner, 1998; Beaty and Taylor, 2001; Nagel and Taylor, 2005). Research on mixed conifer forests on portions of a landscape that were never logged on the west shore of Lake Tahoe also suggests that topography exerted strong control on pre-Comstock forest fire regimes (frequency, return interval, severity) and forest structure (Nagel and Taylor, 2005; Beaty and Taylor, 2007, 2008).

Goals and Research Objectives

The overall goal of this project was to develop spatially explicit reference conditions for pre-Comstock forest landscapes and associated fire regimes for the LTB that can be used by land managers in the ecosystem restoration planning and implementation process. An understanding of the spatial variability in pre-Comstock forest characteristics is essential for understanding if and how planned stand-level activities (mechanical fuel treatments, prescribed burning, etc.) scale up and contribute to restoration of functioning forest landscapes (i.e., wildlife habitat, forest health, hydrologic conditions, etc.). A mismatch between the cumulative effects of stand level treatments in contemporary forests and spatial variability in pre-Comstock vegetation patterns may fail to achieve the goal of restoring fire resilient functioning landscapes. This research builds on previous work on pre-Comstock forests conditions at the stand scale and fills a critical gap in knowledge on the spatial variability of pre-Comstock forest structure and fire regimes across the LTB. The specific objectives of this project were to: 1) identify the relationship between spatial variability in pre-Comstock forest structure (composition, density, basal area, size structure) and topographic variables in the lower and upper montane forest zones of the LTB; 2) identify the relationships between spatial variability in fire regimes (fire return interval, season of burn) and topographic variables in the montane and upper montane zone in the LTB; and 3) develop a spatially explicit reconstruction that distributes and visually represents pre-Comstock forest structure, forest fuels, and fire regimes for lower and upper montane forests in the LTB.

Methods

Study Area

People have been using the forests around Lake Tahoe for at least 8,000 years. The Washoe migrated west from the Great Basin annually to hunt, fish, and gather food (Elliot-Fisk, 1996; Lindström, 2000). Euro-Americans first traveled through the Tahoe region in 1844 but large numbers of Euro-Americans did not settle in the basin until the 1860s. The discovery of the Comstock Lode silver ore deposit in 1859 initiated intense logging in the basin to provide timber for mining operations (Strong, 1984). Logging is estimated to have reduced the area of forest present in the mid 19th century by 67%, with subsequent logging in the 20th century reducing old-growth forests to < 2% of the LTB (Barbour et al., 2002). The climate is Mediterranean with cool, wet winters and warm, dry summers. Most precipitation (80%) falls as snow in the winter. A temperature and precipitation gradient exists in the LTB going from west to east across the lake. Mean monthly temperatures at Tahoe City, California on the west shore of Lake Tahoe range from -1.4°C in January to 15.9°C in August, and mean annual precipitation is 83.8 cm. On the east shore of Lake Tahoe, mean monthly temperatures at Glenbrook, Nevada range from 0.5°C in January to 17.8°C in August, and mean annual precipitation is 45.7 cm.

Forest structure data and field sampling

Data for pre-Comstock forest structure came mainly from the completed studies in the LTB, Lassen Volcanic National Park, and Yosemite National Park (Fig. 1). The limited number of old-growth stands in the LTB necessitated the use of forest plot data from similar forested ecosystems in the Sierra Nevada and Southern Cascades to better represent the variation in forest structure and site characteristics (e.g., slope, aspect, and elevation). For the LTB, plot and stand-level data (N = 185 plots or transects) on pre-Comstock forest structure were obtained for the studies summarized in Taylor (2000b, 2004), Nagel and Taylor (2005), Barbour et al. (2002), Scholl and Taylor (2006), and Beaty and Taylor (2007, 2008). These studies provided information on the composition, size structure, and/or age structure of trees in forests that were never cut in the LTB (except stump data in Taylor, 2004). For pre-fire suppression conditions in Lassen Volcanic National Park, plot and stand-level data (N = 203 plots) were gathered from previous studies including those in Taylor (1990, 2000a). The Lassen plots provided information on the composition, size structure, coarse woody debris, and/or age structure of forests. For Yosemite National Park, plot and stand-level data (N = 399) were gathered from the Vegetation Type Mapping Project conducted by A.E. Wieslander in the 1930s (Wieslander, 1935). The University of California at Berkeley digitized the Wieslander dataset and it is now available from UC Berkeley (http://vtm.berkeley.edu/). While more plots were available in the Wieslander dataset, we eliminated plots with trees species not represented in the LTB (e.g., *Quercus spp.*) and plots outside the elevational range of the LTB (<1,891 m and >3,318 m). Wieslander recorded stems by species in 30 cm size-classes, necessitating the aggregation of the LTB and Lassen datasets into 30 cm size-classes for classification and modeling purposes. Size classes were 10-30 cm, 30-60 cm, 60-90 cm, and 90+ cm. A total of 746 plots were retained for further analysis from LTB, Lassen, and Yosemite.

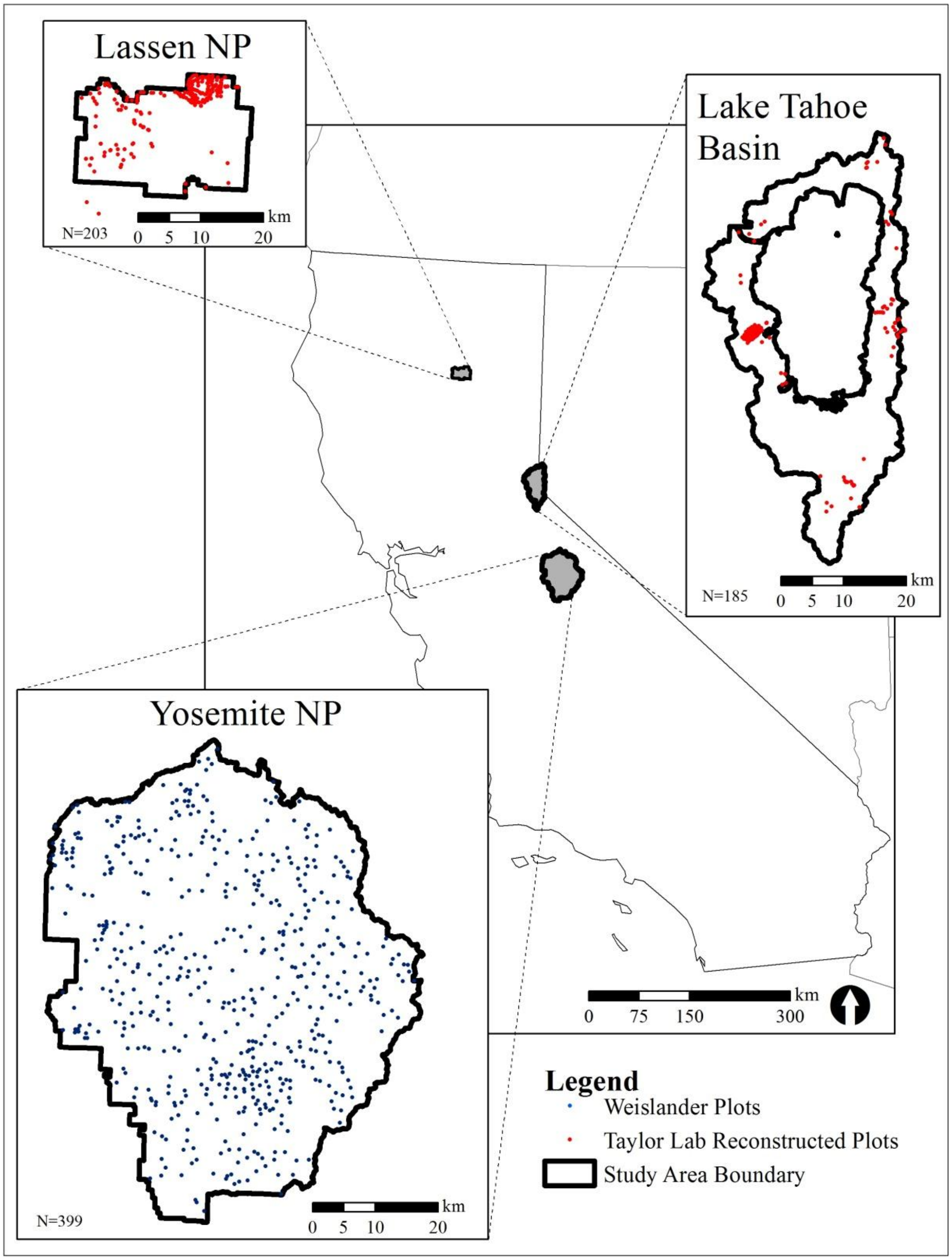

Figure 1. Map of plot locations in the Lake Tahoe Basin (Taylor, 2000b, 2004; Barbour et al., 2002; Nagel and Taylor, 2005; Scholl and Taylor, 2006; Beaty and Taylor, 2007, 2008), Lassen Volcanic National Park (Taylor, 1990, 2000a), and Yosemite National Park, California (Wieslander, 1935).

A preliminary assessment of the LTB, Lassen, and Yosemite datasets indicated that further sampling of additional remnant old-growth forest stands was necessary to ensure a full representation of forest structure and composition, and topographic variables for reconstruction of forest conditions and ecological model development. Consequently, we revisited 136 plots and transects in the LTB to re-measure forest composition and structure. We recorded all coarse woody debris in plots including location, species, and decay class (Maser et al., 1979), and established Brown's planar intercept transects to quantify contemporary surface fuel loads (Brown, 1974). Next, we established 19 new plots in previously undocumented old-growth stands in the LTB to further detail forest composition and structure, coarse woody debris, and site conditions. Finally, because the decay class information for coarse woody debris in Lassen was not collected using Maser et al.'s (1979) criteria, we conservatively classified all course woody debris to a recently downed decay class unless more detailed field notes were available on the status of individual stems. This meant that density and basal could be higher for the reference stand than our estimate because some trees with more decay could have died at an earlier date and would have been alive in the reference stand.

Forest reconstruction

For the LTB and Lassen datasets, forest reference conditions (density, basal area, and diameter at breast height or dbh) for the pre-fire suppression period was reconstructed for plots in uncut forests using dendroecological methods (Fúle et al., 1997). The reference date for the forest reconstruction in the LTB was 1880. Few fires were recorded in fire scar samples in forests on the west or east shore of Lake Tahoe after 1880 (Taylor, 2004; Nagel and Taylor, 2005; Beaty and Taylor, 2007, 2008). In Lassen and Yosemite, the pre-fire suppression period extended into the early 20th century, requiring the reference dates to be adjusted for site-specific land use history. In Lassen, the pre-fire suppression period ended in 1904, the last widespread fire recorded by fire scars (Taylor, 2000a). Reconstructing forest conditions for earlier dates in the LTB and Lassen would be less precise because woody material in the forest would have been consumed by later fires. In Yosemite, the pre-fire suppression period continued until 1899 in some mixed conifer stands in the park (Scholl and Taylor, 2010). Three decades later, Wieslander (1935) surveyed the forest vegetation in the park and found some evidence of recent fires (University of California-Berkeley, 2006). Even if fire was not widespread on the landscape, it is unlikely that regeneration from 1900 to 1930s would have grown into the 10-30 cm size class recorded by Wieslander. Therefore, the Wieslander Yosemite data were assumed to represent the pre-fire suppression era and were not reconstructed further back in time.

