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Impacts of different land management histories on forest change

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Abstract. Many western North American forest types have experienced considerable changes in ecosystem structure, composition, and function as a result of both fire exclusion and timber harvesting. These two influences co-occurred over a large portion of dry forests, making it difficult to know the strength of either one on its own or the potential for an interaction between the two. In this study, we used contemporary remeasurements of a systematic historical forest inventory to investigate forest change in the Sierra Nevada. The historical data opportunistically spanned a significant land management agency boundary, which protected part of the inventory area from timber harvesting. This allowed for a robust comparison of forest change between logged and unlogged areas. In addition, we assessed the effects of recent management activities aimed at forest restoration relative to the same areas historically, and to other areas without recent management. Based on analyses of 22,007 trees (historical, 9,573; contemporary, 12,434), live basal area and tree density significantly increased from 1911 to the early 2000s in both logged and unlogged areas. Both shrub cover and the proportion of live basal area occupied by pine species declined from 1911 to the early 2000s in both areas, but statistical significance was inconsistent. The most notable difference between logged and unlogged areas was in the density of large trees, which declined significantly in logged areas, but was unchanged in unlogged areas. Recent management activities had a varied impact on the forest structure and composition variables analyzed. In general, areas with no recent management activities experienced the greatest change from 1911 to the early 2000s. If approximating historical forest conditions is a land management goal the documented changes in forest structure and composition from 1911 to the early 2000s indicate that active restoration, including fire use and mechanical thinning, is needed in many areas.

Key words: departure; fire exclusion; fire suppression; forest restoration; mixed-conifer forest; reference conditions.

Introduction

Many western North American forest types have experienced considerable changes in ecosystem structure, composition, and function as a result of 20th-century land use practices. The most pronounced changes have occurred in drier forest types historically associated with frequent fire. There is enough consistency across a range of geographic and biophysical gradients to make the following generalities about these changes: large increases in tree density (particularly in smaller size classes), greater proportions of shade-tolerant tree species, and loss of fine- and coarse-grained heterogeneity in vegetation patterns (Fulé et al. 1997, Hessburg et al. 1999, Brown et al. 2008, North et al. 2009, Larson and Churchill 2012, Taylor et al. 2014, Stephens et al. 2015). These changes have contributed to altered contemporary disturbance patterns (Allen 2007, Mallek et al. 2013, O'Connor et al. 2014) and potential loss of ecosystem integrity due to limited tree regeneration following such disturbances (Chambers et al. 2016, Coop et al. 2016, Welch et al. 2016).

The structural, compositional, and spatial changes in dry forests are predominantly attributed to both the exclusion of fire for over 100 yr and timber harvesting focused on large tree removal (Hessburg et al. 1999, Allen et al. 2002, Taylor 2004, Merschel et al. 2014). Fire exclusion over this amount of time removed a key regulating process that historically limited tree establishment and created spatial heterogeneity (e.g., Larson and Churchill 2012, Lydersen et al. 2013). Large tree removal opened a considerable amount of growing space, allowing for rapid tree establishment and growth (Naficy et al. 2010). These two influences co-occurred over a large portion of dry forests in western North America (Hessburg 2015), presumably having a greater effect on forest change than either influence alone. However, it is difficult to know the strength of these interacting influences because there are few controlled comparisons with one or both of these influences removed. That said, Naficy et al. (2010) compared logged and unlogged areas in the northern Rocky Mountains both subjected to fire

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exclusion and suggested that logging had a stronger effect on increasing tree density. In contrast, Knapp et al. (2013) found that logged areas had similar tree density and basal area to nearby unlogged areas and concluded that fire exclusion had a more significant effect on forest change.

Comparing logged and unlogged areas to identify the magnitude of the interaction with fire exclusion is difficult for a number of reasons. First, although there are plenty of unlogged fire-excluded areas (e.g., U.S. National Parks), they tend to occur in somewhat unique biophysical settings relative to logged fire-excluded areas, i.e., higher elevations, different species composition, and greater discontinuity due to exposed rock (Collins et al. 2016). This makes comparisons somewhat confounded by fundamental site differences. Second, many areas that were initially logged with a particular focus on large tree removal experienced subsequent logging entries, perhaps with different objectives (e.g., tree regeneration, sanitation). This potential range in the number and type of silvicultural activities makes identifying a singular "logging" effect problematic. Last, comparisons of logged and unlogged areas based on contemporary forest structure and composition may not account for potential differences in structure and composition prior to 20th-century land use influences.

In this study, we used contemporary remeasurements of a systematic historical forest inventory to investigate forest change. The historical inventory was conducted across a large area (18,600 ha) prior to timber harvesting and before the onset of notable changes associated with fire exclusion (Collins et al. 2015). Beyond the spatial and temporal depth of these data, the historical data opportunistically spanned a significant land management agency boundary, which protected part of the inventory area from timber harvesting. This allowed us to compare forest change following fire exclusion between logged and unlogged areas. Additionally, we assessed the impacts of recent restoration and fuel reduction activities on forest structure and composition relative to the same areas historically, as well as to areas without recent activities. Previous studies employed portions of these data to investigate (1) how recent fire activity on a subset of the historical transects modified contemporary forest structure and composition relative to historical conditions (Collins et al. 2011) and (2) how historical vegetation structure and composition varied across the entire inventory area (Collins et al. 2015). Based on Collins et al. (2011), we were able to acquire additional resources to expand remeasurement area substantially. This expansion allowed for the comparison between land management agencies.

