

USING ARCHIVAL DIGITAL ORTHOPHOTOGRAPHS TO INVESTIGATE THE EFFECTS OF FIRE EXCLUSION AND INSECT OUTBREAKS ON DOUGLAS-FIR IN GRAND TETON NATIONAL PARK AND SURROUNDING AREAS

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OVERVIEW

We conducted a pilot study to establish proof-of-concept for using archival orthophotographs to study the disturbance ecology of Douglas-fir (*Pseudotsuga menziesii*) forests in and around Grand Teton National Park. Douglas-fir forests, which are thought to be influenced by a complex mixed-severity fire regime, are among the most common forest cover types in the Greater Yellowstone region and often comprise the wildland-urban interface. However, fuel management in this key forest type is currently hindered by a lack of basic knowledge on its fire ecology in both the historical and contemporary eras. To explore an approach to addressing this gap, we obtained historic (1940s) aerial photos for much of Grand Teton National Park (GRTE) and the adjacent Bridger-Teton National Forest (Fig. 1). We hypothesized that these photos could be used to assess two important dynamics in Douglas-fir forests: 1) expansion of tree cover into formerly open sagebrush areas (possibly associated with fire exclusion), and 2) regeneration following severe stand-replacing fires that occurred prior to modern record-keeping. The patches resulting from these dynamics are not necessarily apparent on contemporary photos, but comparison with historic photos could elucidate important changes and processes, such as fire exclusion or non-equilibrium forest dynamics (Fig. 1). We proposed to use the orthophotos to identify patches suspected to exhibit these processes, then collect field data on stand structure and tree ages within these patches to test this hypothesis. With these data we addressed several key questions regarding stand dynamics and fire history (see below).

METHODS

In the summer of 2012, we collected field data at four sites covered by Douglas-fir forest in GRTE area (Fig. 2). Each site consisted of two sampled patches (n=8 patches total). At two of the sites, the 1940s and 2000s photos suggested that one patch was an apparently newer stand due to expansion into formerly shrub-dominated communities, with an adjacent patch of apparently older pre-existing forest. At the other two sites, the photos indicated a patch of relatively young even-aged stand consistent with regeneration following a past severe fire, with an adjacent patch of apparently older pre-existing forest.

Within each of the 8 patches, we measured tree sizes and ages in 2-4 randomly located sample plots. At each plot we extracted cores at 30 cm height from the ground (sidehill) from the nearest 16 trees. We noted their species, diameter at breast height (dbh; 1.4 m above ground), and recorded ancillary data on the site – including canopy closure, cover of understory

vegetation, ground cover, evidence of fire (e.g., basal scars), and abiotic characteristics such as slope and aspect. A total of 445 tree cores were taken to a dendroecology lab at Oregon State University, sanded to a fine grit (>400), and crossdated using standard techniques. Only cores that passed near the tree pith were used, with a threshold of <10 inner rings, or <10% of total tree age, extrapolated via widely used mylar overlay techniques. 'Establishment' for purposes of this study was defined as when a tree reached 30 cm height. We also collected a non-systematic sample of fire scar wedges at each site, to obtain a preliminary idea of whether surface-fire scars are feasible to collect in this forest type, and also look for any temporal co-incidence of surface fires with establishment dates of cored trees.

RESULTS & DISCUSSION

Question 1. Where Douglas-fir appears to have expanded into open shrub communities in the past decades:

a. How long has expansion generally taken? What are the stand age patterns in these patches?

In the two sites where photos suggested forest expansion since the 1940s (Flat Creek and Lozier Hill), we found that tree establishment dates were indeed relatively recent. All trees had established in the 20th century (Figs. 3-4). Relatively few trees established early in the century: at Flat Creek, 98% of trees established after 1930, whereas in Lozier Hill, 71% of trees established after 1930. The establishment timing at Flat Creek consisted of a pronounced pulse between 1940 and 1970, with relatively little establishment occurring before or after that period (Fig. 3). The Lozier Hill site showed a more gradual timing, with relatively even amounts of tree establishment from the 1920s through the 1990s (Fig. 4).

Regarding the utility of the historic photos in differentiating pre-existing and recently expanded forest patches, we found that forest patches visible in the 1940s indeed had much older trees at Flat Creek (most trees established in the 1700s and 1800s), but less so at Lozier Hill. At Lozier Hill, the pre-existing patches had a fairly similar age distribution as in the expansion patch, but with a few older 'legacy' trees that were distinctly older than the main cohorts. This suggests that, in some cases, the pre-existing forests identified by the photos may have consisted of scattered, low-density woodlands of older trees that have subsequently filled in with younger cohorts, with similar timing to the adjacent expansion patches. In contrast, in sites such as Flat Creek, the adjacent pre-existing forest is markedly older than the newly expanded forest, showing a broad array of much older trees at higher density. Overall, the photos were well validated in terms of identifying expansion patches, but less certain in identifying truly older forest adjacent to those patches.

b. Can fire exclusion be attributed to these changes? What other mechanisms might be involved, such as climate, wildlife impacts to microsites, etc.?