Forest reference conditions for the pre-Comstock era in the LTB were reconstructed using measurements of the contemporary forest and the following reconstruction procedure. These steps were modified from Fulé and colleagues (1997, 2002): 1) the diameter of live trees in 1880 (with increment cores to the pith) was determined by subtracting the radial growth from 1880 to the contemporary sampling date; 2) the diameter of live trees in 1880 (with incomplete increment cores or no increment cores) was determined by subtracting species-specific average annual radial growth, estimated from cored trees >100 years old (n = 1509), from the measured diameter for each year from 1880 to the contemporary sampling date; 3) the death date for dead and down trees was estimated using tree decay class and cumulative species-specific decomposition rates calculated from diameter-dependent equations (Thomas, 1979; Rogers, 1984); 4) decomposition rates for each species were calculated for slow (25th percentile), median (50th percentile), and fast (75th percentile) decomposition to estimate the sensitivity of death date estimates to decomposition rates and reference forest structure; and 5) the diameter of dead and down trees alive in 1880 was estimated by subtracting species-specific average annual radial growth from the measured diameter for each year from 1880 to the estimated death date, and adjusted for loss of bark if appropriate. The same methodology was used to reconstruct pre-fire suppression conditions with the Lassen dataset except the target year of reconstruction was 1904. A reconstruction of mixed conifer forest for the year 1899 in Yosemite National Park was statistically similar to 1911 forest survey data in the same location indicating that reconstruction values provide a robust estimate of reference period forest conditions (Scholl and Taylor, 2010). Sensitivity analyses also indicates that estimates of pre-fire suppression tree density, basal area, and tree diameter are not strongly influenced by variation in decomposition conditions used to estimate tree death date (Scholl and Taylor, 2006). Thus, the pre-fire suppression forest condition estimates are robust given the inherent limitations of using dead trees and logs as evidence of the pre-fire suppression forest.

Forest structural type classification

Groups of plots (N = 746) with similar pre-Comstock forest structure and composition were identified using cluster analysis. First, a matrix was developed using the density of each tree species in 30 cm (11.8 inch) size-classes for each plot. Species included white fir (*Abies concolor*), red fir (*Abies magnifica*), Jeffrey pine (*Pinus jeffreyi)* or ponderosa pine (*Pinus ponderosa*), sugar pine (*Pinus lambertiana*), lodgepole pine (Pinus contorta), western white pine (*Pinus monticola*), incense cedar (*Calocedrus decurrens*), and mountain hemlock (*Tsuga mertensiana*). While other species exist in the LTB, such as aspen (*Populus tremuloides*) and whitebark pine (*Pinus albicaulis*), we were not able to locate suitable old-growth sites for reconstruction, necessitating the removal of plots with less abundant species for modeling purposes. Next, Ward's method was used to link plots and relative Euclidean distance was used as the similarity measure (McCune et al., 2002). Ward's method minimizes within-group variance relative to between-group variance, and relative Euclidean distance eliminates differences in total abundance between plots (van Tongeren, 1995). The cluster analysis resulted in five clusters or forest structural groups as determined by a multi-response permutation procedure (MRPP; McCune et al., 2002) that assessed the discrimination of groups identified by the cluster analysis. MRPP is a nonparametric technique used to test the hypothesis of no difference between two or more groups of entities. Following a preliminary assessment of summary statistics for each cluster, we created additional sub-clusters within each of the main five forest structural groups. Forest sub-types were determined by selecting only plots within one of the five main clusters and re-clustering the plots using the same methodology. The analysis resulted in three forest type sub-clusters within each of the five main forest structural types, except for one main forest structural type that had four sub-types selected by the MRPP. In summary, the cluster analysis identified five main forest structural types and 16 forest structural sub-types from the 746 plots used to characterize pre-fire suppression forest structure and composition in the LTB.

Forest structural type spatial modeling

The spatial location of the five main forest types and 16 forest sub-types across the landscape was determined by using a random forest (RF) model and topographic and climatic variables associated with each of the 746 source plots. Random forest models are an extension of classification and regression trees (CART); however, rather than building a single CART model, RF builds hundreds of CART models using randomized subsets of plots and their associated explanatory variables (Cutler et al., 2007). Each CART is a bootstrapped sample representing ~63% of the dataset, with a remaining portion (out-of-bag observations) used to test the percent correct classification of the CART model. Then, the predictions for each of the many CART models are combined to determine the strongest explanatory variables in the RF model. Further explanation of CART and RF is available in De'ath and Fabricus (2000) and Cutler (2007), respectively.

Fourteen topographic and climatic explanatory variables were extracted for each of the plots in the LTB, Lassen, and Yosemite including 11 variables generated from 100-m (1-ha resolution) digital elevation models (DEM; Table 1). The 1-ha resolution was selected because it represented a unit of scale useful to forest managers while maintaining variability in topography across the landscape. In a RF model, there is no penalty on degrees of freedom for including more explanatory variables. DEM-derived variables included elevation (m), slope (degrees), northness and eastness (measures of aspect ranging from -1 [south or west] to 1 [north or east]), average annual solar radiation (watts/m^2), total seasonal solar radiation, topographic wetness index (TWI; a measure of moisture availability derived from local upslope area and slope steepness), and topographic position index (TPI; location on the landscape relative to the surrounding pixels). We also extracted maximum and minimum temperature and total annual precipitation normals (1971-2000; 800-m resolution) from the PRISM Climate Dataset (2011). The climate variables were scaled to 1-ha resolution by assigning the value of the 800-m pixel to the centriods of the 100-m pixels included in the larger grid. While this method of downscaling is crude, our primary objective was to capture the strong precipitation and temperature gradient from west to east across the LTB. We also note that 30-year normals for the contemporary period do not represent the absolute values of pre-Comstock climate; however, our goal with the inclusion of climate data in the explanatory variable pool was to address the relative difference in climate and growing conditions across the LTB.

We considered additional variables including soil characteristics and remote sensing products but changes in land use (i.e., Comstock logging) have altered soil properties and vegetation from their pre-Comstock state, rendering such variables unsuitable as explanatory variables in the RF model. We addressed non-vegetated (i.e., barren or rock) and shrub areas by clipping contemporary non-vegetated and shrub areas greater than 10 ha from the pre-Comstock forest structural type maps. It is assumed that non-vegetated and large areas of shrubs likely existed in the past. For areas of smaller size, the maps represent the potential forest structural type.

Table 1. Summary of physiographic variables used in the random forest models by subtype forest structural groups. ABCO = White Fir; ABMA = Red Fir; PICO = Lodgepole; PIJE = Jeffrey Pine; TSME = Mountain Hemlock; PIMO = Western White Pine.

Main Forest Type	Forest Subtype	Stand ID	Elevation (m)	Eastness	Northness	Slope (degree)	TPI	TWI	Min Temp (°C)	Max Temp (°C)	Precip (cm)	Annual Sol Rad (watts/m^2)	Winter Sol Rad (watts/m^2)	Spring Sol Rad (watts/m^2)	Summer Sol Rad (watts/m^2)	Fall Sol Rad (watts/m^2)
White Fir	ABCO-ABMA-PIJE	1150	2107	0.09	-0.11	15.2	-5.2	5.1	0.1	13.2	114.7	1568262	120543870	122014758	122262330	121282979
	Mid ABCO-PIJE	1250	2157	-0.16	-0.14	21.6	-5.7	4.9	-1.2	12.6	108.1	1537871	120255622	121803826	122061644	121032588
	Small ABCO-PIJE	1450	2058	0.03	-0.05	21.1	-8.7	6.2	-0.3	13.1	112.9	1559501	120168996	121733196	121997741	120963348
	ABCO-PIJE-PILA	11150	2093	-0.23	0.21	16.1	5.5	3.7	0.1	13.4	114.0	1579787	120805540	122187579	122419967	121496928
Jeffrey Pine	Small PIJE-ABCO	4150	2084	-0.02	0.14	21.7	0.6	5.6	-0.6	12.8	112.6	1619917	120559067	121938207	122147387	121267479
	Large PIJE-ABCO	4250	2166	0.00	0.03	21.4	-3.6	5.2	-0.7	12.8	116.5	1573432	120356168	121849445	122110002	121086483
	Mid PIJE-ABCO	4450	2133	0.11	0.02	22.6	1.9	5.5	-0.5	12.8	100.4	1625019	120430362	121792641	122002645	121137702
Red Fir	ABMA-PIMO	2150	2466	0.09	0.08	21.5	3.2	3.9	-1.9	11.2	124.9	1527725	120612908	122005354	122275014	121286505
	Mid-Large-ABMA	2250	2349	-0.09	0.02	16.3	2.2	4.9	-1.1	12.0	128.2	1614111	120721475	122105887	122326046	121415382
	Small ABMA	2350	2281	0.12	0.03	16.1	7.6	4.6	-0.6	12.3	124.8	1615455	120874570	122252888	122465073	121585744
Lodgepole Pine	Small PICO	3150	2175	0.06	-0.06	12.1	-2.3	6.1	-1.5	12.3	129.8	1573458	120523180	122042836	122302465	121304445
	PICO-ABMA	3450	2588	-0.12	0.01	11.3	0.1	3.6	-2.6	11.1	123.2	1695710	121092762	122411954	122604631	121752705
	PICO-TSME	31250	2754	-0.11	-0.05	10.2	-0.3	3.2	-3.8	10.1	123.8	1705576	121113163	122410887	122596997	121751116
Subalpine	TSME-ABMA	5150	2668	0.02	-0.11	15.1	-2.3	3.1	-3.2	10.1	151.1	1515822	120935506	122250110	122452844	121576626
	TSME-PIMO	5350	2717	-0.23	0.01	14.1	9.8	3.3	-3.2	9.8	165.8	1661994	121021831	122385768	122598414	121714956
	Not present in LTB	51550	2802	-0.11	0.20	11.5	-3.4	2.8	-4.5	9.5	135.5	1713950	121148484	122473354	122658615	121806394

Fire regime data and spatial modeling

Data on pre-Comstock fire regimes and topography were compiled from the location of samples of wood with crossdated fire scars (N = 134 from LTB and N = 92 from Lassen) in studies summarized in Taylor (2000a), Taylor and Beaty (2005), Nagel and Taylor (2005), Scholl and Taylor (2006), and Taylor and Beaty (2007, 2008). These samples provided information on the pre-fire suppression mean point fire return interval and season of fire in lower (i.e., pine and white fir) and upper (i.e., red fir and western white pine) montane forests (Table 2). Samples were distributed over a broad range of elevation, slope, and aspect.

Table 2. Sampling locations and mean point fire return intervals for forest types including in the random forest model that was used to distribute fire frequency in the LTB. PFRI = point fire return interval; CE = Common Era.

Location	Forest Type	Mean PFRI (years)	Period	Species Sampled	N
Lake Tahoe Basin	Mixed Conifer	19.6	1122 - 1998 CE	Jeffrey Pine, Incense Cedar, Ponderosa Pine, Sugar Pine	134
Lassen Volcanic National Park	Mixed Conifer	26.7	1523 - 1994 CE	Jeffrey Pine, Ponderosa Pine	53
Lassen Volcanic National Park	Red Fir	73.8	1728 - 1994 CE	Red Fir, Western White Pine	39

A spatially explicit representation of fire frequency (point fire return interval or PFRI) was derived using a RF model and seven DEM-derived explanatory variables including elevation, slope, TPI, TWI, total annual solar radiation, and northness and eastness. We did not use our reconstructed forest type as an explanatory variable because pre-fire suppression forests were not distributed across the landscape for Lassen, where a portion of the samples were collected. The RF model of fire frequency differed from the RF model of forest classification because fire frequency was a continuous variable and goodness of fit statistics on the out-of-bag samples were reported rather than percent correct classification.