Methods

Study area and field data

Data sheets for individual historical inventory transects were all obtained from the National Archives and Records Administration repository at San Bruno, California, USA. The location of these transects on the ground spanned portions of the Stanislaus National Forest (NF) and Yosemite National Park (NP) in the central Sierra Nevada (Fig. 1). A majority of the study area is characterized as lower montane Sierra Nevada mixed conifer, consisting of sugar pine (*Pinus lambertiana*), ponderosa pine (*P. ponderosa*), white fir (*Abies concolor*), incense-cedar (*Calocedrus decurrens*), and Douglas-fir (*Pseudotsuga menziesii*) (North et al. 2016). Red fir (*A. magnifica*), which is considered upper montane, was present on a small portion of the study area. Climate consists of generally cool, wet winters and warm, dry summers. Annual precipitation is a mixture of rain and snow, which averages 50–60 cm/yr. Mean monthly temperatures range from 4°C in January to 20°C in July (Crane Flat Remote Automated Weather Station, 1992–2016). Prior to 1900, low- to moderate-severity fire was common in this area, with a mean point fire return interval of 12 yr (Scholl and Taylor 2010); this was based on reconstruction with extensive fire scar and age structure data in an area overlapped by the Yosemite portion of our study area (Fig. 1).

The historical forest inventory of our study area was conducted in 1911, and consisted of belt transects located systematically based on the Public Land Survey System (PLSS). Transects spanned the mid-line of quarter-quarter sections (16.2-ha survey units; quarter-quarter or Q-Qs) in a 40.2 × 402 m area (1.6 ha) and were a 10% sample of each inventoried Q-Q (USFS 1911, Collins et al. 2011). All trees >15.2 cm (6 in.) in diameter at breast height (dbh) were tallied by species within belt transects. Trees 15.2–30.5 cm (6–12 in) dbh were tallied in a single class labeled as "poles." Trees >30.5 cm (12 in) dbh were tallied into classes based on dbh and tree height. The dbh classes were 5.1 cm (2 in) and height classes were 4.9 m (16 ft; see Collins et al. [2011] for a copy of the historic data sheet). Records specific to the historical inventory in this area indicate that all trees were tallied (USFS 1911), but the lack of California black oak (*Quercus kelloggii*) suggests that the inventory may have been limited to all conifers. Additionally, while dead trees appear to have been recorded on all transects, it is possible that only those that were considered merchantable were actually included. Shrub cover was recorded by species for each transect. Data sheets also contained written descriptions of site characteristics, noting evidence of any logging prior to the survey. Based on these descriptions, there was no logging in any of the areas inventoried in 1911.

We used a PLSS layer in ArcGIS, which contained Q-Q boundaries, to obtain Universal Transverse Mercator coordinates for the starting and ending points of these transects. These points defined the theoretical centerline of the historical belt transects. We use the term "theoretical" to point out uncertainty in the exact transect locations due to potential errors incurred in locating (compassing and distancing) transects originally. In order