Historic photos of formerly open areas are commonly used to illustrate forest 'encroachment' as a likely symptom of fire exclusion. This is a possibility for these stands. At Flat Creek, we did find fire scars in adjacent stands from the late 1800s, with no such evidence during the 20th

century. On the other hand, at Lozier Hill, we found fire scars throughout the 1900s. Our pilot fire scar sampling was not systematic or complete, and we do not yet know how much area those fires covered or whether they likely affected the expansion patch area. However, the pilot sampling suggests that additional fire scar data for Douglas-fir forests in the study area could further clarify disturbance patterns and relationships.

An interpretation we are considering is whether the expansion patches truly represent an ‘encroachment’ of forest cover into formerly stable shrub communities, or instead represent slow, non-equilibrium forest successional dynamics. It is also possible that, given the extremely slow regeneration dynamics that Rocky Mountain Douglas-fir can exhibit, the expansion patches are actually similar to the stand-replacement patches, but captured by photos at a different point in post-fire succession. In this scenario, the open patches identified in the 1940s photo would be from past stand-replacing fires, which were taking decades to begin to regenerate – perhaps on drier, low-productivity sites. It is possible that the open patches in the 1940s photos actually had small-stature regeneration that was not yet visible from the air; the age distribution at Lozier Hill is consistent with this supposition (Fig. 4). Forest dynamics could thus be described as a continual cycle of very slow regeneration/in-filling (possibly influenced by surface fires as well), followed by eventual stand-replacing fires, which again regenerate very slowly, and so on. One factor we have not resolved, however, is that we observed little to no old snags or logs in open patches in the 1940s photos; thus, if those patches did originate from prior fires, they would have occurred many decades previously. We have not resolved this interpretation in this pilot study, but have begun to consider it for the next iteration of the study.

As for climatic and wildlife drivers of establishment, and potential influences of settlement-era human disturbances (e.g., open areas could partly have been the result of past logging or land clearing), those analyses are ongoing via cross-referencing with long-term records of climate, wildlife populations, and land use.

c. What characteristics differentiate expansion stands versus surrounding older patches?

Our pilot sample afforded preliminary analysis of differences between recently expanded and adjacent pre-existing forests. In terms of abiotic setting (Fig. 7), recently expanded stands were not different from pre-existing stands in elevation or slope steepness; however, there was a tendency for recent stands to be on slightly warmer and drier aspects, which would be consistent with the expectation that expansion (or extremely slow regeneration) would be more likely on warmer, drier, less productive slopes that are often less conducive to tree cover. In terms of stand structure, we detected no difference in basal area between recent and pre-existing stands (Fig. 8). Tree size distributions were generally smaller in recent stands, but this was counteracted by higher tree densities, leading to similar basal area. Thus, simple stand structure metrics like basal area may not be useful by themselves in discerning stand histories. In terms of susceptibility to bark beetle outbreaks, higher basal area stands are considered more at risk. Despite the similar basal area between recent and older stands, we observed more bark beetle activity in the pre-existing stands; this may be due to a higher prevalence of large-diameter trees in pre-existing stands. Alternatively, there may be another contributing factor driving outbreaks in pre-existing stands other than stand density or basal area. We are currently exploring other potential factors.

Question 2. Where historic photos suggest a stand-replacing fire prior to modern record-keeping:

- a. *What are stand age distributions? What can be learned about past fire effects within and adjacent to these burns?*

In the two sites for which historic photos showed an apparently younger, even-aged patch (but is now largely not discernible from surrounding stands in current photos), we found distinct age distributions compared to adjacent stands. Specifically, there was a strong pulse of tree establishment for a 30-50 year period at both sites, starting in 1900 at Snow King and 1880 at Pritchard Pass (Figs. 5-6). In neither site's young stand was there any establishment prior to these pulses. Small amounts of regeneration continued during ensuing decades, in some cases several decades later that may indicate subsequent recruitment of a shade-tolerant understory.

In contrast, stands adjacent to these patches ("older patches") showed much broader age distributions dating back to the mid-1700s (Figs. 5-6). Large-diameter dead and rotten trees that could not provide core samples were also abundant. These stands were in fact much older than the patches we identified in the historic photos. Interestingly, the older stand at Pritchard Pass did show a secondary cohort that established at approximately the same time as the main cohort in the adjacent younger stand (Fig. 6), suggesting regeneration after a possible surface fire that was co-incident with the stand-replacement event. Although we have yet to confirm this notion with our fire scar samples, we did collect those samples from the site and were able to identify apparent fire scars, suggesting that further sampling could sufficiently test the idea. Fire scars were also evident at Snow King even in the young stand (but not co-incident with tree establishment dates according to our small pilot sample), providing further indication of a mixed-severity fire regime that could be better parameterized with more comprehensive sampling.