Surface fuels

Two methods were used to estimate pre-Comstock surface fuel loads for median stand conditions. The Fire and Fuels Extension of the Forest Vegetation Simulator (FFE-FVS; Western Sierra Variant) was used to estimate fuel loads from the list of trees (species and diameter) from the reconstructed forest structural subtypes. Fuel was accumulated in each plot for a period of years equal to the observed point fire return interval modeled above and assigned to each forest subtype. Because forest subtypes overlapped with a continuous range of point fire return intervals from 12.9 to 95.8 years, we chose to classify the point fire return interval range into 5 equal size categories and assigned the middle value for each category (21, 38, 55, 71, and 87 years). Then, we assigned the most common fire return interval category that overlapped with each forest subtype (see Table 9 for fire return interval and fuel estimates). This assignment resulted in only the 21-, 38-, and 55-year categories being used for fuel accumulation. Finally, surface fuel estimates were output by time-lag size class from FFE-FVS.

The second estimation method used van Wagtendonk and Moore's (2010) annual fuel deposition rate tables to calculate an annual fuel deposition for each tree in a forest structural subtypes (Tables Method). The tables provided annual fuel deposition rates by fuel time-lag size class for each species and size class in a plot with a specified basal area. Each tree in the reconstructed plot was assumed to deposit an amount of fuel proportional to the percentage of the total stand basal area, as reported in van Wagtendonk and Moore (2010). Fuel was then accumulated for a period of years equal to the modeled point fire return interval categories (described above), accounting for time-lag size class specific fuel decomposition at the rates used by FFE-FVS. The fuel load in each time-lag class for each plot was the estimated by summing values for each tree in the forest subtype tree list.

The fuel estimates from the different methods were then used to choose the most similar standard fuel models (Anderson, 1982; Scott and Burgan, 2005) for each subtype forest structural group using the Fuels Management Analyst (FMA). FMA was also used to estimate potential surface fire behavior for each of the 15 forest subtypes. To more accurately estimate fire behavior in our subtype stands, we added seedling and saplings to each forest subtype tree list. Seedling (range 7-22 stems/ha) and sapling (range 19-56 stems/ha) numbers were estimated from contemporary plot data in the LTB for plots representing the five main forest types. Without a seedling and sapling canopy layer, the fuel ladder is discontinuous and the likelihood of crown fire is diminished. Crown fuel variables were estimated for tree lists in each subtype, using the Crown Mass routine in FMA, to calculate potential crown fire behavior (Carlton, 2008). Potential surface fire behavior for pre-Comstock forests was simulated using Crown Mass in FMA (Carlton, 2008). Crown Mass calculates potential fire behavior and some first order fire effects from stand tree list that include tree species, dbh, tree height, crown ratio, and structural stage. The crown ratio and tree height were derived from the list of tree species and tree diameters using FVS.

Fire behavior

We used standard surface fuel models to estimate potential fire behavior rather than custom models because we did not have a way to calibrate custom pre-Comstock fire behavior models with observations of actual fire behavior (Rothermel and Rinehart, 1983; Burgan and Rothermel, 1984). The standard models have been calibrated with observed fire behavior under conditions similar to those simulated in the model runs. We chose standard surface fuel models for each subtype forest structural group by entering our surface fuel estimates from FFE-FVS and Tables Method into the Crown Mass module of FMA which compares observed fuel loads to standard fuel models. We selected the standard fuel model with the lowest % difference using suggested weighting factors (Anderson, 1982; Scott and Burgan, 2005).

Fire intensity depends on weather conditions and fuel moisture content, or weight of water/dry weight of fuel (Reinhardt and Crookston, 2003). We were interested in fire behavior and effects under the most extreme fire weather conditions. Therefore, potential fire behavior was calculated for the 98th percentile weather conditions with FireFamily Plus using data from the Truckee remote automated weather station (RAWS) for the months of the fire season (June 1 to September 31), to represent extreme fire weather conditions (Table 3; Bradshaw and Brittain, 1999). Simulations of potential fire behavior were computed for each subtype under extreme weather conditions and each of the standard fuel models selected. We chose five variables to represent potential fire behavior: 1) rate of spread, 2) flame length, 3) crowning index (minimum windspeed to support active crown fire), 4) torching index (windspeed at 6.06 m above the ground needed to ignite the crown), and 5) categorical crown fire type (surface, passive crown fire, active crown fire). Additionally, we provide estimates of tree mortality by diameter class for each subtype and fuel model to characterize fire effects on individual stems.

Table 3. Upper 98th percentile weather conditions for weather and fuel moisture used for fire behavior simulations for pre-Comstock forest conditions in the Lake Tahoe Basin, USA. Data are from the Truckee, California remote automated weather station May-October 1961-2006. Foliar moisture was assumed to be 80% under 98th percentile conditions weather conditions.

Climate Variable	98th percentile
Dry bulb temperature (°C)	30.6
Low relative humidity (%)	5
High relative humidity (%)	100
Wind speed (km h^{-1})	32
Fuel moisture	
1-h (%)	2
10-h (%)	3
100-h (%)	5
Live woody (%)	70
Foliar moisture content (%)	80

Results

Forest structure

The forest reconstruction method for LTB forests was not sensitive to variation in decomposition percentile class (Table 4). There were no differences in the reconstructed mean density, basal area, or diameter for the low, moderate, and high decomposition models (p > 0.05, ANOVA). Since the LTB reconstruction was not sensitive to variation in decomposition model, we report only the results for the 50th percentile model in both the LTB and Lassen Volcanic National Park. Note that the Lassen reconstruction used only the 50th percentile model because of non-specified decay class for coarse woody debris.

The cluster analysis and MRPP resulted in five main forest structure groups: White Fir, Jeffrey Pine, Red Fir, Lodgepole Pine, and Subalpine (Tables 5 and Fig. 2). Each group has a defined density and basal area by 30 cm diameter class and tree species. The White Fir group had a median 200 stems and 41.1 m^{3} per ha and basal area was dominated by white fir (64.9% relative abundance) followed by Jeffrey pine (17%).

The Jeffrey pine group had the fewest stems per ha (113) and the lowest median basal area (29.6 m^3/ha). The most dense forest structural group was the Subalpine group (330 stems/ha) which was dominated by mountain hemlock (65.8%) with smaller amounts of lodgepole pine (16.5%), western white pine (11.0%), and red fir (6.2%). The Red Fir group had the highest basal area with 54.8 m^3/ha and was primarily composed of red fir (71.9%) and western white pine (14.9%). Please note that data are available online via the USFS by 30-cm diameter class, including minimum and maximum values for density and basal area.

Table 4. Mean diameter (cm), basal area (m^2/ha), and density (stems/ha) for the pre-Comstock forest estimated using three decomposition condition models (25^{th} percentile, 50^{th} percentile, 75^{th} percentile). Values are for trees >10 cm dbh. Decomposition classes were not significantly different (ANOVA, $p > 0.05$).

	25th %tile	**50th %tile**	**75th %tile**
Diameter	36.79	37.13	36.27
Basal Area	40.53	37.48	35.66
Density	235.07	217.45	212.41

We further parsed the main forest groups into subtypes based on forest structure to better understand within group variability of species composition, density, and basal area (Table 6). The cluster analysis and MRPP within each main group resulted in three subtypes for each main group, except the White Fir group which had four subtypes. Subtypes were named by the dominant one or two species in the group and a “small”, “mid”, or “large” diameter descriptor of the most dominant species (where appropriate). Of the four White Fir subtypes, the Small ABCO-PIJE subtype (white fir-Jeffrey pine) was most abundant (23.6% of LTB area) in terms of the percentage of the LTB covered by the forest subtype (Tables 5 and 6). Small ABCO-PIJE had a median density of 206.5 stems/ha and occupied moist, low elevation (2058 m) sites that are lower in topographic position compared to the surrounding forest. The Large PIJE-ABCO (Jeffrey pine-white fir) subtype was most abundant (16.3% of LTB area) in the Jeffrey Pine forest group and had 95.1 stems/ha. Large PIJE-ABCO occupied moister and higher elevation (2166 m) sites than the rest of the main forest group. The Mid-Large ABMA (red fir) subtype was most abundant (36.9% of LTB area) in the Red Fir forest group and had 225 stems/ha. Mid-Large ABMA occupied moist, mid-elevations (2349 m) within the overall forest type. PICO-TSME (lodgepole pine) was the most abundant (4.8% of LTB area) subtype within the Lodgepole Pine forest type and had 200.0 stems/ha. PICO-TSME occupied moist, low elevation (2175 m) sites. Finally, the Subalpine forest type occupied the highest elevations but sparsely populated the landscape. The Subalpine subtypes are differentiated mostly by slope position, with TSME-ABMA (mountain hemlock-red fir; 340 stems/ha and 0.7% of LTB area) occupying the slope positions topographically below the surrounding area.

Table 5. Percent coverage of the Lake Tahoe Basin, median density, median basal area, and relative abundance (%) of each species for the five main forest structural types. Contemporary % basin coverage is from Manley et al. (2000). Please note that data are available online via the USFS by 30-cm diameter class, including minimum and maximum values for density and basal area.

Main Forest Type	Pre-Comstock % Basin Coverage	Contemporary % Basin Coverage	Median Density (stems/ha)	Median Basal Area (m^3/ha)	Relative Abundance (% of Forest Type)							
					White Fir	Red Fir	Lodgepole Pine	Jeffrey Pine	Incense Cedar	Sugar Pine	White Pine	Mountain Hemlock
White Fir	24.9	32.7	200	41.1	64.9	9.6	0.7	17.0	1.4	6.0	0.4	0.0
Jeffrey Pine	20.4	23.3	113	29.6	21.4	3.6	0.2	69.9	2.8	1.9	0.1	0.0
Red Fir	47.6	8.7	228	54.8	4.1	71.9	3.1	3.2	0.6	1.3	14.9	0.9
Lodgepole	5.9	14.1	289	45.1	1.6	8.8	82.0	1.5	0.0	0.0	3.0	3.0
Subalpine	1.1	21.1	330	50.7	0.0	6.2	16.5	0.0	0.5	0.0	11.0	65.8

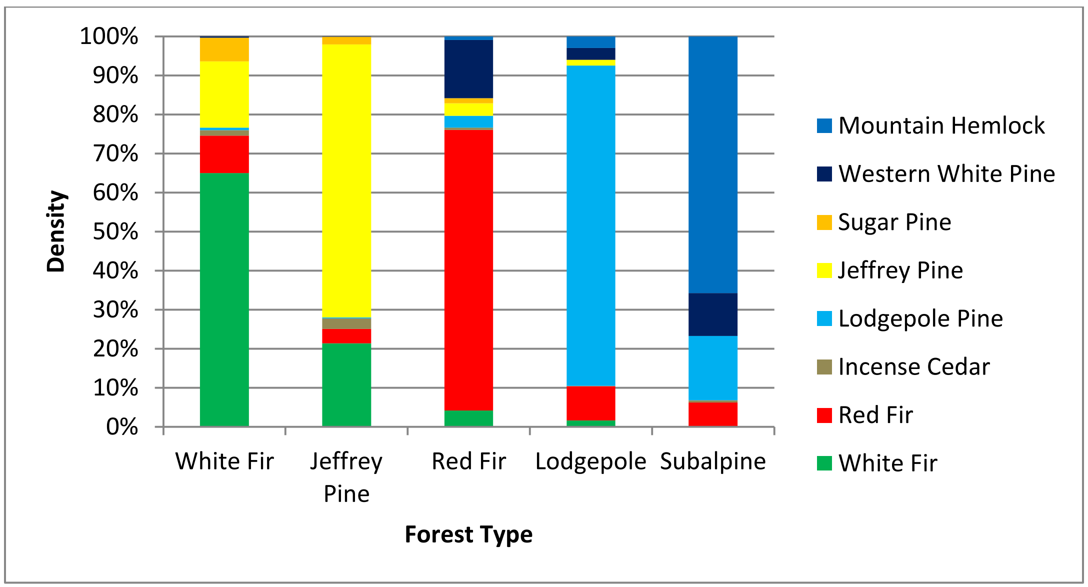

Figure 2. Relative abundance (%) of species as determined by density in each of the five main forest structural types.

