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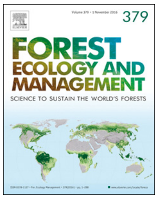

Accuracy of node and bud-scar counts for aging two dominant conifers in western North America

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ABSTRACT

Accurately aging trees is critical for understanding tree demography and tree responses to environmental change. Given the proliferation of studies aimed at understanding the effects of climate and disturbance on forest ecosystems, it is important to understand the tradeoffs between field-based age estimates and precise dendrochronological techniques. We assessed the accuracy of age estimates from node counts in the field against precise tree-ring counts at the root-shoot boundary, in 1279 ponderosa pine and 1268 Douglas-fir seedlings sampled from across three study regions in the western U.S. We also assessed the accuracy of age estimates from bud-scar counts in the field against node counts and precise tree-ring counts in a subset of 757 seedlings from the Northern Rockies. Node counts systematically underestimated ring counts by an average of 4.1 years, with bias increasing with tree age. At annual, ± 1-, ± 2-, and ± 5-yr precision, the accuracy of node counts was 5%, 15%, 29%, and 74% across all regions and species, respectively. Similar results were found for bud scars. Given the magnitude of the bias between field-based methods and ring counts, it is critical to select appropriate aging methods, based on the precision required to answer specific ecological questions. To improve the accuracy of field-based age estimates in these species, we provide a tool for correcting for the bias when precise dendrochronological aging is not feasible.

1. Introduction

Ongoing global change, including increased drought stress on trees (Allen et al., 2010; van Mantgem et al., 2009; Williams et al., 2012) and an increased frequency of wildfires and other stand-initiating disturbances (Abatzoglou and Williams, 2016; Dale et al., 2001; Westerling et al., 2006), has motivated a renewed interest in understanding patterns of tree establishment and recruitment (e.g. Stevens-Rumann et al., 2018). The resilience of forests to these stressors ultimately depends on the ability of trees to reestablish and survive. Studies of forest demography at varying temporal scales highlight post-disturbance vegetation change (Bergeron, 2000; Mast et al., 1998; Rother and Veblen, 2017; Turner, 2010), shifts in treeline (Coop and Givnish, 2007; Daniels and Veblen, 2003; Kearney, 1982), and climate-driven recruitment and stand dynamics (League and Veblen, 2006; Savage et al., 1996). Understanding the pattern and timing of tree recruitment is critical to disentangling the drivers of these processes.

Quantifying the impacts of climate change, climate variability, and disturbances on forest dynamics ultimately requires estimating recruitment dates, and thus tree age. Field-based methods such as node or bud-scar counts are commonly used to provide approximate tree ages, and they have the advantage of being efficient and non-destructive (Dovčiak et al., 2005; Haire and McGarigal, 2010; Harvey et al., 2016; Millar et al., 2004; Sprugel, 1976; Urza and Sibold, 2013). However, node and bud-scar counts are only proxies for true tree age (Urza and Sibold, 2013). Cross-dated tree rings, from tree cores or cross sections, provides a more precise method for dating trees (Speer, 2010; Stokes and Smiley, 1968; Telewski, 1993; Telewski and Lynch, 1991). However, ring counts provide the age of a tree at sample height, which would underestimate true tree age, unless samples are obtained at the root-shoot boundary. While this may be accounted for with decadal-scale age classes or age-height adjustments, this limits the scope of ecological questions that can be addressed.

Increasingly, a number of studies are attempting to infer the impacts of seasonal- to annual-scale climate on the establishment and early survival of conifer species from across western North America (Dobrowski et al., 2015; Donato et al., 2016; Harvey et al., 2016; League and Veblen, 2006; Rother and Veblen, 2017; Tepley et al., 2017). For these purposes, one needs annual accuracy in tree-establishment dates, as even 1–2 years of error could obscure relationships to

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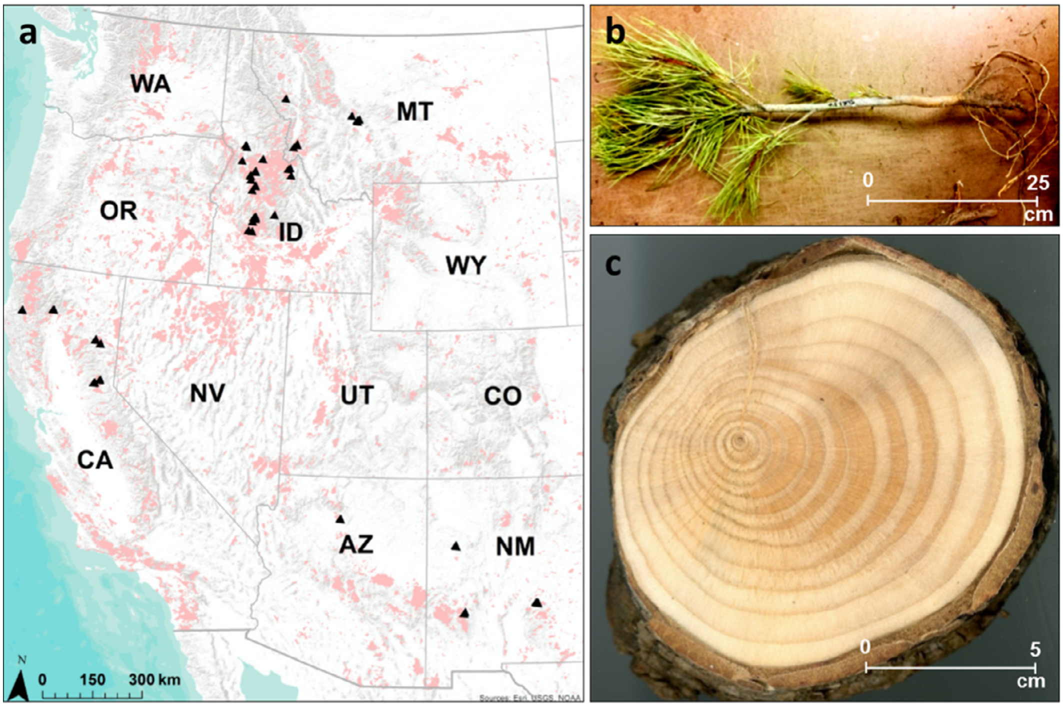