Regarding the utility of the historic orthophotos, we found high utility in accurately identifying "landscape scars" of prior stand-replacing fires. In both of our pilot sites, the age distributions were consistent with the notion of a stand-replacing disturbance that generated a relatively even-aged cohort of Douglas-fir in an otherwise older forest matrix. Most of these patches are now difficult to see in current aerial photos, or from hillslope views in the field. Overall, the historic photos show excellent promise for future research into Douglas-fir forest fire regimes in the GRTE area. One limitation of the use of historic orthophotography is the need for accurate mapping of forest types. It was difficult to differentiate patterns of meadow infilling and fire scars in Douglas-fir versus lodgepole pine forests. Companion vegetation maps did not always identify them correctly. As a consequence, some potential study sites were rejected in the field due to misidentification in mapping.

- b. *What characteristics differentiate stands from past surface fires versus stand-replacement patches and patches without detectable fire history?*

The most notable characteristic of stand-replacing fire sites was that they occur on cool northeast aspects (Fig. 7). This pattern is sensible, as this is where moist microsites are more likely to prevail, which allow greater biomass and fuel continuity to accumulate, which, when an extreme fire season occurs, is more likely to burn intensely. There were few abiotic differences between stand-replacing fire patches and adjacent older stands, with the exception of a slight tendency toward steeper slopes (Fig. 7) – again, sensible since steeper slopes often burn the most severely due to greater convective heat transfer. Our pilot investigations thus may suggest a relationship between burn severity and topography, which may have further implications for beetle outbreak distributions in relation to slope and aspect. This is another area that could be tested in future investigations.

In terms of stand structure, there was a slightly (though not significantly) higher basal area in younger stands compared to adjacent older stands (Fig. 8). These relatively productive sites can likely support higher basal area than those at the expansion sites, consistent with the notion of stand-replacing fire occurring in denser, higher basal area stands of Douglas-fir. In terms of susceptibility to bark beetle outbreaks, we generally observed greater bark beetle activity in older stands, possibly for the same reason as stated above (more large-diameter trees). We suspect that the similarity in live basal area between older and younger stands arises, in part, from beetle-caused mortality in older stands, which has reduced live basal area from previously higher levels there. We collected data on dead stems, including the proportion of those trees that were beetle-killed, and analysis of those data is ongoing.

SYNTHESIS & SUMMARY

A primary outcome of this pilot research on Douglas-fir forests of Grand Teton National Park and surrounding areas is: (1) the historic orthophotos from the 1940s show excellent promise for elucidating stand-replacing fire dynamics and subsequent regeneration in Douglas-fir forests, even in landscapes where such patches are no longer discernible in current photos; and (2) the historic orthophotos show moderate promise for detecting forest expansion areas, in that they can reliably show newly expanded areas but cannot always discern these from adjacent stands that may or may not have been pre-existing. A stronger set of criteria for delineating pre-existing stands in such sites will be an important component of continuing this research; we are confident that such criteria can be designed and met in future studies based on what we learned from the current work (e.g., using existing LiDAR data to quantify canopy structure in greater detail).

These initial data suggest that Douglas-fir regeneration following stand-replacing fires is a multi-decadal process, with a distinct pulse of tree establishment within 30-50 years following the disturbance. This finding is consistent with data on Douglas-fir forests burned by the 1988 Yellowstone Fires, in which regeneration has continued for ~25 years (Donato et al., unpublished data). Site factors such as slope and aspect may be affecting the timing of reforestation, with some drier sites being delayed several decades. Because regeneration and successional dynamics in Rocky Mountain Douglas-fir forests are so poorly understood to date, these studies provide key baseline information on which to build future research and management directions.

Douglas-fir expansion into former shrub or meadow communities appears to be a more variable process. In some cases, tree establishment can happen in a pulse within a few decades, while in others it may be an essentially continual process over time. We view the key question to be whether these sites were actually forested at some point in their past, long prior to the historic photo timepoint when the patches were open (1940s). If so, this would carry important implications, as the expansion would not be considered ‘encroachment,’ but rather extremely slow regeneration of a disturbed forest stand. We plan to continue this line of inquiry in future work, to seek evidence either supporting or not supporting this hypothesis.

MANAGEMENT IMPLICATIONS

All four study sites indicated a 19th-century history of both stand-replacing fire and mixed-severity surface fire in Grand Teton National Park and the Bridger-Teton National Forest. A pattern of increasing basal area within younger stands and some older stands reflects a trend of tree recruitment throughout the 20th century. These patterns have manifested during a period of relatively few fires burning in Douglas-fir forests, when compared to fire scar records from the pre-settlement period. The degree of fire regime departure is uncertain, however, due to poor understanding of the spatial extent of fire events recorded on some fire-scarred trees, and because stand-replacing fires appear to have been part of the historic regime.

Historic aerial photographs, when orthorectified and compared in a GIS to modern versions, can be used to identify and evaluate disturbance and regeneration patterns over the larger landscape. Accurate vegetation mapping is key to correct attribution of fire regimes, however. As Douglas-fir fire regimes are better understood, this spatial information could help in prioritizing sites where prescribed fire or alternatives to fire suppression are warranted.