Table 6. Median density (stems/ha), basal area (m^3/ha), and relative abundance by species for the 15 subtype forest structural groups. (Note that one subalpine subtype was removed because the random forest model did not find suitable ecophysiographic conditions for the group in the LTB.) Please note that data are available online via the USFS by 30-cm diameter class, including minimum and maximum values for density and basal area.

Main Forest Type	Forest Subtype	Stand ID	% Basin Coverage	Median Density (stems/ha)	Median Basal Area (m^2/ha)	Relative Abundance (% of Subtype) White Fir	Red Fir	Lodgepole Pine	Jeffrey Pine	Incense Cedar	Sugar Pine	White Pine	Mountain Hemlock
White Fir	ABCO-PIJE-PILA	11150	0.08	154.00	61.40	45.09	2.67	0.00	28.32	0.84	23.08	0.00	0.00
	ABCO-ABMA-PIJE	1150	1.12	220.00	50.20	48.16	25.54	0.00	13.81	2.08	9.85	0.55	0.00
	Mid ABCO-PIJE	1250	0.09	182.50	45.00	67.08	3.97	2.69	24.95	0.00	0.00	1.31	0.00
	Small ABCO-PIJE	1450	23.64	206.50	30.70	78.50	1.67	0.78	15.24	1.40	1.81	0.14	0.00
Jeffrey Pine	Small PIJE-ABCO	4150	1.16	150.00	24.70	23.95	0.47	0.03	74.19	0.80	0.43	0.13	0.00
	Large PIJE-ABCO	4250	16.34	95.11	39.80	12.76	9.41	0.45	65.12	7.73	4.28	0.25	0.00
	Mid PIJE-ABCO	4450	2.93	93.00	27.30	26.23	3.40	0.33	66.81	0.98	2.26	0.00	0.00
Red Fir	ABMA-PIMO	2150	10.72	178.00	46.40	4.24	25.62	7.82	1.60	0.30	0.29	56.93	3.20
	Mid-Large-ABMA	2250	36.87	225.00	56.70	4.38	78.61	2.75	4.12	1.03	1.39	7.58	0.13
	Small ABMA	2350	0.02	300.00	58.90	3.68	83.33	1.36	2.58	0.00	1.54	6.45	1.05
Lodgepole Pine	PICO-TSME	3150	4.78	200.00	15.10	6.18	3.44	84.08	4.89	0.08	0.00	0.76	0.57
	Small PICO	3450	0.78	351.00	54.20	0.13	13.74	80.62	0.58	0.00	0.07	3.84	1.03
	PICO-ABMA	31250	0.33	264.50	59.60	0.16	4.64	82.81	0.00	0.00	0.05	3.56	8.79
Subalpine	TSME-ABMA	5150	0.66	340.00	66.50	0.13	12.74	12.06	0.00	0.26	0.00	9.71	65.09
	TSME-PIMO	5350	0.47	322.00	46.10	0.00	2.40	1.47	0.00	1.17	0.00	16.88	78.08

Spatial modeling

The main and subtype forest structural groups were distributed across the LTB using random forest models. For the main groups, the overall percent correct classification was 51.5% with a kappa of 0.37 (Table 7). When the White Fir and Jeffrey Pine groups were allowed to overlap to account for the overlap observed in mixed conifer forests, the overall percent (fuzzy) correct classification increased to 62.7%. The Red Fir group had the highest percent correct classification (62.3%) and the Jeffrey Pine group had the lowest percent correct classification (30.3%). The most important variables explaining spatial variation in forest structural types were elevation followed by maximum temperature, slope, minimum temperature, precipitation, and summer solar radiation (Fig. 3). The spatial reconstruction of pre-Comstock forests using the five main forest structural groups shows several distinct patterns (Fig. 4). First, the White Fir (24.9% of LTB area) and Jeffrey Pine (20.4% of LTB area) groups were dominant in the lower elevations on the west and east shores, respectively. Second, the Red Fir group (47.6% of LTB area) was dominant in the upper elevations above the White Fir and Jeffrey Pine groups and was present on all sides of the basin. Third, the Lodgepole Pine group (5.9% of LTB area) was present in two distinct areas, high elevations above the Red Fir group and flat, low elevation areas. Fourth, the high elevation Subalpine group (1.1% of LTB area) was the least dominant forest type restricted to the interface between the Red Fir and Lodgepole Pine groups.

Table 7. Random forest results for main forest structural groups. N is the number of plots assigned to each group during cluster analysis. For the % Fuzzy Correct, the White Fir and Jeffrey Pine groups were considered correctly classified if either White Fir or Jeffrey Pine was chosen as a classification. This adjustment allowed for the overlap that is common in mixed conifer forests. GLO % correct is the assessment of classification error between the GLO forest structural types and the modeled forest structural types.

Main Group	N	% Correct	% Fuzzy Correct	GLO % Correct
White Fir	158	52.5	71.5	25.4
Red Fir	207	62.3	62.3	66.3
Lodgepole	194	58.2	58.2	16.7
Jeffrey Pine	119	30.3	74.8	57.8
Subalpine	67	34.3	34.3	28.6
Total	745	51.5	62.7	50.5
Kappa	.	0.37	0.51	.

For the subtype forest structural group random forest models, the overall percent correct classification averaged 47.8% (Table 8). The Jeffrey Pine subtype group model had the highest with 60.3% correct classification while the Subalpine group had the lowest at 40.3% correct. Kappa values were lower (range 0.06 – 0.38) for the subtype models but still showed some explanatory power, allowing for a more spatially detailed understanding of subtype forest structural groups within each of the five main forest structural groups. The spatial reconstruction of the pre-Comstock forest structural subtypes showed that some subtypes were more prevalent than others (Fig. 5 and Table 6). One of the Subalpine subtype groups was not mapped in the basin because suitable topographic conditions were not found in the basin despite their inclusion in the random forest model. Therefore, we excluded this subtype forest structural group from further analysis, resulting in 15 subtype groups.

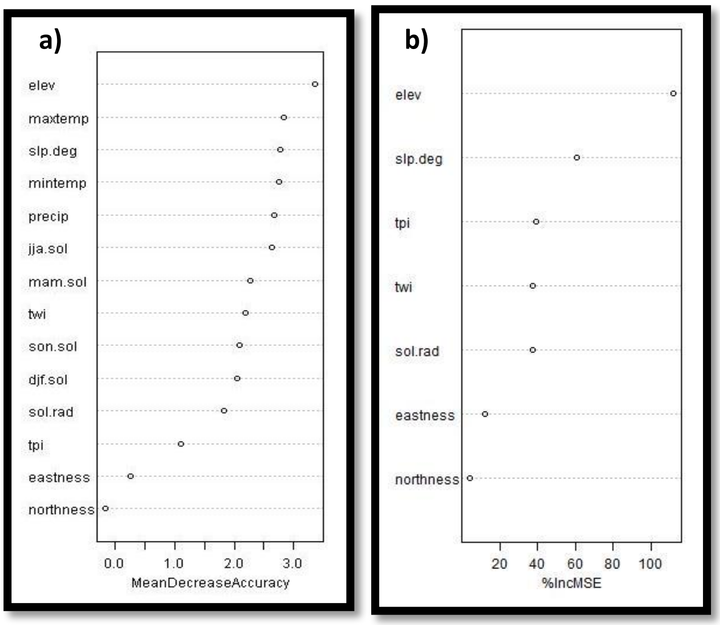

Figure 3. Random forest model results showing the explanatory power of each predictor variable for the main forest structural groups (a) and point fire return interval models (b). In panel a, the model classified the main forest structural groups and predictor strength was assessed by the mean decrease in accuracy when predictor variables were not included in the classification model. In panel b, the model regressed point fire return interval against the continuous predictors and was assessed by the percent increase in the mean square error (MSE) when predictor variables were not included in the regression model. Results for each of the subtype models are not shown.

Table 8. Random forest results for subtype forest structural group models. Random forest models were used to distribute the subtype groups within the distributions of each main forest group. % Correct is the overall classification and range is the range of % correct classification among forest subtypes.

Subtype Group Model	Kappa	% Correct	Range
White Fir	0.1	44.3	0 - 68
Red Fir	0.14	44.5	15 - 73
Lodgepole	0.06	49.8	39 - 70
Jeffrey Pine	0.38	60.3	25 - 61
Subalpine	0.2	40.3	21 - 58