Fig. 1. Sampling sites in low-elevation dry mixed-conifer forests that burned between 1992 and 2007 across the western continental United States (a). Pink areas indicate all fires that occurred from 1984 to 2014 from the Monitoring Trends in Burn Severity dataset. (b) Nodes visible on a seedling sample in the field. (c) Annual rings at the root-shoot boundary visible using a 1200 dpi scanner.

seasonal or annual climate variability. Aging trees or seedlings with annual accuracy requires counting tree rings at the root-shoot boundary (Telewski, 1993), which is time-intensive and usually requires destructive sampling (Bergeron, 2000; Rother and Veblen, 2017).

Given the proliferation of studies aimed at understanding the effects of climate and disturbance on Western forests, it is important to understand the implications of aging trees using field-based methods versus precise dendrochronological techniques. We assessed the accuracy of age estimates from node counts in the field against precise ring counts at the root-shoot boundary in 2547 samples from two dominant low-elevation conifers in western North America. We sampled 1279 ponderosa pine (*Pinus ponderosa* Douglas ex P. Lawson & C. Lawson) and 1268 Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) seedlings and saplings from across three study regions in the western United States (Fig. 1) to assess how the accuracy of node counts varies with species, region, tree age, and vertical growth rates. In a subset of 757 seedlings in the Northern Rockies, we also assessed the accuracy of age estimates from bud-scar counts in the field against node counts and precise tree-ring counts. We expected that node and bud-scar counts would underestimate tree ages based on ring counts, with this difference increasing in older and faster-growing trees due to loss of lower branches and radial bark growth in older trees.

2. Methods

2.1. Study area

The study was conducted in three regions across the western continental United States in dry mixed-conifer forests dominated by ponderosa pine (*Pinus ponderosa* Douglas ex P. Lawson & C. Lawson) and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco). Sampling was conducted in recently burned stands in northern California, the Northern Rockies (Idaho and Montana), and the Southwest (Arizona and New Mexico) (Fig. 1a). Across the California study sites, mean annual temperatures range from 8.5 to 15.6 °C, and mean total annual precipitation ranges from 645 to 1870 mm (30-yr normals, 1981–2010) (Daly et al., 2008; PRISM Climate Group, 2017). The California region experiences hot, dry summers and cool wet winters. Across the Northern Rockies, mean annual temperatures range from approximately 3.3 to 8.4 °C, and mean total annual precipitation ranges from 318 to 878 mm (30-yr normals, 1981–2010) (Daly et al., 2008; PRISM Climate Group, 2017). The Northern Rockies region experiences warm dry summers and cool wet winters. Across the Southwest study region, mean annual temperatures range from 8.0 to 10.0 °C , and mean total annual precipitation ranges from 388 to 667 mm (30-yr normals, 1981–2010) (Daly et al., 2008; PRISM Climate Group, 2017). The Southwest experiences snow in winters and rain in late June through September due to the North American Monsoon. Terrain in these study regions is mountainous, often characterized by steep topography.

In all regions, study sites were located in low-elevation montane forest, where ponderosa pine and Douglas-fir are close to the edge of their climatic tolerance. In total, post-fire trees were sampled at 55 sites in ponderosa pine and Douglas-fir dominated forests that burned in years spanning 1992 to 2007. All sites burned at moderate to high severity (as classified by the Monitoring Trends in Burn Severity program), and have N/NE or S/SW aspects. Samples were collected as part of a larger study investigating the effects of seasonal to annual climate variability on the timing and rate of post-fire conifer regeneration.

2.2. *Sampling design and field measurements*

At each site we sampled all tree seedlings and saplings (hereafter “juveniles”) in a 60-m long belt transect, with transect width varying from 2 to 40 m, based on the goal of sampling approximately 30 juveniles per site, distributed in proportion to the on-site species composition. Node counts were recorded for seedlings and saplings as a field-proxy for age (Fig. 1b), following a standardized protocol that was implemented by each of the three-member field crew. We counted a node where a set of branches extended from the main stem of the sample, and we added the current year’s leader to the count. After node counts, each sample was cut with a hand saw approximately 10 cm above the root collar, excavated to approximately 10 cm below the root