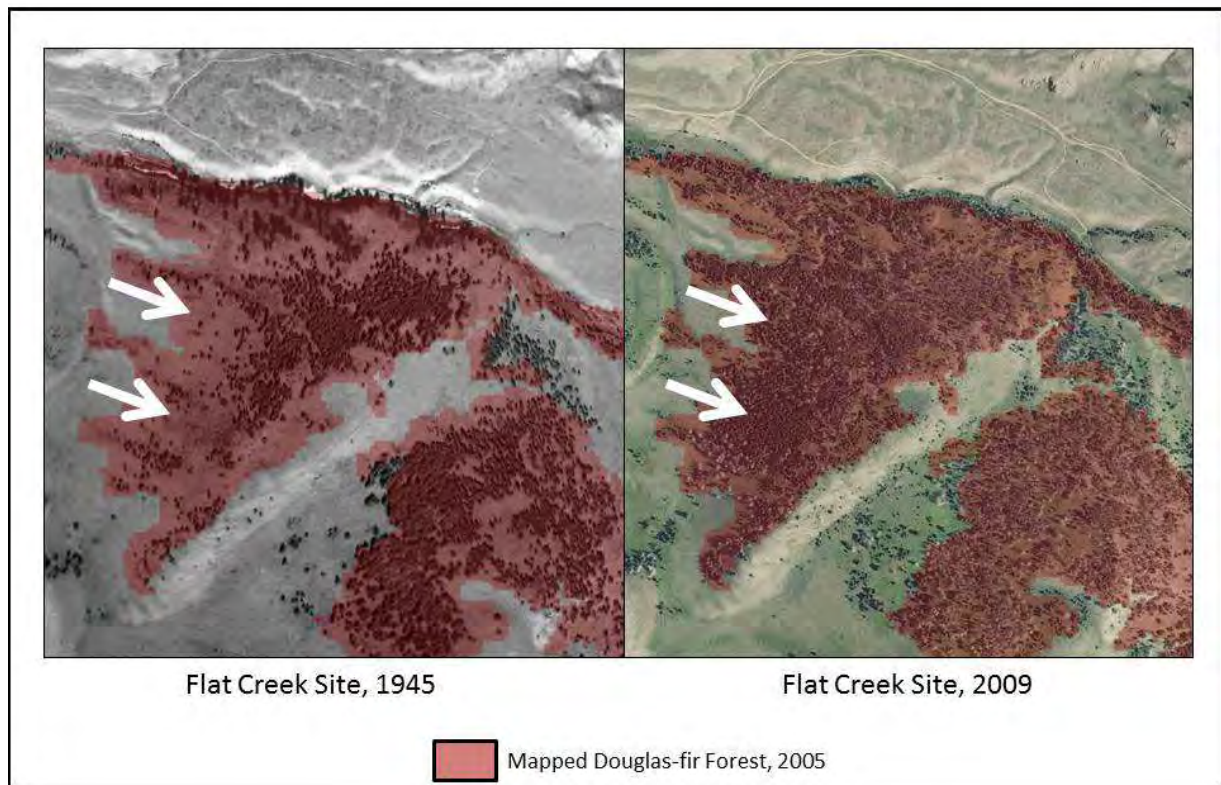


Figure 1. Example of comparison of 1945 and 2009 aerial photos, showing increase in forest cover and candidate sampling sites.