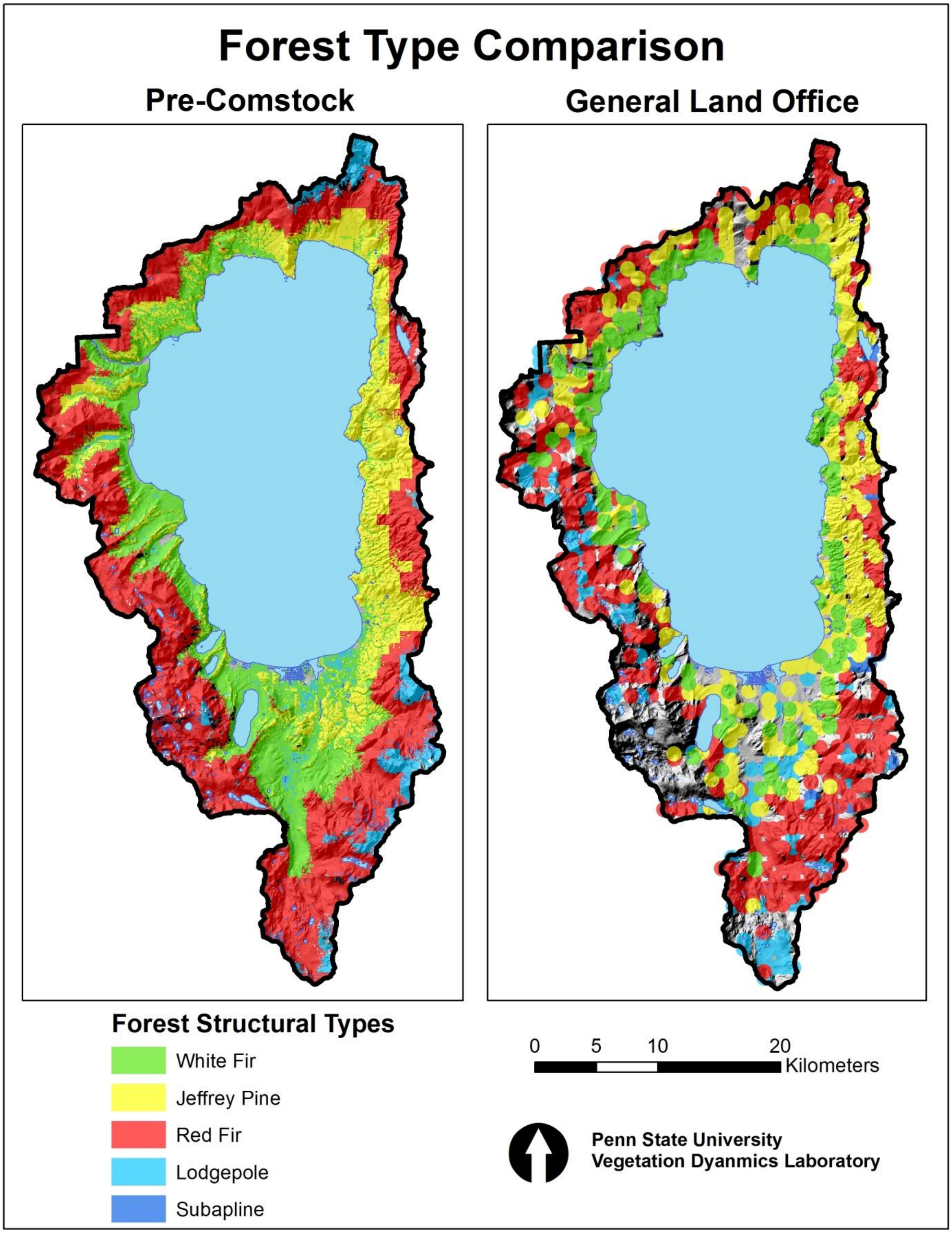

Figure 4. Spatially explicit representation of pre-Comstock the five main forest structural groups in the LTB and a comparison to a forest type mapped created from GLO survey records collected in the late 1850s.

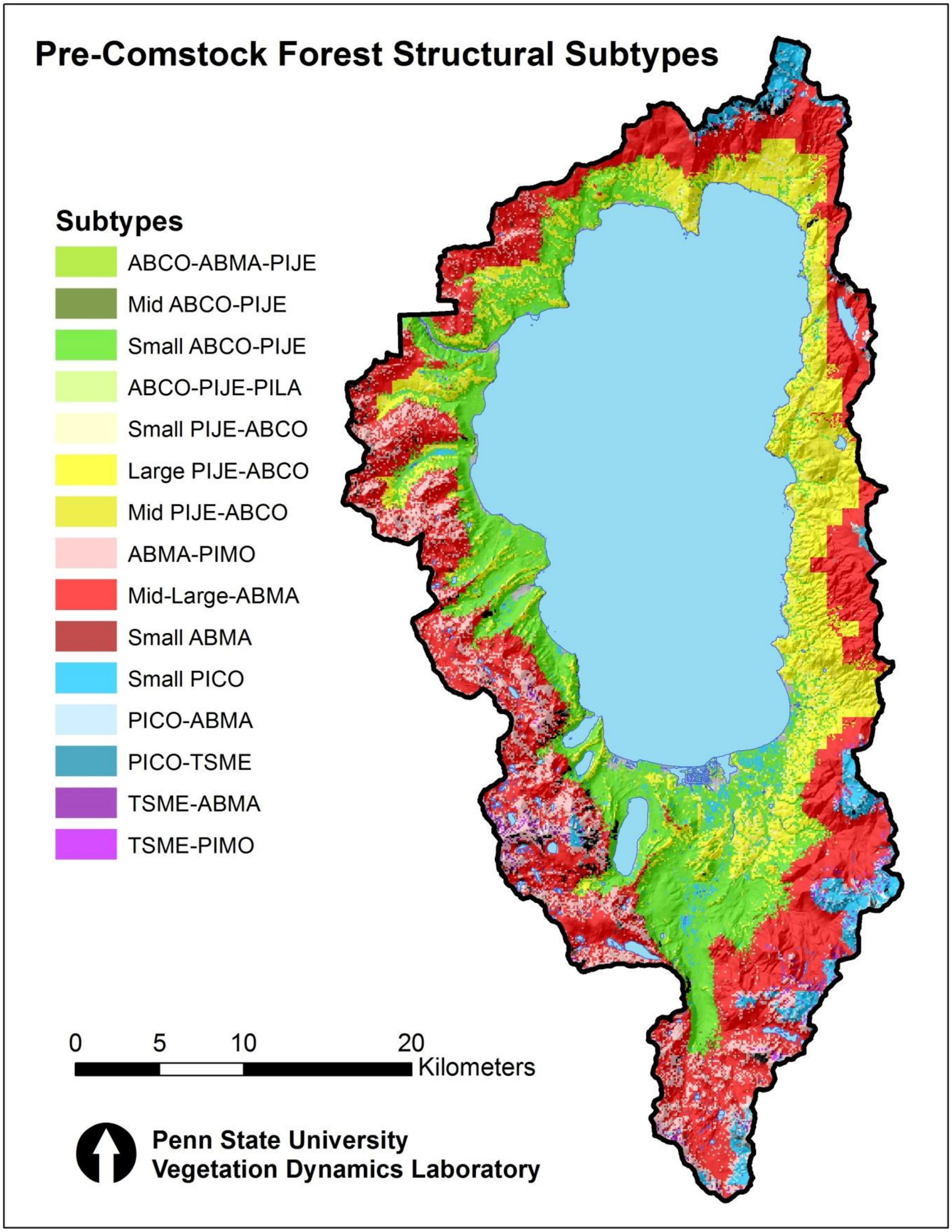

Figure 5. Spatially explicit representation of pre-Comstock the 15 subtype forest structural groups in the LTB. ABCO = White Fir; ABMA = Red Fir; PICO = Lodgepole; PIJE = Jeffrey Pine; PIMO = Western White Pine; TSME = Mountain Hemlock.

Fire regime data and spatial modeling

Point fire return interval was distributed across the LTB with a random forest model resulting in 67% of the variance explained in the fire-scar derived PFRI data. Elevation was the primary explanatory variable followed by slope, TPI, TWI, and annual solar radiation (Fig. 6). Modeled PFRI values ranged from 13-95 years. Fire seasonality was also calculated for both the mixed conifer and high elevation fire-scarred samples. Seasonality was determined for 63% of the mixed conifer samples and 75% of the high elevation samples. Of the samples with a determined seasonality, the majority of fire events occurred in the dormant season for both mixed conifer (98.5%) and high elevation (81.6%) forests. The spatial reconstruction of pre-fire suppression PFRI is clearly influenced by the elevational gradient from the lake to the Tahoe Rim showing a decrease in fire frequency with an increase elevation (Fig. 6). For display and accumulation of surface fuels by subtype forest structural group, the map of modeled PFRI was categorized into five fire frequency classes (see above).

Fuels and fire behavior

Estimates of surface fuels varied by method (Table 9). The FFE-FVS method generally produced lower amounts of total 1-HR, 10-HR, and 100-HR fuels for the White Fir and Jeffrey Pine subtype forest structural groups than the Tables Method, and higher amounts than the Tables Method for the Red Fir, Lodgepole, and Subalpine subtypes. This difference in surface fuel estimates was reflected in the FMA suggestion of a surface fuel model for each subtype with only one subtype having the same fuel model suggestion (Table 10 and Fig. 7). Fuel models ranged from 8.96 mg/ha total 1-100 HR fuels (TU2) to 24.64 mg/ha total 1-100 HR fuels (TU5). However, the most common fuel models were TL4 (13.89 mg/ha total 1-100 HR fuels) and TL5 (18.03 mg/ha total 1-100 HR fuels) for the FVS and Tables Methods, respectively, showing that FMA model suggestions for FVS and the Tables Method were similar for some subtypes. Under the 98th percentile fire weather conditions, the White Fir subtypes showed potential for passive crown fires using four different surface fuel models. All other subtypes were classified as surface fire regimes. However, the Lodgepole and Subalpine subtypes showed high mortality of stems with surface fire with the heavier surface fuel models (e.g., TU05 and FB10) despite the lack of crown fire (Fig. 8). Spatially explicit representations of fuel models in the LTB were created by mapping the fuel model (FVS and Tables Method recommendations) in place of the forest structural subtypes (Fig. 7).

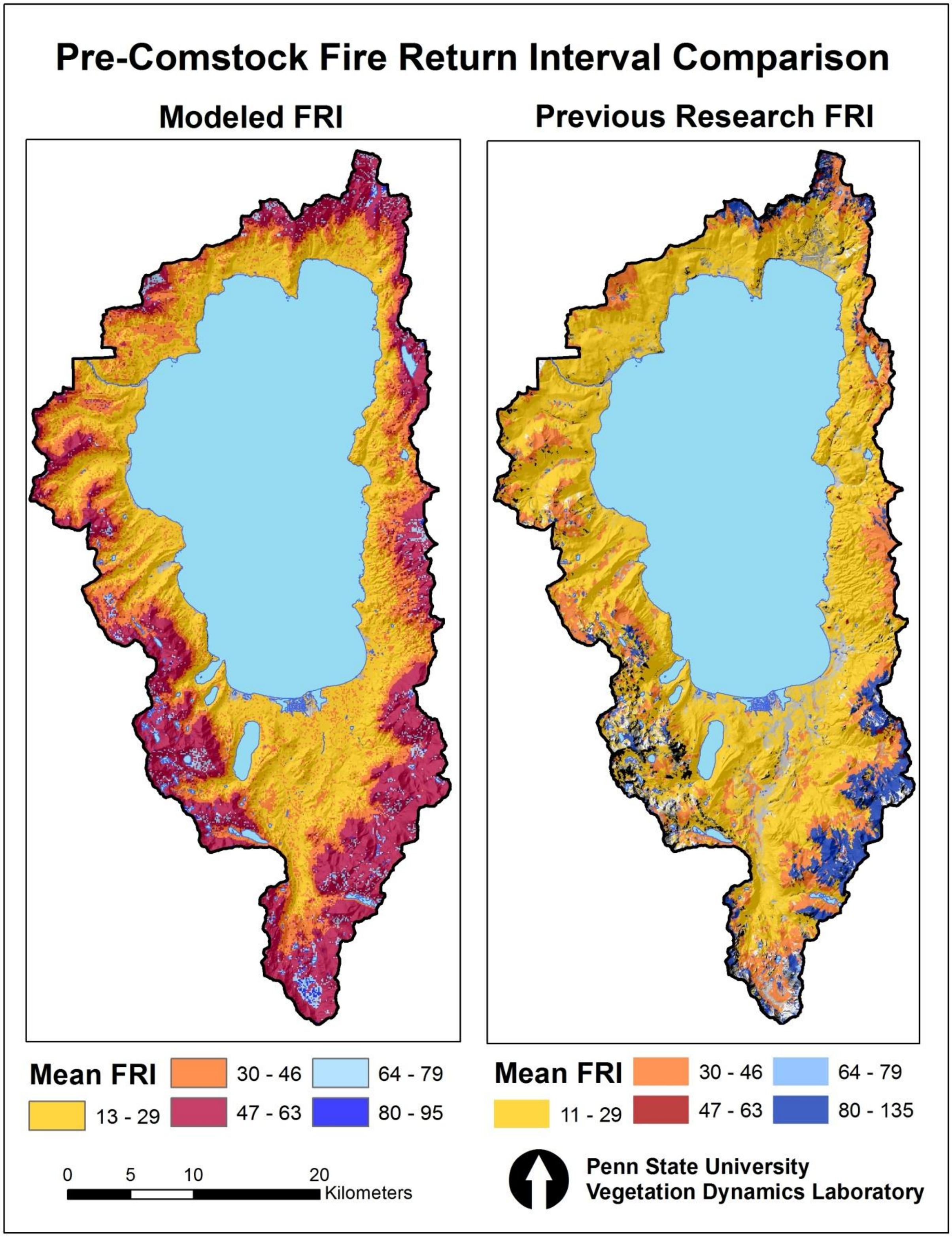

Figure 6. Spatially explicit representation of pre-Comstock point fire return interval (FRI) in the LTB distributed using a random forest model and a comparison to the Fire Return Interval Departure map created from published data for LTB (Van de Water and Safford 2011).