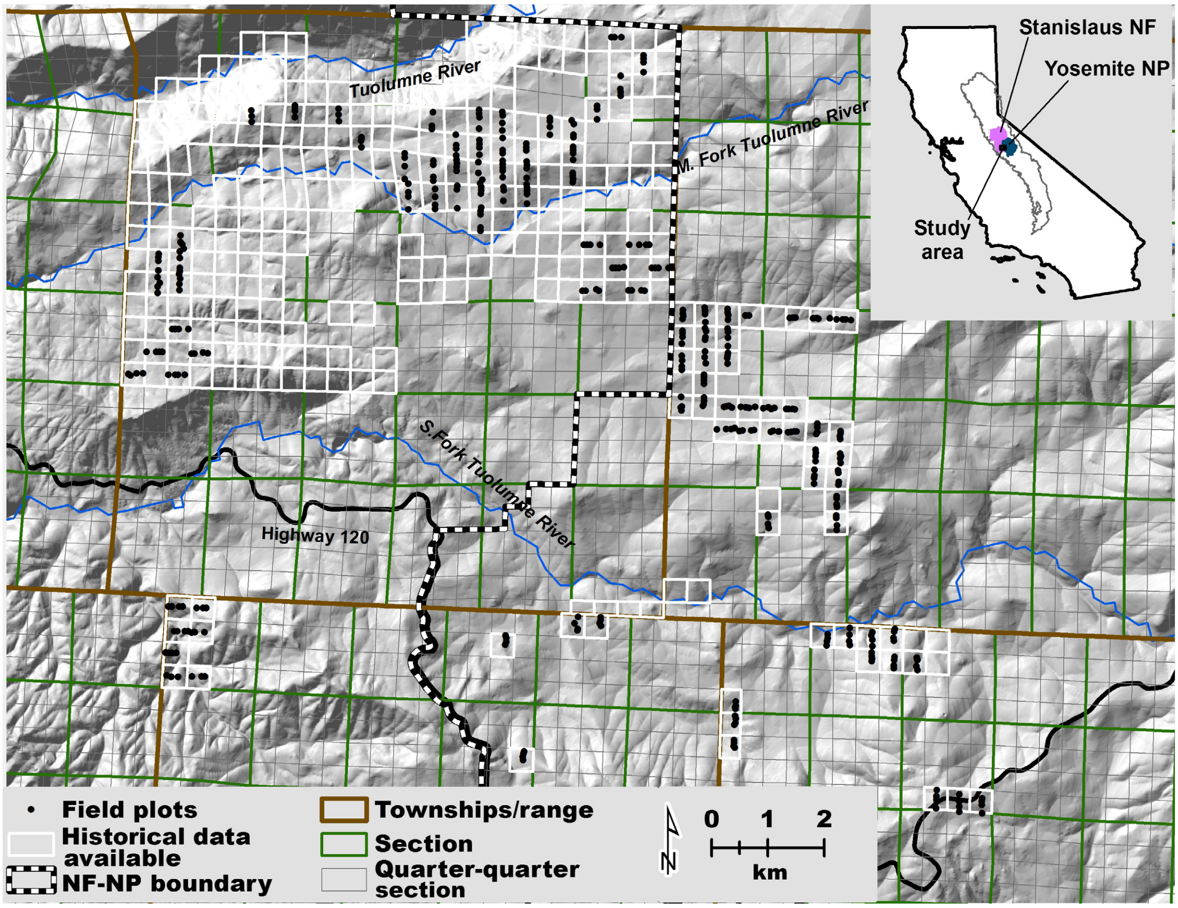

FIG. 1. The extent of available data (with actual data sheets) from a systematic timber inventory conducted in 1911, which spanned portions of the Stanislaus National Forest (NF) and Yosemite National Park (NP). The inventory was based on the Public Land Survey System, with transects placed in individual quarter-quarter sections (white outlines). Remeasurement (black dots) was based on original transect locations, but due to several limitations, remeasurement was not conducted on all transects with historical data. [Color figure can be viewed at wileyonlinelibrary.com]

to remeasure a greater number of transects, we opted to subsample from within the original belt transects. Subsampling was done by establishing four 0.1-ha circular plots (radius 17.8 m) centered at random, non-overlapping distances along the theoretical historical transect centerline (Fig. 1). In some cases, only three plots were established for a given historical transect (13% of transects). In each plot, we recorded tree species, height, and dbh for all trees 5.1 cm dbh and above. In addition, we recorded shrub cover by species (ocular estimate), aspect, and slope at each plot. Remeasurement was spread out across three non-consecutive years: 2005, 2007, and 2013. Initial remeasurement (2005, 2007) focused on Yosemite NP; additional funding allowed for expanding remeasurement to the Stanislaus NF (2013). A large wildfire, the Rim Fire, occurred in August of 2013 and burned the entire study area, with a considerable portion of that at high severity (Lydersen et al. 2016). This fire curtailed our remeasurement efforts, and as a result only 105 of the 294 historical transects obtained were actually remeasured. The remeasured transects spanned a majority of the historical inventory area, but at lower density (Fig. 1). Elevation for remeasured historical transects ranged from 1,200 to 2,140 m.

Recent management activities

We assigned recent management activities (since 1995) to remeasured plots that intersected previous fires and silvicultural treatments. These activities included prescribed fire, managed wildfire, mechanical thinning alone, and mechanical thinning followed by pile burning. Since the analyses were conducted using individual transects as the observational unit, two or more plots for a given transect needed to have the same activity type to be assigned to that transect. Multiple activity types occurred in only three transects; in those instances only the most recent activity was used. For burned plots, we assigned a fire severity class using thresholds for the relative differenced normalized burn ratio described by Miller and Thode (2007). These fire severity classes have been assessed with independent field data sets by Miller et al. (2009) and

Lydersen et al. (2016) and have been shown to capture distinct changes in basal area and tree density caused by fire. Remotely sensed estimates of fire severity allowed for consistent estimates of fire-caused change across fires and years, and were used over field-based estimates due to the wide range in time since last fire.

Spatial and statistical analyses

We generated the following forest structure and composition variables for each remeasured transect (n = 105; 55 in NF, 50 in NP): live and dead basal area, basal area proportion of pine species, total tree density, tree density by dbh class (15.2–30.4 cm, 30.5–61.0 cm, 61.1–91.4 cm, >91.4 cm). These variables were scaled to the common unit area (1 ha), which for the remeasurement data involved aggregating sub-plots within a given transect. Shrub cover by species was summed into two stature classes, "tall" and "short." The tall shrub class was dominated by several *Ceanothus*, *Arctostaphylos*, and *Quercus* species; the short class was dominated by *Chamaebatia foliolosa* (bear clover). We tested for differences in these variables across agency lands (NP vs. NF) and change over time (1911–2000s). Additionally, we grouped transects by recent management activity to test for differences among groups within a given period and change over time within a group. Management activity groups were 1, no recent activity; 2, mechanical thinning (NF) or low-severity fire (NP); and 3, moderate severity fire (Table 1). Note that none of the NF transects met the criteria to be categorized as low severity fire. All statistical tests were carried out using a repeated measures analysis (Proc Mixed; SAS Institute 2009). Diagnostic plots of the residuals indicated good compliance with the normality and homogeneity of variance assumptions for most variables. However, dead basal area, large tree density (>91.4 cm dbh), and tall shrub cover were log(x + 1)-transformed, which improved compliance with model assumptions. Differences between agency lands and time periods were inferred from Tukey-Kramer adjusted P values, with α = 0.05. For comparisons involving recent management activity groups we opted to run each agency separately and then used the Slice command in Proc Mixed to compare between periods for an individual group, and between groups for a given period. We did this to remove less important pairwise comparisons (e.g., group 1 NF 1911 to group 3 NP 2000s) and ultimately control the Tukey penalty for multiple comparisons.