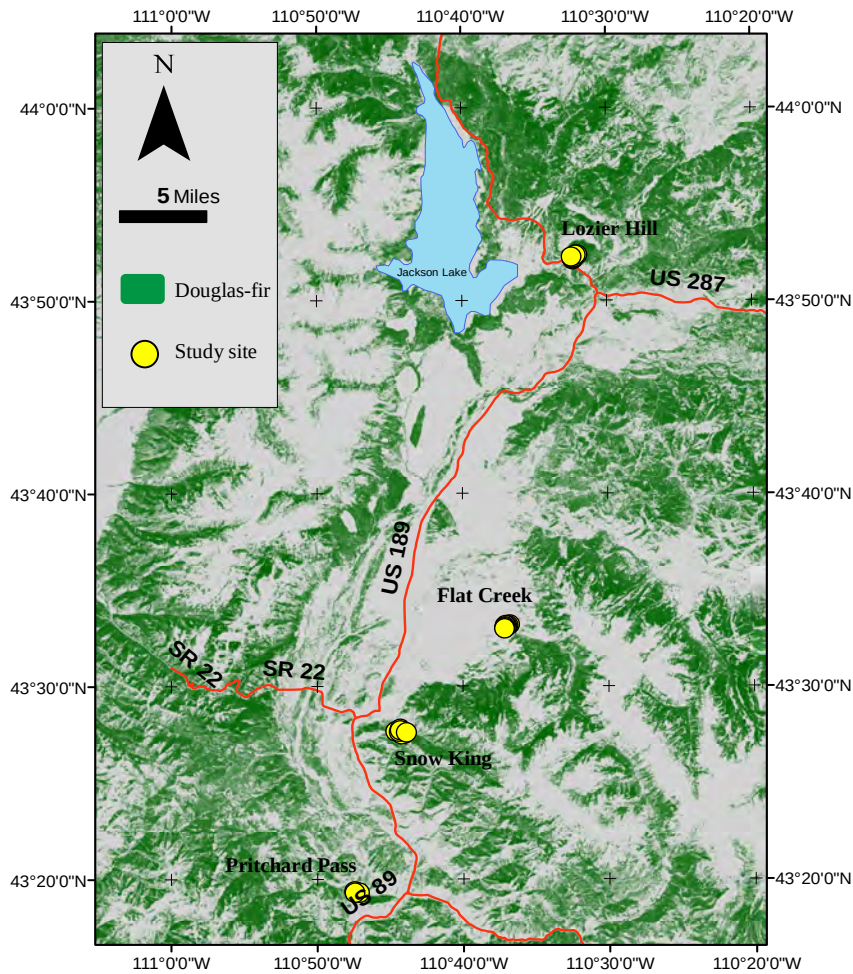


Figure 2. Study area map. Within each of the four indicated study sites, two patches, containing 2-4 plots each, were sampled for tree structure and age. Lozier Hill and Flat Creek contained areas where Douglas-fir had apparently expanded into formerly sagebrush areas, according to the historic photos. Snow King and Pritchard Pass contained areas of relatively young, even-aged forest in the historic photos, suggestive of past stand-replacing fires.

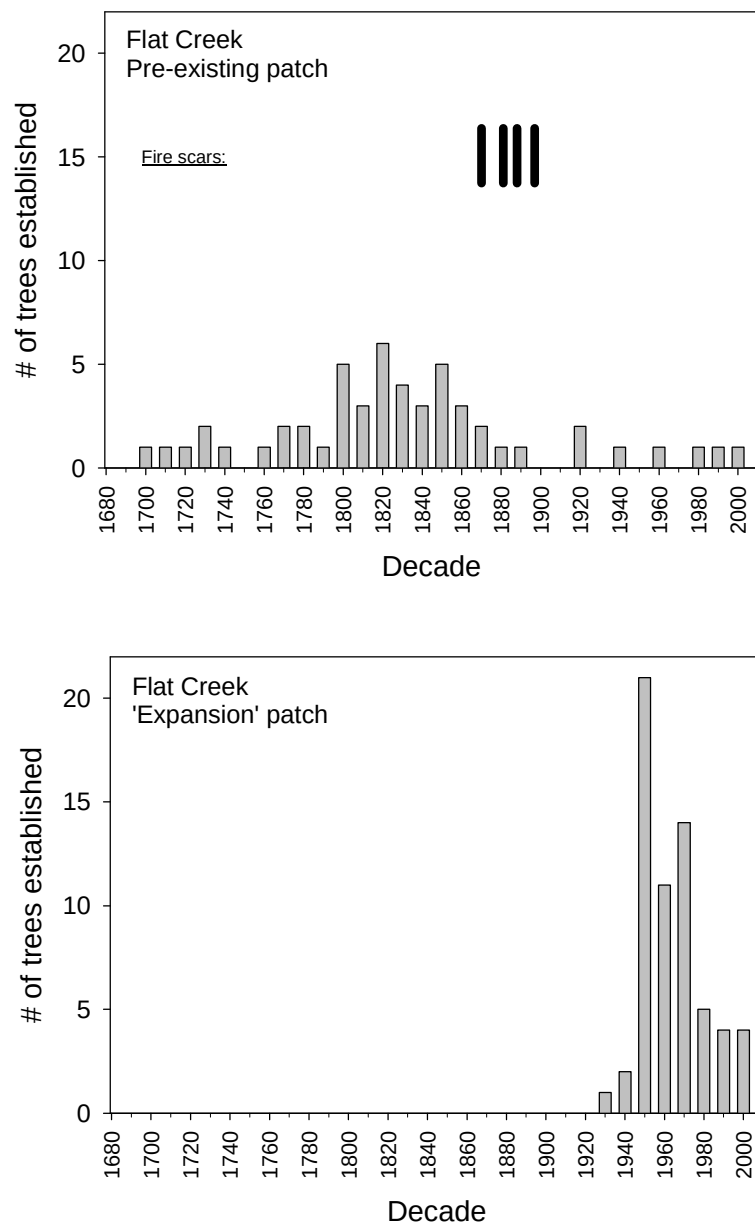


Figure 3. Establishment dates of trees at Flat Creek.