Table 9. FFE-FVS and Tables Method (van Wagtendonk and Moore 2010) surface fuels by subtype forest structural group and calculated using median stand conditions. The Tables Method did not produce estimates of duff. Fuel models were suggested by FMA and the model with the least % difference was selected. FRI = Fire Return Interval. Fuel loads are in mg/ha and canopy bulk density (CBD) is in kg/m^3.

Main Forest Type	Forest Subtype	Stand ID	FRI	1-HR		10-HR		100-HR		1s-100s Total		1000-HR		LITTER		DUFF		CBD		Fuel Model	
				FVS	Tables	FVS	Tables	FVS	Tables	FVS	Tables	FVS	Tables	FVS	Tables	FVS	Tables	FVS	Tables	FVS	Tables
White Fir	ABCO-ABMA-PIJE	1150	21	1.05	2.60	1.70	3.81	3.52	5.17	6.27	11.56	10.80	3.23	1.66	2.76	28.81	.	0.04	0.02	TL04	TL05
	Mid ABCO-PIJE	1250	38	1.25	6.68	2.51	6.43	6.50	16.76	10.26	29.84	10.28	19.42	2.26	4.55	33.31	.	0.04	0.02	TL04	FB10
	Small ABCO-PIJE	1450	21	1.52	2.80	2.67	8.09	4.32	4.64	8.51	15.52	15.21	1.16	2.51	6.54	32.55	.	0.05	0.03	TL05	TU02
	ABCO-PIJE-PILA	11150	21	1.05	1.93	1.77	2.44	3.09	1.19	5.91	5.56	10.04	0.18	1.93	1.52	29.50	.	0.05	0.04	TL04	TL05
Red Fir	ABMA-PIMO	2150	55	4.12	3.32	6.16	2.37	11.11	1.03	21.39	6.74	8.13	0.99	2.17	1.01	21.15	.	0.04	0.02	FB10	TL05
	Mid-Large-ABMA	2250	55	3.49	2.82	8.89	3.58	16.15	1.70	28.54	8.11	12.32	7.50	4.08	2.91	33.11	.	0.10	0.04	TU02	TL05
	Small ABMA	2350	21	1.61	2.11	3.07	2.40	5.60	1.12	10.28	5.64	12.21	2.58	3.43	2.31	34.43	.	0.11	0.04	TL05	TL05
Lodgepole Pine	Small PICO	3150	55	3.61	0.34	4.55	0.02	5.26	0.00	13.42	0.36	6.79	0.00	3.63	0.74	18.10	.	0.06	0.02	TL05	FB08
	PICO-ABMA	3450	55	10.44	3.79	14.13	3.67	25.36	1.79	49.93	9.25	41.60	0.00	2.69	6.56	26.99	.	0.04	0.03	TU05	TL05
	PICO-TSME	31250	55	9.03	2.35	11.49	1.86	18.88	0.90	39.40	5.11	23.68	0.00	4.08	4.28	26.10	.	0.05	0.04	TU05	TL04
Jeffrey Pine	Small PIJE-ABCO	4150	21	0.96	0.20	1.23	0.69	1.34	0.29	3.54	1.19	11.04	0.00	1.66	1.84	18.77	.	0.02	0.02	TL04	TL03
	Large PIJE-ABCO	4250	21	1.41	0.27	1.88	10.84	2.67	4.52	5.96	15.64	15.95	0.00	1.50	9.30	24.44	.	0.02	0.01	TL04	TL07
	Mid PIJE-ABCO	4450	21	0.96	0.13	1.23	2.89	1.48	1.21	3.67	4.23	11.29	0.00	0.92	3.23	18.28	.	0.01	0.01	TL04	TL07
Subalpine	TSME-ABMA	5150	55	7.21	2.69	9.45	3.25	16.13	1.50	32.79	7.44	13.15	8.18	3.52	2.73	23.79	.	0.05	0.03	FB10	TL05
	TSME-PIMO	5350	55	10.84	3.34	13.91	3.36	19.69	1.55	44.44	8.27	50.42	6.63	4.55	4.46	29.93	.	0.06	0.05	TU05	TL05

Table 10. Simulated fire behavior under extreme (98th percentile) weather conditions for each subtype forest structural group. Fire types are surface (S), passive crown (PC), and active crown (AC). Fuel models from either Scott and Burgan (2005) or Anderson (1982).

Main Forest Type	Forest Subtype	Stand ID	Fuel Model	Flame length (m)	Rate of spread (m/h)	Torching index (km/h)	Crowning Index (km/h)	Fire Type
White Fir	ABCO-ABMA-PIJE	11501	TL4	1.4	0.6	4.9	61.0	Passive Crown Fire
			TL5	2.7	1.0	0.0	61.0	Passive Crown Fire
	Mid ABCO-PIJE	12501	TL4	1.5	0.6	4.2	64.1	Passive Crown Fire
			FB10	5.4	2.4	0.0	64.1	Passive Crown Fire
	Small ABCO-PIJE	14501	TL5	2.7	1.0	0.0	50.9	Passive Crown Fire
			TU2	7.2	1.6	0.0	50.8	Passive Crown Fire
	ABCO-PIJE-PILA	111501	TL4	1.4	0.6	4.9	55.5	Passive Crown Fire
			TL5	2.7	1.0	0.0	55.5	Passive Crown Fire
Red Fir	ABMA-PIMO	21501	FB10	5.4	2.4	38.4	83.2	Surface Fire
			TL5	2.7	1.0	158.6	83.2	Surface Fire
	Mid-Large-ABMA	22501	TU2	7.1	1.6	66.5	40.3	Surface Fire
			TL5	2.7	1.0	148.7	40.4	Surface Fire
	Small ABMA	23501	TL5	2.7	1.0	128.8	39.2	Surface Fire
			TL5	1.5	0.6	299.7	39.2	Surface Fire
Lodgepole Pine	Small PICO	31501	TL5	2.7	1.0	114.2	68.0	Surface Fire
			FB8	1.2	0.5	277.8	68.0	Surface Fire
	PICO-ABMA	34501	TU5	5.0	3.2	20.5	49.1	Surface Fire
			TL5	2.7	1.0	133.8	49.1	Surface Fire
	PICO-TSME	312501	TU5	5.0	3.2	20.6	42.9	Surface Fire
			TL4	1.4	0.6	311.8	42.9	Surface Fire
Jeffrey Pine	Small PIJE-ABCO	41501	TL4	1.5	0.6	205.4	83.2	Surface Fire
			TL3	1.0	0.5	318.5	83.2	Surface Fire
	Large PIJE-ABCO	42501	TL4	1.5	0.6	0.0	110.7	Surface Fire
			TL7	1.6	0.9	0.0	110.7	Surface Fire
	Mid PIJE-ABCO	44501	TL4	1.5	0.6	0.0	147.1	Surface Fire
			TL7	1.6	0.9	0.0	147.2	Surface Fire
Subalpine	TSME-ABMA	51501	FB10	5.1	3.2	24.4	35.4	Surface Fire
			TL5	2.7	1.0	153.7	35.4	Surface Fire
	TSME-PIMO	53501	TU05	5.3	2.4	32.4	51.0	Surface Fire
			TL5	2.7	1.0	133.8	51.0	Surface Fire

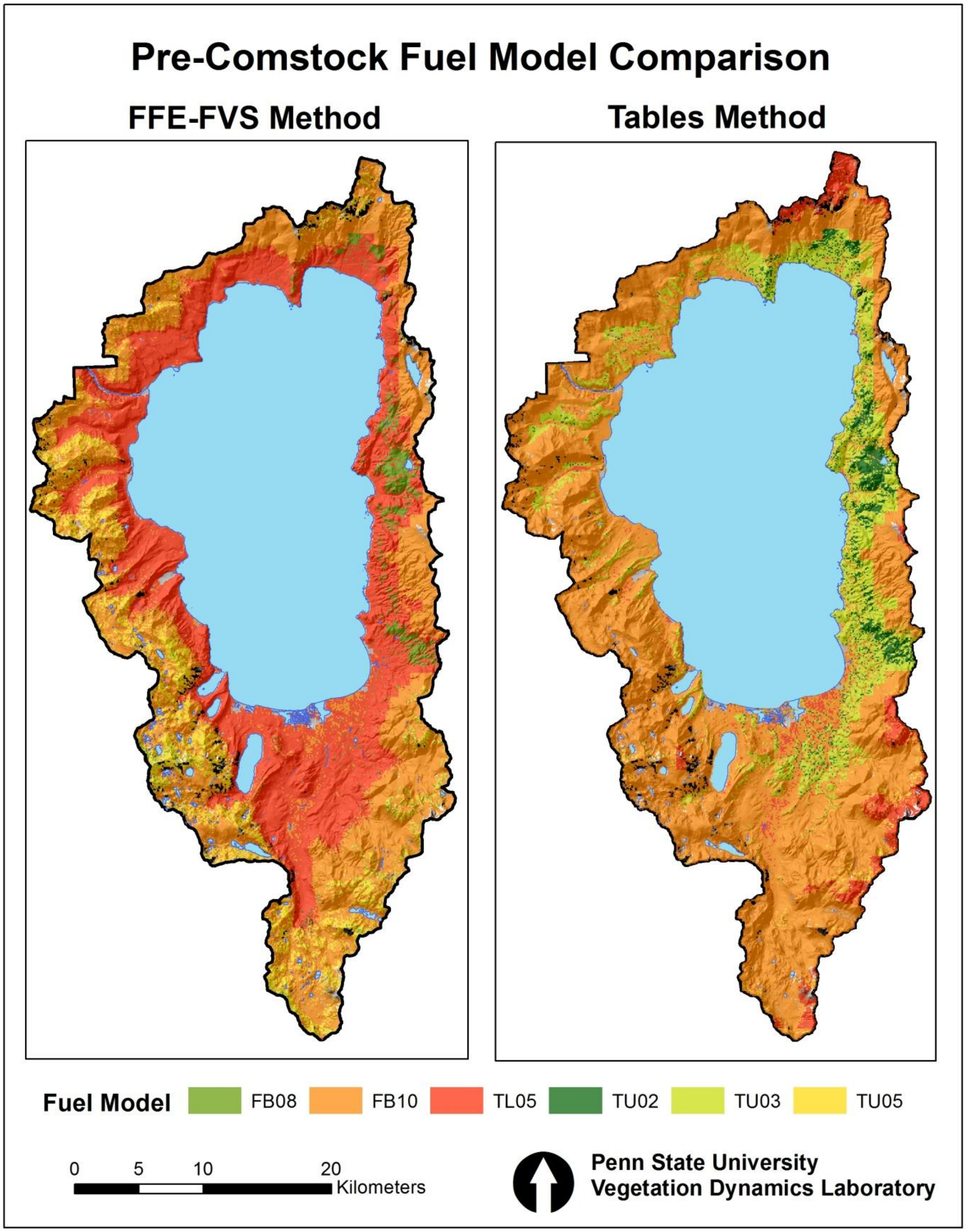

Figure 7. Spatially explicit representations of pre-Comstock fuel models in the LTB. Models were suggested by FMA from fuels estimated for tree lists in FFE-FVS and the Tables Method (van Wagtendonk and Moore 2010).