Results

Our analyses included just over 22,000 trees (historical, 9,573; contemporary, 12,434). In 1911, live basal area was significantly greater in the NP portion of the survey area (Fig. 2A). In both the NP and NF, live basal area significantly increased from 1911 to the early 2000s, with contemporary NP basal area being significantly greater than that of the NF ($\bar{x}$ = 46 and 34 m^2/ha, respectively). Dead basal area followed a similar pattern, with contemporary values in NP well in excess of those in NF ($\bar{x}$ = 16 and 4 m^2/ha, respectively). Both shrub cover and the proportion of live basal area occupied by pine species declined from 1911 to the early 2000s. In NF area, the decline was only statistically significant for short-stature shrub cover, while in NP area, shrub cover in both height strata and pine basal area proportion were significantly lower (Fig. 2B, C). In 1911, NP tall shrub cover was significantly greater than NF ($\bar{x}$ = 40% and 18%, respectively). The change in the proportion of small trees (15.2–30.5 cm dbh) that were pine species was stronger than that for pine BA. Contemporary small pine proportions for both NF and NP areas were less than one-half of what they were in 1911, with NP areas having significantly lower contemporary proportions than NF areas (Fig. 2D).

There were considerable increases in total live tree density (trees >15.2 cm dbh) from 1911 to the early 2000s in both NF and NP areas (Fig. 3A). These increases were most pronounced in the two smallest size classes (15.2–30.5 and 30.6–61.0 cm dbh). Although contemporary live tree density was higher in NF than in NP (263 and 236 tree/ha, respectively) this difference was not statistically significant. For large trees (>91.4 cm dbh) alone, the change from 1911 to the early 2000s was different between NF and NP; large trees declined significantly in NF from 9 to 4 trees/ha, but was unchanged in NP (Fig. 3B). These opposite directions of changes are particularly noteworthy given that in 1911 NP had significantly greater large tree density than NF.

Recent management activities had a varied impact on the forest structure and composition variables analyzed. In

Table 1. Summary of historical inventory transects and their contemporary remeasurement.

Site	Total historical units	Units remeasured		Elevation (m)		Units remeasured by recent activity type					
						None		Mechanical (NF); low severity (NP)		Moderate severity	
		Transects	Plots	Mean	Range	Transects	Plots	Transects	Plots	Transects	Plots
Stanislaus NF	232	55	209	1,381	1,201–1,562	35	130	15	59	5	20
Yosemite NP	62	50	196	1,650	1,365–2,140	24	96	13	52	13	48

Notes: The historical inventory spanned portions of the Stanislaus National Forest (NF) and Yosemite National Park (NP). Recent management activity types are explained in *Methods*.

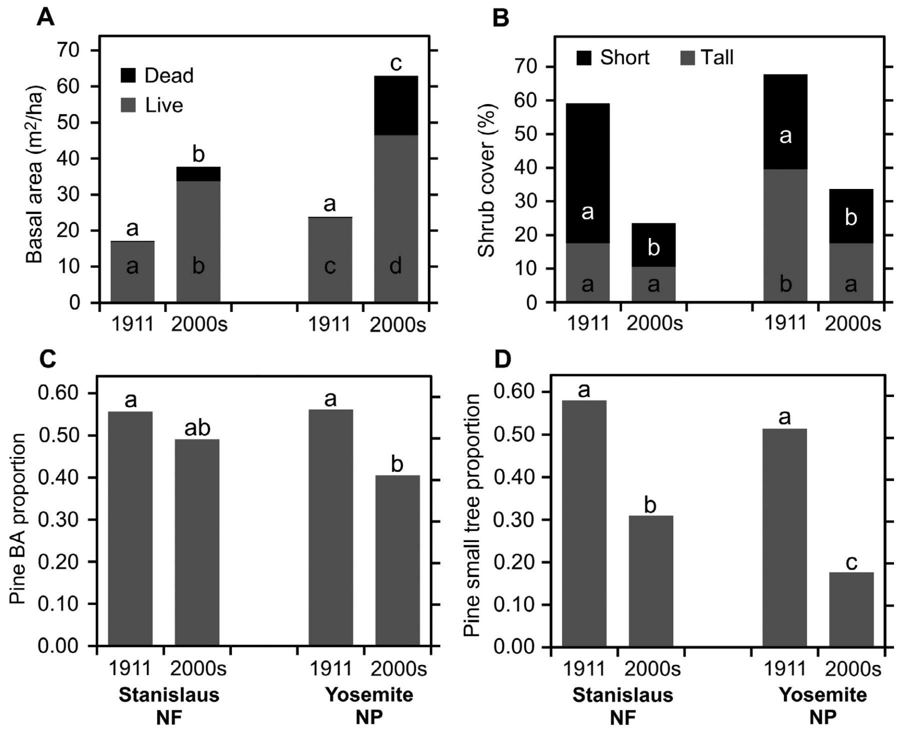

FIG. 2. Average historical and contemporary forest conditions based on a systematic forest inventory conducted in 1911, which spanned portions of the Stanislaus National Forest (NF) and Yosemite National Park (NP). Different lowercase letters indicate statistically significant differences ($P \leq 0.05$) between period/agency. Two sets of comparisons are represented in (A) live and dead basal area and in (B) >0.5 m tall and <0.5 m tall shrub cover. (C) Pine basal area (BA) proportion combines both *Pinus ponderosa* and *P. lambertiana*. (D) Pine proportion of live tree density for small trees only (dbh 15.2–30.5 cm).

general, areas with no recent management activities experienced the greatest change from 1911 to the early 2000s. In NF, live basal area significantly increased from 1911 to the early 2000s for group 1 (no recent activity) and group 2 (mechanical thinning; Fig. 4A). Similar increases occurred for group 1 (no recent activity) and group 2 (low severity fire) in NP. Only group 3 (moderate severity fire) did not have significantly different basal area relative to the same transects historically, which was the case for both NF and NP. Contemporary basal area was statistically similar across the three NF groups, but significantly lower for NP groups 2 and 3. Dead basal area significantly increased for all groups (NF and NP) from 1911 to the early 2000s.