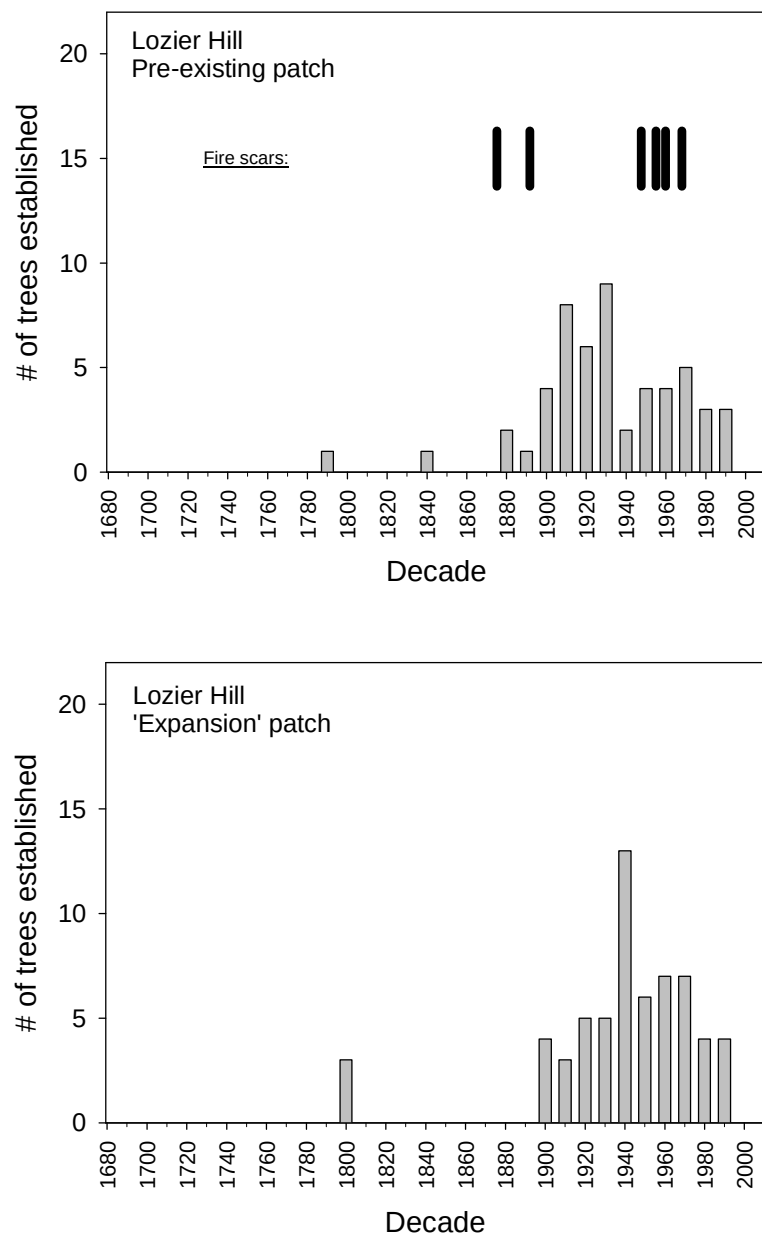


Figure 4. Establishment dates of trees at Lozier Hill.