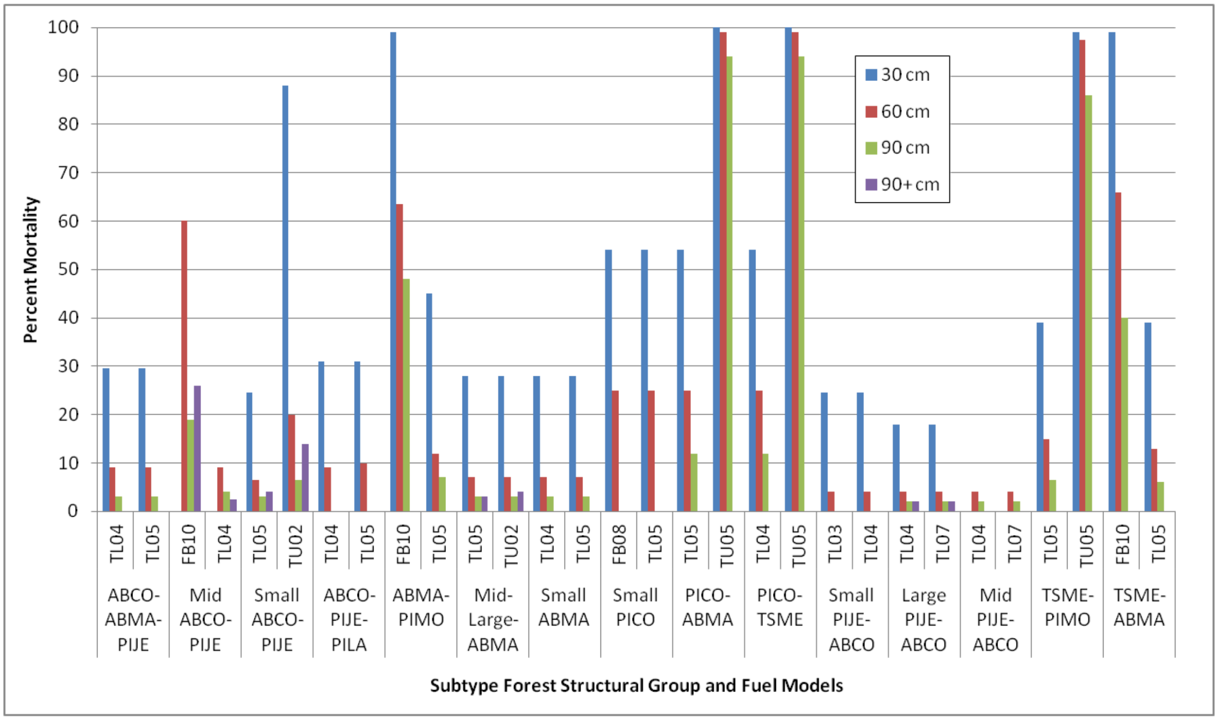

Figure 8. Percent mortality of stems by 30 cm (11.8 in) diameter bin are presented for two fuel models suggested by FFE-FVS and the Tables Method in each subtype forest structural group.

Discussion

Forest structure

The spatially explicit reconstruction of pre-Comstock forest types, fire frequency, surface fuels, and fire behavior involved the novel combination of dendroecological reconstruction, ecological modeling, and fuel and fire behavior modeling on a landscape scale. To assess the strength of our reconstruction of pre-Comstock forest types, we compared our modeled density and basal area estimates to previous studies of presettlement forest composition and structure in the LTB and the greater Sierra Nevada on a stand scale (Table 11). Beaty and Taylor (2007, 2008) characterized the fire history and forest structure of a 2000-ha watershed (General Creek) on the west shore of Lake Tahoe. The watershed was a primarily mixed conifer forest composed of white fir and Jeffrey pine as the dominant species during the contemporary period. For general comparison, we considered mixed conifer as analogous to the modeled White Fir forest type. Taylor (2004) utilized stump plots in Jeffrey pine, red fir, and lodgepole pine stands on the east shore of Lake Tahoe to indentify forest reference conditions on early cut-over lands. Then, Taylor et al. (in review) implemented a similar method of forest reconstruction as we have described above to reconstruct forest conditions in these plots on both the east and west shores of Lake Tahoe for four of five forest types modeled for our project. Taylor et al. (in review) reported overall mean densities of 136.9 stems/ha (range 68-186 stems/ha) and basal areas of 42.6 m^2/ha (range 25.5-59.7 m^2/ha). The density estimates were lower for the previous studies than in the modeled forest types, while the basal area estimates were similar overall. Differences between individual modeled forest types and previous studies might be attributed to the smaller range of environmental variation in the previous research plots. It must be noted that the plot data in Beaty and Taylor (2007, 2008), Taylor (Taylor, 2004), and Taylor et al. (in review) were included in the random forest model. Therefore, it is expected that estimates of stand structure from these studies fall within the range of model estimations.

Barbour et al. (2002) sampled 38 old-growth stands remaining in the LTB and described the stand density and basal area for trees greater than 40 cm. Stems greater than 40 cm were likely established prior to settlement and extensive logging in the late 1800s, and therefore, can be used to provide an estimate of pre-Comstock stand structure. Overall, Barbour et al.'s estimates of average stand density (107 stems/ha) were lower than the modeled density (216 stems/ha) and average basal area (54 m^2/ha) was greater than the modeled stands (44 m^2/ha). Differences in estimates of density and basal area between old-growth sites and the modeled stands were likely a product of the limited number of old-growth sites remaining the LTB, underestimation in the point-quarter sampling technique, and Barbour et al. (2002) did not sample coarse woody debris and reconstruct forest conditions as the current study has done. Most of these old-growth stands were re-sampled for our forest reconstruction model.

We compared our results to the General Land Office (GLO) survey of the LTB conducted from 1861 to 1897. The GLO data include approximately 2600 tree measurements collected at the corners and quarter-corners as witness trees during land surveys. While the data are coarse and have well-known limitations (Bourdo, 1956; Williams and Baker, 2011), they provide broad estimates of species composition, density, and basal area near the time of initial Euro-American settlement in the LTB. We classified each tree into a forest type matching the five main forest types that are identified by our model of pre-Comstock forest structural types. This classification was conducted by assigning a witness tree to the dominant forest type that it represented. For example, a red fir tree was assigned to the Red Fir forest type and a Jeffrey pine was assigned to the Jeffrey Pine forest type. While this is a coarse interpretation, it is replicable and provides a broad comparison to our model. We calculated density (stems/ha) and basal area (m^3/ha) using a point-quarter methodology that used mean distance to tree at each corner to estimate stand structure parameters for the basin overall (Cottman and Curtis, 1956). The overall GLO density was 78 stems/ha compared to an overall median of 218 stems/ha in our model (Table 11). Basal area in the GLO dataset (27.8 m^2/ha) also underestimated the modeled basal area (44 m^2/ha). The large difference in density and basal area estimates was likely caused by biases associated with selecting witness trees (e.g., large and identifiable species) and the method of stand structure calculation. Little can be done to remedy the bias in tree selection but we might be able to address the method of calculation. We calculated the GLO stand density and basal area using the median distance to each tree at a point instead of the mean distance. This approach may be more appropriate because the distribution of distances to trees was not normally distributed (Shaprio-Wilk test, $W = 0.72$, $p < 0.0001$) making the median a more accurate measure of central tendency. When the median distance was used to calculate stand statistics, the overall basin density and basal area increased to 147 stems/ha and 52.4 m^2/ha, respectively. Comparisons between forest types was not suitable for this analysis, however, we have presented these data in Table 11 for reference. The median distance statistics were more similar to the modeled values but the bias in tree selection was still present.

Next, we used the GLO data to make a spatial comparison to our map of pre-Comstock forest structure types. We mapped each witness tree in the basin as classified above and allowing higher elevation forest structural types to be plotted on top of lower elevation forest structural types (e.g., red fir would be visible instead of white fir; Fig. 4). Visually, the GLO map appears to represent the modeled forest types including: 1) the White Fir-Jeffrey Pine type split on the west and east shores; 2) the Red Fir type just above the White Fir and Jeffrey Pine forest types in elevation; 3) the Lodgepole type located in the higher elevations as well as in the flat, low elevation sites; and 4) the sparse Subalpine type at the highest elevations. We quantified the classification error of the random forest model by asking if the assigned GLO forest type at each survey point matched the modeled forest type at that same point. We found that our model correctly classified 50.5% of the GLO survey points with the strongest and weakest classification in the Red Fir (66.3% correct) and Lodgepole (16.7% correct) forest types, respectively (Table 7). The GLO data provided an independent validation of the random forest model and showed that the model is consistent in its classification accuracy. Additional work (outside the goal of the current project) could be conducted to better model the GLO data in a spatially explicit manner and calculate stand statistics; however, bias in tree selection will still exist.

We used Sudworth's (1900) survey of The Stanislaus and Lake Tahoe forest reserves and adjacent territory to estimate density and basal area in similar forest types to compare with our reference estimates for the LTB. We assigned each of Sudworth's (1900) 18 plots, which had a similar species composition to the LTB, to a LTB forest structural type by the most abundant species in each plot. The overall density (218 stems/ha) and basal area (35.3 m^2/ha) in the Sudworth dataset are similar to values for our modeled forest types, 218 stems/ha and 44 m^2/ha, respectively. For the individual forest types, density and basal area estimates were always higher than the modeled forest types. The discrepancy in stand structure by forest type was likely caused by a bias in Sudworth's (1900) data towards merchantable material and small sample size compared to our LTB sample.

Contemporary species composition and stand structure conditions in the LTB were documented by Beaty and Taylor (2007, 2008), Taylor (2004), and Taylor et al. (in review) in some of the remaining old-growth stands (collectively referred to as the Taylor Contemporary and Reference data). Additional contemporary data was gathered from the Region 5 (R5) Ecology Plot Data administered by the US Forest Service under the Forest Inventory and Analysis program. While the exact locations of the R5 data are not disclosed, the plot data provided a broad comparison to our modeled pre-Comstock forest conditions. Both contemporary datasets showed that the modeled pre-Comstock forest was three to five times less dense than the present forests for the White Fir, Jeffrey Pine, Red Fir, and Lodgepole forest types (Table 11). Contemporary basal area was also greater in the present day forest than in the modeled pre-Comstock forest. However, Taylor (2004) suggests that the basal area in the reference Red Fir and Lodgepole Pine forest types were greater than or equal to the contemporary period (Table 11). Taylor (2004) reported that the species composition and diameter distributions differed between the contemporary and reference stands, stating that reference red fir and lodgepole pine trees were larger in diameter than contemporary trees and there were few reference trees < 30 cm in diameter. The decomposition of small diameter stems was a potential source of error in our reconstruction that would have the effect of decreasing pre-Comstock forest density. However, we did reconstruct to the time of the last fire to reduce the likelihood of consumption by fire. Additionally, Fulé et al. (1997) argued that doghair thickets were unlikely to have established under a frequent fire regime, and while underestimation of small diameter stems was possible, these trees were unlikely to have formed a large component of the pre-Comstock forest structure. Data were less conclusive for the Subalpine forest structural type because insufficient contemporary plot data existed for this forest type in the LTB.