Shrub cover, pine basal area proportion, and proportion of small trees that were pine generally declined across groups from 1911 to the early 2000s, but there were some notable exceptions. For group 1, this decline was statistically significant for both tall and short stature shrubs in NF, but only tall shrubs in NP (Fig. 4B). Short stature shrub cover also declined significantly for group 2 in both NF and NP. For group 3, however, tall and short shrub cover was not significantly different across the two time periods in either NF or NP. Contemporary shrub cover (both tall and short) did not differ among groups in NP, but NF group 3 had significantly greater shrub cover than group 2 (tall only) and group 1 (short only). In NF the decreases in pine basal area proportion were not significant for any of the groups, while in NP groups 1 and 2 had significantly lower contemporary pine basal area proportion (Fig. 4C). There were no significant differences in pine basal area proportion among groups for the contemporary period in NF. NP group 3 had significantly greater pine basal area proportion than NP group 1. Small pine proportion decreased significantly for all NF and NP groups, except NF group 1 (Fig. 4D). Contemporary NP group 3 had significantly greater small pine proportion than the other two contemporary NP groups, but was still significantly lower than the same areas in 1911 (Fig. 4D). There were no significant differences in contemporary small pine proportion among NF groups.

Changes in tree density between time periods for all groups paralleled the changes in overall tree density. All groups (NF and NP) had significantly greater contemporary live tree density (Fig. 5A). There were differences in contemporary live tree density between groups, however, none of these differences were significant in NF. NP groups 2 and 3 had significantly lower contemporary tree density than group 1. Focusing on large trees only, NF groups 1 and 2 had significant declines from 1911 to the early 2000s (Fig. 5B). This decline is particularly noteworthy for group 2 in NF because it had significantly greater large tree density in 1911, relative to groups 1 and 3. NP group 1 had noticeably greater contemporary large tree density than both the same group in 1911 and

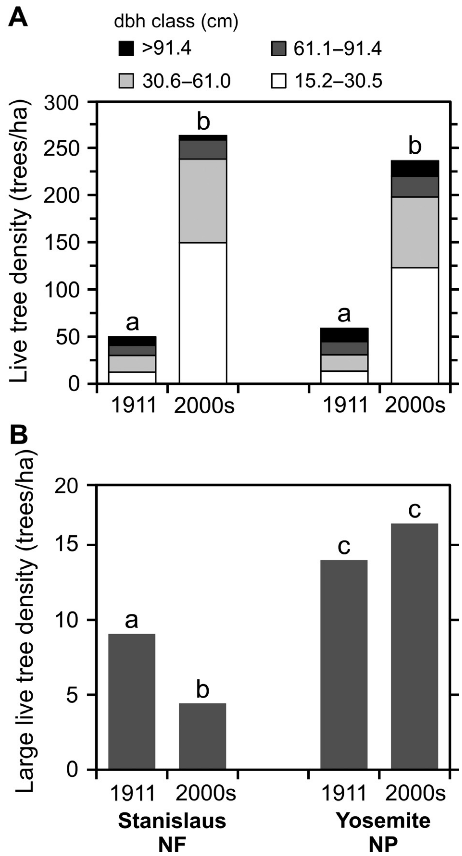

Fig. 3. Average historical and contemporary live tree density based on a systematic forest inventory conducted in 1911, which spanned portions of the Stanislaus National Forest (NF) and Yosemite National Park (NP). Different lowercase letters indicate statistically significant differences ($P \leq 0.05$) between period/agency. Comparisons indicated in panel A are for aggregated tree density (all trees >15.2 cm dbh), while panel B comparisons are for only trees in the largest size class (dbh > 91.4 cm).

the other NP groups in the early 2000s. However, the only significant difference was contemporary NP group 1 having more large trees than NP group 2.

Discussion

Historical data sets are being increasingly used to describe forest conditions when ecosystem structure and function were primarily driven by natural processes and disturbance (Collins et al. 2015, McIntyre et al. 2015, Stephens et al. 2015, Hagmann et al. 2017). These data sets generally provide greater detail compared to other forest reconstruction approaches (Collins et al. 2017). The historical data set we used was not only detailed (e.g., trees by species and size, shrub cover by species), it was conducted in a systematic manner, which allowed for remeasurement. The level of detail and the ability to remeasure approximately the same areas allowed for an explicit assessment of forest change following 100 yr of management. Additionally, the serendipity of having nearly one-half of our remeasured area protected from timber harvesting over this period added a unique aspect to assessing forest change.

The graphical and statistical comparisons we present demonstrate a few important points about change in relatively productive forests that historically experienced frequent fire. First, overall forest structure and composition changed dramatically from 1911 to the early 2000s, with approximately a doubling of live basal area, halving of shrub cover, and a four- to fivefold increase in the density of live trees >15.2 cm dbh. This serves as further robust evidence of considerable forest change in these systems. Second, although there were some existing differences across the landscape in 1911, the direction and even the magnitude of forest change was relatively similar across the two agencies (NF and NP). This was true for all of the forest structure and composition attributes analyzed, with one notable exception, the decrease in large live trees in NF. Third, recent active management (burning and mechanical thinning) had an inconsistent impact on forest structure and composition relative to both recent passive management (fire suppression) and historical conditions.