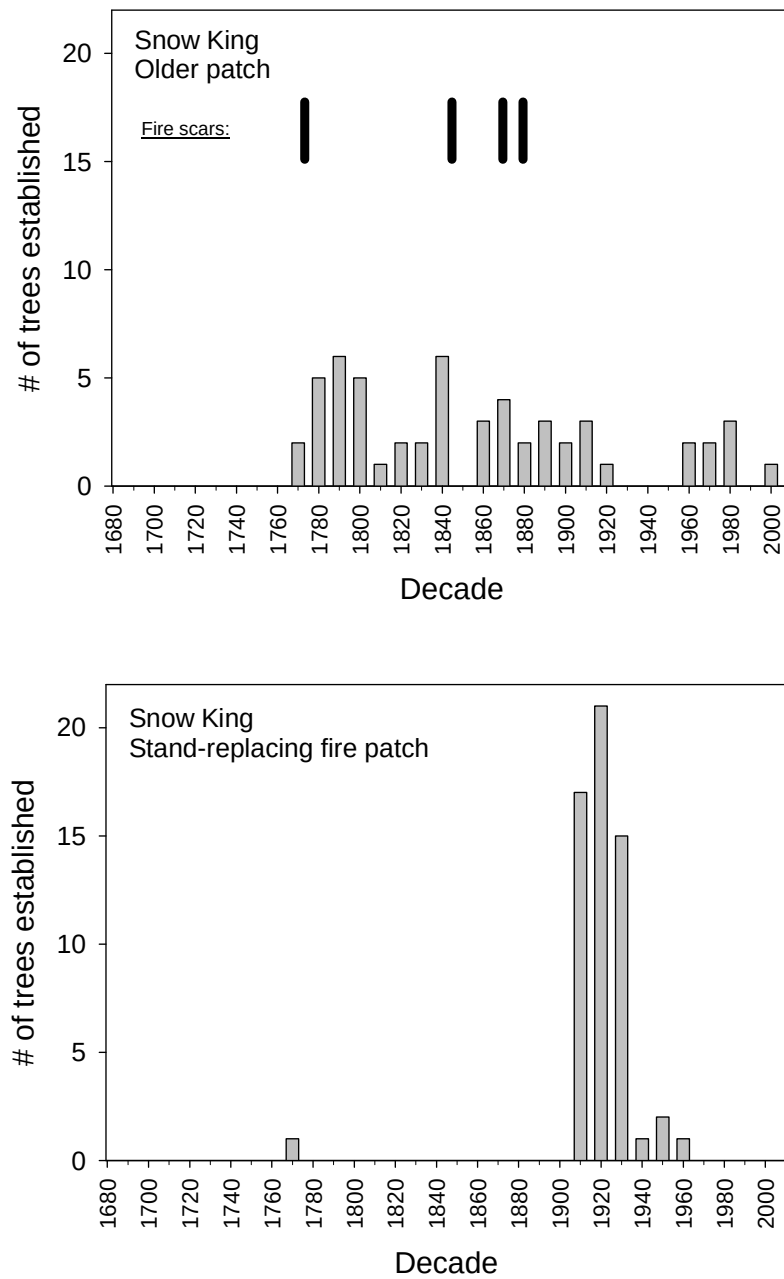


Figure 5. Establishment dates of trees at Snow King.

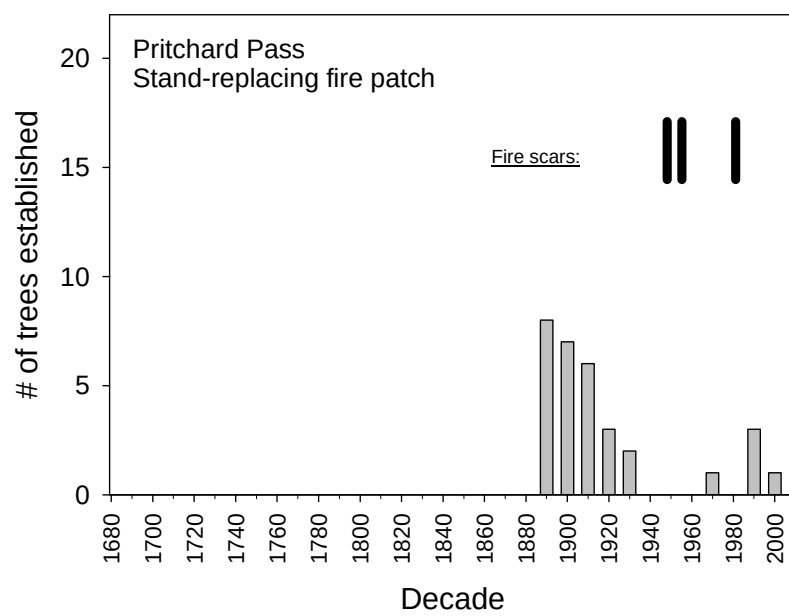
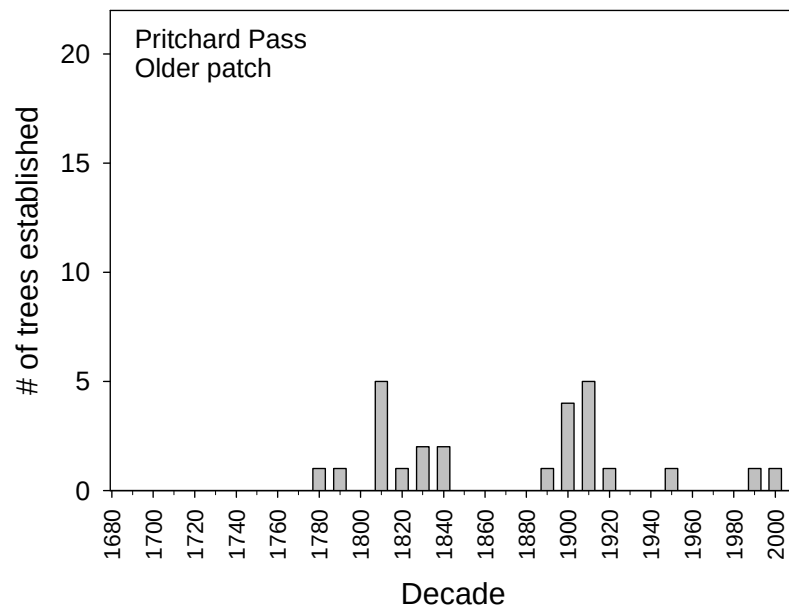


Figure 6. Establishment date of trees at Pritchard Pass.