In the Lake Tahoe Watershed Assessment, Manley et al. (2000) discussed the basin coverage of the five contemporary forest types that corresponded to the modeled pre-Comstock forest types. We calculated the contemporary percent basin coverage (using only forested acres) of each forest type to compare to the modeled forest types. All forest types saw some increase in percent coverage at the expense of the Red Fir forest type, which decreased by 38.9% (Table 4). The change in percent cover of the Red Fir forest type was the greatest change in forest composition in the entire basin. The biggest increase was in the Subalpine forest type; however, this result was likely spurious and a consequence of forest definition. As expected, the White Fir and Lodgepole Pine forest types expanded coverage in the contemporary period.

Fire regime data and spatial modeling

We compared our modeled PFRI map to Van de Water and Safford's (2011) Fire Return Interval Departure (FRID) map constructed for the LTB (Fig. 6). The FRID map estimated fire frequency for each forest polygon in the LTB by assigning polygons a fire return interval observed prior to significant Euro-American settlement. Mean fire return interval data was collected during an exhaustive review of published and unpublished literature including 20+ publications in which the co-author, Dr. Taylor, was a primary or secondary author. The visual comparison between our modeled PFRI and the FRID map showed three trends: 1) minimum and maximum fire frequencies were similar for both maps; 2) fire frequency decreased with increasing elevation; and 3) the modeled PFRI had a more continuous transition from one frequency category to the next rather than the abrupt transitions in the FRID map.

Fuels and fire behavior

Pre-Comstock fuels were accumulated in both FFE-FVS and the Tables Method for a specific fire return interval for each forest structural subtype. Actual FRIs and accumulation periods longer than 55 years likely occurred in the pre-Comstock era, and our estimates of fuels and fire behavior might not fully represent the range of past conditions. However, both methods of accumulation suggested moderate to heavy surface fuel load models from FMA. Potential fire behavior for all forest structural subtypes with these surface models predicted only surface fire except for White Fir which was predicted to support passive crown fire under 98^{th} percentile weather conditions. More passive or even active crown fire may have been predicted under extreme weather conditions if there were better estimates of crown base height and understory conditions for pre-Comstock forests. However, these data were not available and could not be accurately reconstructed. This limitation would primarily affect the height to live crown base but we were able to partly account for this by including contemporary values for seedlings and saplings in reference forest structural types. By adding only a modest number of small stems, potential fire behavior in the White Fir structural type changed from surface fire to passive crown fire. A second limitation that would have influenced height to live crown base estimates for pre-Comstock forests was associated with how tree heights were estimated from diameter in FVS. Because tree diameter data were binned into 30 cm size classes, the tree height estimates resulted in a stepped forest canopy structure instead of a continuous distribution of crown mass from the crown base to the top of the canopy. The stepped forest structure may have reduced the potential for passive crown fire using FMA, but this possible effect was not tested with typical tree diameter data.

To compare the pre-Comstock surface fuel models for the five main forest types to the contemporary fuel conditions, we selected CALVEG (California Vegetation Type) forest types in the Fuel Characteristic Classification System (FCCS) that were analogous to our modeled forest types (Table 12; Ottmar and Safford, 2011). Overall, the contemporary fuel models provided by FCCS for medium and large diameter trees for each of the forest types had heavier fuel loadings than the pre-Comstock fuel models. The expected fire behavior from these heavier fuel models would likely be more severe with greater potential for crown fire and mortality of larger diameter stems. We did not calculate fire behavior and effects in contemporary stands for this project.

Limitations

The identification of spatially explicit reference conditions has some necessary limitations related to the forest reconstruction, spatial modeling, and estimation of surface fuels and fire behavior. First, the forest reconstruction did not reconstruct understory stems <10 cm and was likely to have underestimated density and basal area a small amount. Second, the spatial model was limited by the input of predictands and predictors. The predictands were the plot level data used in the cluster analysis and random forest model. There was a necessary bias in the location of sampling sites because we needed to target relict old-growth stands that could be grown backwards and reconstructed. The distribution of old-growth stands was not random across the landscape and was likely related to accessibility, species/quality of timber, and demand for wood. The predictors were the topographic and climatic characteristics associated with each plot. Because we sought to identify spatially explicit conditions prior to settlement and logging, many of the predictor variables such as remote sensing imagery and soil conditions were either not available or rendered moot. Thus, our random forest model was limited by the lack of available predictors. Despite the limitation in predictor variables, our model still performed as well as models that predict contemporary forest structure for other locations in the western US (e.g., Grossmann et al., 2010; Ohmann et al., 2011). Third, the strength of our model is not in the forest structural type prediction of an individual one hectare grid cell in the LTB, rather it is to represent the broader spatial pattern of forest types and median structural conditions. Predicting the pre-Comstock forest structure at a single point would not be prudent because there was likely a range of variation in species composition, density, and basal area. Fourth, bias in field site selection towards extant old-growth stands in the most common forest types precluded us from identifying areas that burned severely before Comstock logging. Thus, we were not able to spatially represent or estimate areas affected by high severity disturbance such as fire, avalanches, or landslides that occurred in the LTB.

A fifth limitation is associated with the estimation of surface fuels for each of the forest structural subtypes. We estimated fuels based on median density conditions for each species in each subtype using two methods, FFE-FVS and the Tables Method based on van Wagtendonk et al.'s (2010) equations of annual fuel deposition. Surface fuel load estimates from either method were likely affected by the underestimate of density of understory stems (<10 cm), variations in fire frequency (years of accumulation), and rate of decomposition of surface fuels. To partially accommodate for these limitations, we used the methods to identify the most similar standard fuel models to simulate fire behavior. Finally, the estimation of potential fire behavior for pre-Comstock stands would vary by fuel model and fire weather conditions. We focused on the potential for different fire types (surface, passive crown, active crown) under severe fire weather conditions (98th percentile). However, we did simulate potential fire type for two models for each forest structural subtype to bracket the potential fire type that might be expected from variability in fuel estimates. Despite these limitations, we believe this body of work represents the closest approximation to pre-Comstock forest structure, fuels, and potential fire behavior given the severity of 19th century logging in the LTB and the inherent limitations of using historical ecological methods to estimate forest characteristics.

Conclusions

We reconstructed pre-Comstock forest structural types using 745 plots in the Lake Tahoe Basin, Lassen Volcanic National Park, and Yosemite National Park, cluster analysis, and a random forest model. Specifically, we identified the relationship between spatial variability in pre-Comstock forest structure (composition, density, basal area, and size structure) and topographic variables in the lower and upper montane forest zones of the LTB. Next, we identified the relationships between spatial variability in fire regimes (fire return interval, season of burn) and topographic variables in the montane and upper montane zone in the LTB. Finally, we developed a spatially explicit reconstruction that distributes and visually represents pre-Comstock forest structure, forest fuels, and fire regimes for lower and upper montane forests in the LTB. We have produced the following products as part of this project:

1. ArcGIS layers of pre-Comstock forest structural types (and subtypes), fire return interval, and surface fuels that are also available as .kmz files viewable in Google Earth.
2. Stand Visualization System (SVS) and EnVision simulations of pre-Comstock forest structural types.
3. Spreadsheets containing density (stems/ha) and basal area (m^2/ha) by species and 30 cm bin for each main forest structural type and subtype.
4. Summary tables of data reported above.
5. Workshop PowerPoint presentation slides detailing project methods and results.
6. Three manuscripts submitted or in preparation for scholarly journals.

These products will be freely available to the public on the Vegetation Dynamics Laboratory website at Penn State University, the Tahoe Regional Planning Authority's data clearinghouse website, and the US Forest Service Pacific Southwest Region's GIS clearinghouse website.

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Deliverables

Milestones/ Deliverables	Starting Date	Ending Date	Description	Status Update	% Complete
Initial transfer			PSW submits deliverables schedule and requests funds from BLM		100%
Agreement	8/1/08	9/15/08	Establish award agreement		100%
Geographic data	8/1/08	6/30/09	Compile stand structure data	All old-growth data located, and compiled into digital format except GLO data. FIA data for sites in the basin still need to be added to the data base.	100%
Outreach	7/1/09	8/15/09	Meet with Basin stakeholder agencies	Initial meeting to brief agencies on project goals, critical dates and deliverables.	100%
Geographic data	7/1/09	8/31/09	Conduct 1st year field work and prepare summary report	Two months of field work to resample forests was conducted by a team from Penn State and the Forest Service. The Sept. 30 progress report serves as the summary.	100%

	9/1/09	6/1/10	Analyze presettlement stand structure and fire regimes from field and tree core data for all studies using data from FIA, the R5 Ecology Plot database, Stand Exams, plots sampled for the TRPA Lake Tahoe Basin IKONOS vegetation map, and plots sampled for the NRCS Lake Tahoe Basin soil survey	All GLO data have been entered into a GIS. All other ecological data collected and entered. Hemispherical photos and fuel data have been entered and are being analyzed. Spatial and temporal analysis of data is underway.	100%
Outreach	4/1/10	6/1/10	Annual progress report to PSW with simultaneous distribution to agencies	Data from the 2009 field season has been summarized and results have been reported in meetings with PSW scientists and ecologists.	100%
	6/1/10	7/31/10	Meet with Basin stakeholder agencies	Meetings with CA state Park, USFS, and PSW scientists took place in the Lake Tahoe Basin during this period.	100%
Geographic data	7/1/10	8/31/10	Conduct 2nd year field work and prepare summary report	Two months of field work were conducted in old-growth forest stands throughout the basin. The Sept. annual report serves as a summary report.	100%
	12/31/10	12/31/11	Integration of geospatial data sets and development of DFA and CART, and Random Forest models of presettlement forest structure	A new Ph.D. student with GIS/modeling experience was recruited to assist the project. GIS data needed for modeling have been collected and organized in a GIS. Data for each sampling location has been extracted in a GIS and CART models are being formed.	100%
	6/30/11	6/30/12	Develop spatially explicit representations of presettlement forest landscapes within GIS and	Preliminary models using pre fire suppression forest structure and composition data from Tahoe, Yosemite,	100%

			digital maps and representations of conditions; write and submit publications	and Lassen Park have been developed and are being tested. Models predict species distribution and forest structure and composition. A fuel layer for 1873 mixed conifer forests has also been developed.	
Outreach	7/31/11	3/30/12	Basin workshop on using information	We expect to schedule this workshop in March 2012 because of the later time of the Tahoe Science Consortium in late May	100%
Geographic data	8/31/11	6/30/12	Submit final report and digital data of presettlement forest landscape (maps and compositional group summaries)		100%

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