The considerable change in these and other dry western North American forests has primarily been attributed to the long-adopted practices of fire suppression and exclusion, and to timber harvesting focused on large tree removal. While there is certainly evidence that both practices had an impact (e.g., Naficy et al. 2010, Knapp et al. 2013, Merschel et al. 2014), our finding suggests the fire suppression may have been the dominant driver of structural and compositional change in these forests. This is indicated by the similarities within our large historical inventory area between NF, which experienced extensive timber harvesting and fire suppression, and NP, which experienced a long period of fire suppression prior to the relatively recent reintroduction of fire (van Wagtendonk 2007). The similarities were in both magnitude of overall change from historical conditions (Figs. 2A–C, 3A) and in contemporary conditions (Figs. 2B, C, 3A). It is difficult to know with certainty what the actual extent and intensity of timber harvesting was throughout the NF portion of the study area, but digitized historical maps obtained from Stanislaus NF staff indicated that nearly half of our NF remeasured areas were "railroad-harvested" from 1918 to 1942. The remaining NF remeasured areas were harvested post World War II, when the availability of mechanized equipment and operational expertise allowed for greater access into the forest. An overwhelming majority of these harvests were partial cuts focused on large tree removal (M. Gmelin, *personal communication*). This is corroborated by documentation of the "USFS standard practice" in this area, which involved removing most trees over 91 cm (36 in.) dbh and partially removing trees 30–90 cm (12–35 in.) dbh (Hasel et al. 1934). Based on Stanislaus NF digitized maps, only 10% of the remeasurement plots were within areas identified as having even-aged management (i.e., plantations).

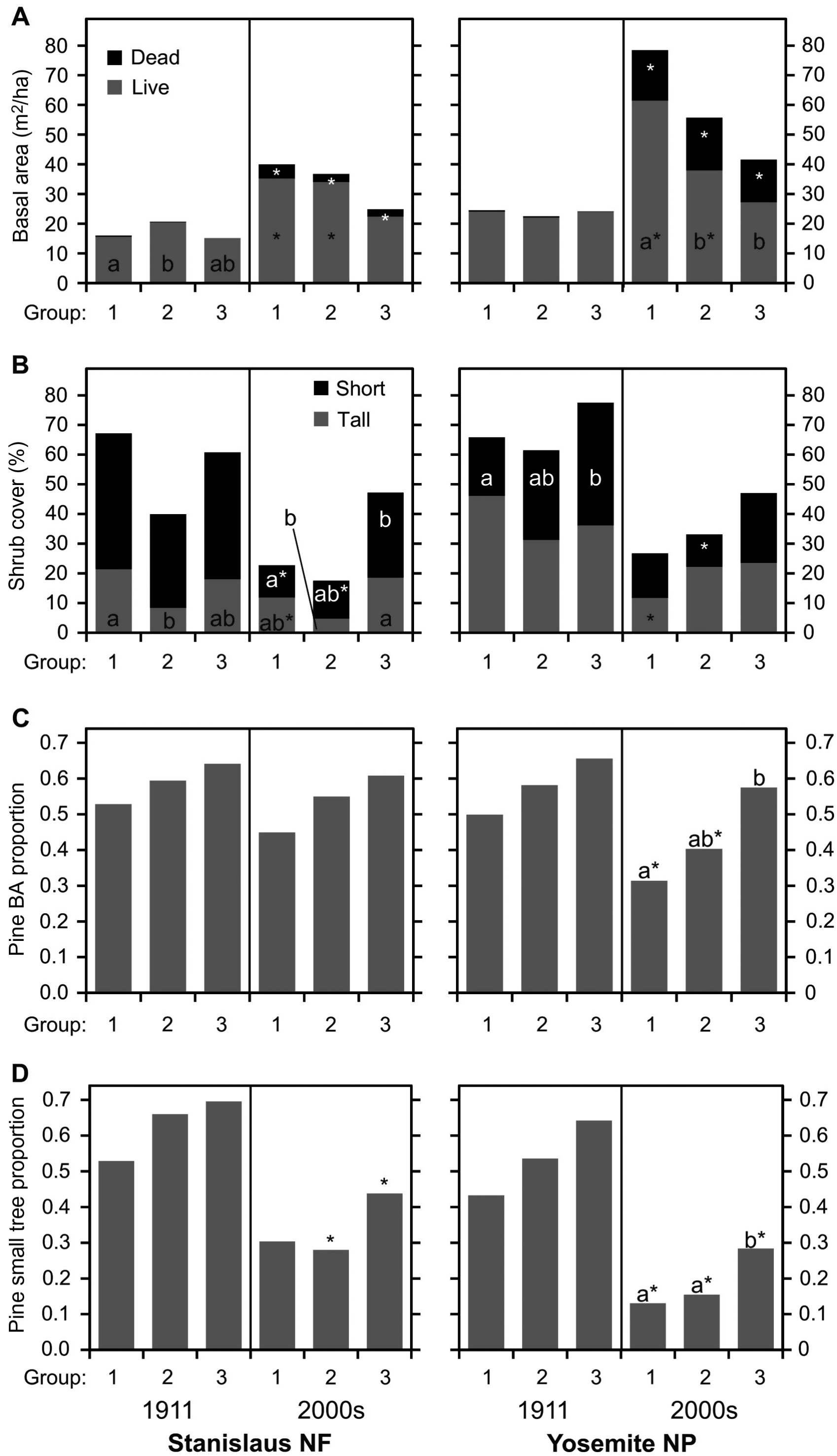

FIG. 4. Recent management activity group averages for historical and contemporary forest conditions based on a systematic timber inventory, conducted in 1911, which spanned portions of the Stanislaus National Forest (NF) and Yosemite National Park (NP). Group numbers represent 1, no recent activity; 2, mechanical thinning (NF only) or low-severity fire (NP only); and 3, moderate severity fire. Asterisks indicate significant differences ($P \leq 0.05$) between periods for an individual group, while different lowercase letters indicate statistically significant differences ($P \leq 0.05$) between groups for a given period. Two sets of these comparisons are represented in (A) live and dead basal area and in (B) >0.5 m tall and <0.5 m tall shrub cover. (C) Pine basal area (BA) proportion combines both *Pinus ponderosa* and *P. lambertiana*. (D) Pine proportion of live tree density for small trees only (dbh 15.2–30.5 cm).