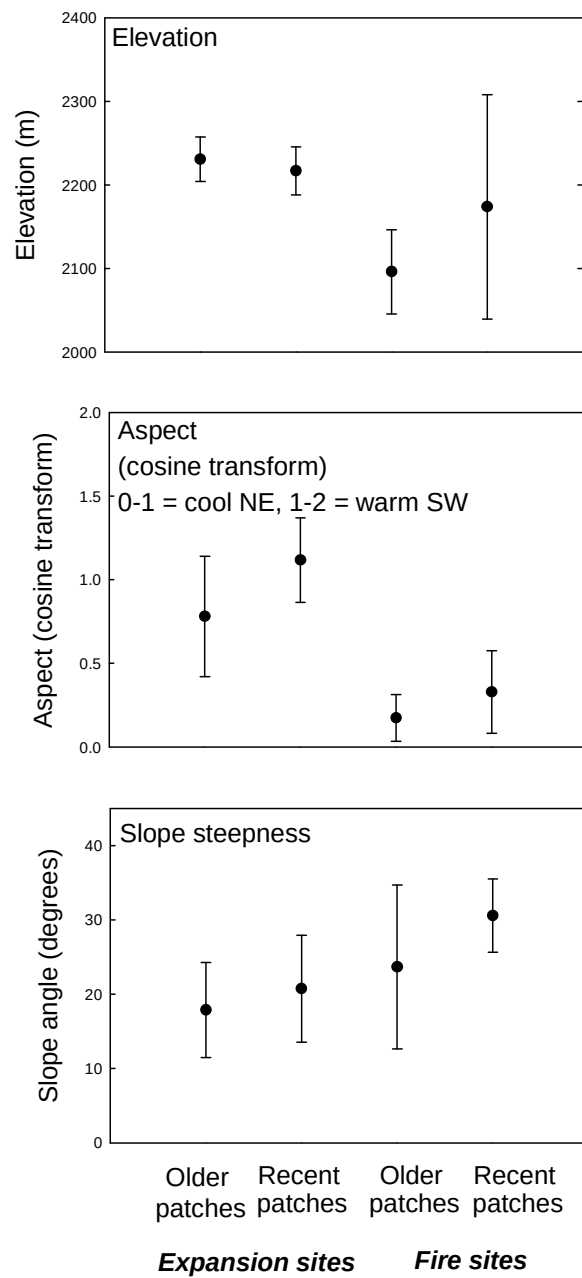


Figure 7. Elevation, aspect and slope steepness in the study sites. Data are means $\pm$ 95% confidence intervals.

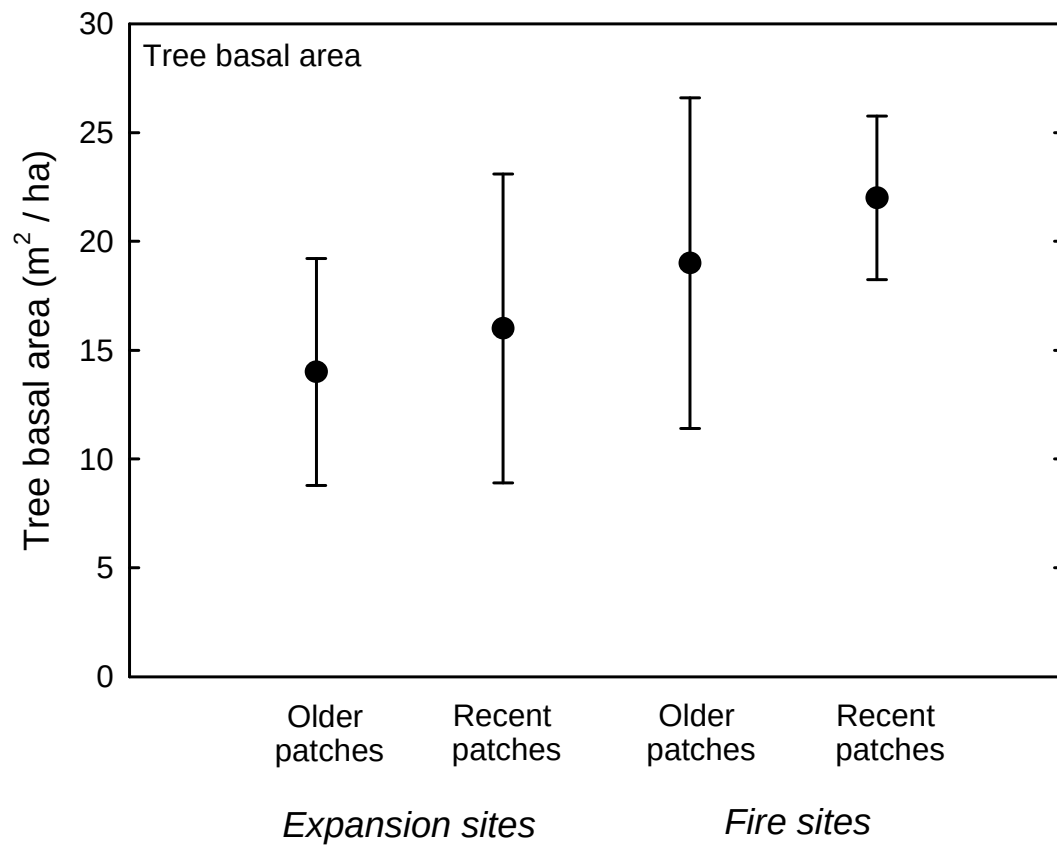


Figure 8. Tree basal area in the study sites. Data are means $\pm$ 95% confidence intervals.