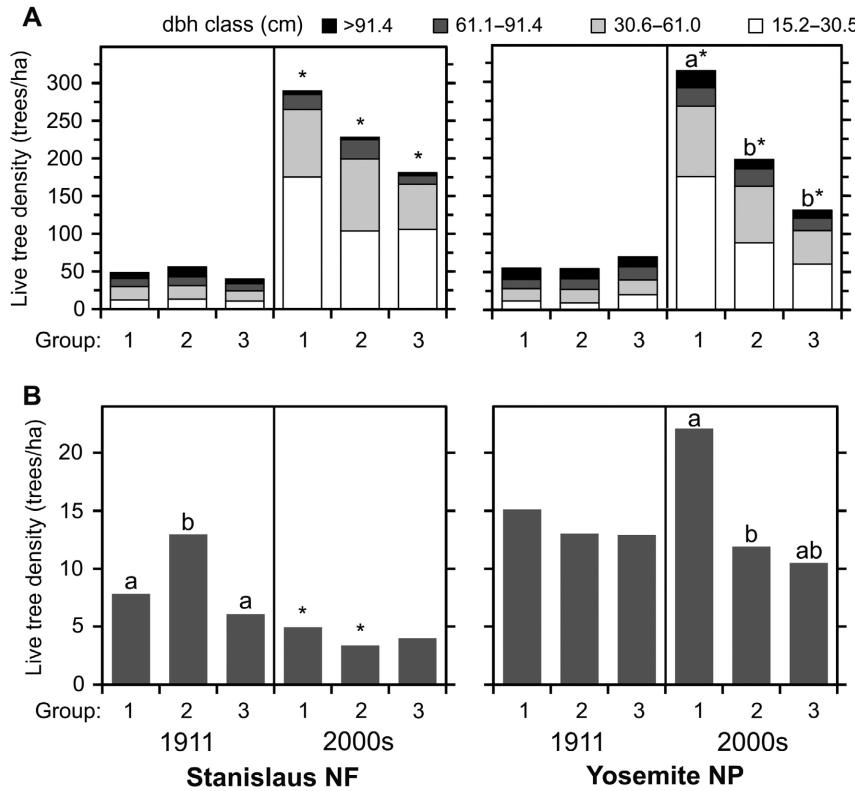

FIG. 5. Management activity group averages for historical and contemporary live tree density based on a systematic timber inventory, conducted in 1911, which spanned portions of the Stanislaus National Forest (NF) and Yosemite National Park (NP). Group numbers are as in Fig. 4. Asterisks indicate significant differences ($P \leq 0.05$) between periods for an individual group, while different lowercase letters indicate statistically significant differences ($P \leq 0.05$) between groups for a given period. Comparisons indicated in panel A are for aggregated tree density (all trees >15.2 cm dbh), while comparisons in panel B are for only trees in the largest size class (>91.4 cm).

The similarity between NF and NP areas in our study is worth further discussion given the attention that NPs and other "protected" areas have received in recent studies (Odion et al. 2014, Miller and Aplet 2016, Naficy et al. 2016, Stevens et al. 2016). A common assertion made about these areas is that they can represent contemporary reference sites, from which we can characterize more natural ecosystem dynamics (e.g., Collins and Stephens 2010, Boisramé et al. 2016) or describe the natural range of variation in forest structure and composition (e.g., Lydersen and North 2012, Collins et al. 2016). This assertion is partially based on the fact that, in many of these areas, fire has been reintroduced or restored as a key landscape-level ecosystem process (Collins and Stephens 2007, Larson et al. 2013, Parks et al. 2015). If these areas indeed are reference sites then we can assess the degree to which other sites exposed to more intensive management have been altered relative to these contemporary reference sites (e.g., Miller et al. 2012). However, results from our study area suggest that overall NP areas are as altered as NF areas for several forest structure and composition attributes relative to historical conditions. For some attributes, namely dead tree basal area and pine proportion (both BA and small trees), NP areas appear to be more departed from historical conditions than NF areas (Fig. 2A, C, D). Based on these findings, we caution against using overly broad assumptions about departure from the historical or natural range of variation in protected areas relative to more intensively managed areas.

Our findings indicating similar directions and magnitudes of change for NF and NP areas and, in some cases, greater change for NP areas, do not support the notion that there is a compound effect of both fire suppression and timber harvesting on the forest structure and composition. However, there are a couple key considerations that temper this assertion. First, the obvious effect that timber harvesting had relative to fire suppression alone was on the contemporary density of large trees, for which there was a halving in NF and no change in NP from 1911 to the early 2000s (Fig. 3B). Large trees are a critical component to many western North American forest types for both wildlife habitat provisioning and resistance to surface fire (North et al. 2009, 2017). It has been suggested that these large trees, particularly if they are old, are an ecological cornerstone to which forest restoration strategies can be anchored (North et al. 2009, Franklin and Johnson 2012). The absence or deficiency of large trees across a given landscape not only represents a departure from the historical range of variability, but it could carry some ecological consequences, i.e., diminished wildlife populations due to insufficient habitat. The second consideration has to do with the greater change for some forest structure and composition attributes in NP areas. In addition to being evident in the overall averages (Fig. 2A, C, D), this was also the case when separated out by recent management activity. The "no recent activity" group in NP appeared to have even greater change from 1911 to the early 2000s than the same group in NF (Fig. 4C, D). It is possible that elevation and site productivity are driving this. Studies of forest change from both the American Southwest (O'Connor et al. 2017) and Pacific Northwest (Merschel et al. 2014) demonstrated the greatest structural and compositional changes in areas of intermediate productivity (i.e., warm and moist). Within our study area, mean elevation for NP areas is over 250 m higher than that for NF areas (Table 1). Since our study area does not include subalpine forest types, our NP areas are likely akin to the intermediate productivity areas captured in Merschel et al. (2014) and O'Connor et al. (2017). This difference in elevation/site productivity may explain the differences in live basal area and tall shrub cover that existed between NF and NP areas in 1911 (Fig. 2).

Recent management activities have impacted the degree of departure from historical conditions. Areas that experienced recent moderate severity fire had several forest structure and composition attributes that were statistically similar to the same areas in 1911 (Figs. 4, 5). For both NF and NP, only dead basal area and total live tree density were statistically different from 1911 for this group. Areas recently thinned (NF) or burned at low severity (NP) remained statistically different from the same areas in 1911 for most attributes (Figs. 4, 5), although, comparing among groups for the contemporary period, these areas tended to have intermediate values between areas that experienced moderate severity and areas with no recent management (Figs. 4, 5). This suggests that both mechanical thinning and low severity fire modified forest structure relative to passive management (full fire suppression), but the degree of modification was not enough to approximate the historical conditions that existed in these areas. Previous work from a subset of the same historical inventory area indicated a similar distinction between low and moderate severity fire (Collins et al. 2011). The explanation was that low severity fire was not intense enough to kill trees that established early in the fire suppression/exclusion period. It is interesting that the same distinction was identified in this study given the expanded remeasurement and that this distinction existed for both NF and NP areas. This, however, was not corroborated by recent research, which suggested low severity fire can restore some forest structure attributes relative to historical conditions (Becker and Lutz 2016). Again, the fact that we remeasured the same areas for our assessment of forest change gives us greater confidence in our findings.

Our comparisons between NF and NP areas, as well as comparisons among recent management activity groups, are not without a few inconsistencies that are worth considering. The concern regarding comparisons among recent management activity groups is largely related to the unequal sample sizes among groups (Table 1). This is particularly the case for the groups in the NF areas, for which only five transects were in the moderate severity fire group, while there we 35 transects in the no recent activity group. This disparity among number of transects likely played role in the lack of significant differences among these groups in the contemporary period (Figs. 4, 5).

Management implications

Restoration efforts in dry western North American forests are often guided by information on historical forest conditions (Swetnam et al. 1999). The assumption underlying these efforts is that historical conditions reflect a state driven by natural disturbance patterns, especially fire, which was more resilient to disturbance and stressors than the current state (Safford et al. 2012). If approximating historical forest conditions is indeed one of the goals for these forests the change in forest structure and composition from 1911 to the early 2000s indicates that active restoration is needed in many areas. Whether or not the specific conditions that were measured in 1911 are to be actual targets for restoration is debatable. It is possible that the structure of these forests in 1911 were too open to provide the type of services that are desired by some current land management objectives. Regardless, it is clear from our comparisons that these forests have changed dramatically. The impacts of these changes are becoming more apparent in not only the extent and ecological effects of recent wildfires (Jones et al. 2016, Stephens et al. 2016*a*), but also in recent widespread tree mortality epidemics (Young et al. 2017). These events cannot be viewed as "one-offs"; increasing trends in large fire occurrence (Westerling 2016), proportion and extent of high severity fire (Miller and Safford 2012, Stevens et al. 2017), and tree mortality (van Mantgem 2009) have occurred throughout the western United States over the last few decades. While it is clear that climate has a role in these trends, the role of forest change cannot be ignored.

The question of how or by what means to proceed with forest restoration is elucidated by our findings comparing recent management activities. Moderate severity fire clearly came closest to approximating historical forest conditions in our area. However, to assume that moderate severity fire should or even could be implemented at large scales would be somewhat naive. Moderate severity fire generally occurs when surface fire behavior is intense enough to either scorch the crowns of some overstory trees or support localized crown fire (Lydersen et al. 2016). This type of fire behavior is often too risky for prescribed fire applications. While managed fire is a likely tool for achieving these types of fire effects

(Boisramé et al. 2017), relying on managed wildfire runs the risk of undesirable high severity effects. Beyond the actual implementation, moderate severity fire can result in a substantial pulse of woody fuels from fire-killed trees that increases fire behavior and effects in subsequent fires (Collins et al. 2016). Low severity fire may be more practical to implement, and can be effective at modifying forest structure relative to un-manipulated areas. However, on its own, low severity fire likely cannot modify structure enough to approximate historical conditions. Mechanical thinning can be readily implemented in many areas, but is limited by a number of legal, operational, and administrative constraints (North et al. 2015). The reality is that a combination of moderate severity fire (via managed wildfire), low severity fire (via prescribed fire and managed wildfire), and mechanical thinning (perhaps with a greater range of intensities) will be needed to realize large scale forest restoration. Perhaps landscape-level analyses can inform a prioritization scheme for where and by what means forest restoration efforts can be conducted to achieve large scale forest resilience (e.g., Ager et al. 2013, Stephens et al. 2016*b*, Thompson et al. 2016).

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Data Availability

Data available from the USDA Forest Service Research Data Archive: https://doi.org/10.2737/rds-2017-0045