FINAL REPORT

Assessing post-wildfire conifer regeneration: Validation of a non-destructive seedling aging method

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Table of Contents

List of Tables

List of Figures

List of Abbreviations

RMSE – Root mean square error

Keywords

Ponderosa pine; black spruce; grand fir; non-destructive aging; post-fire regeneration; conifer regeneration; terminal bud scar

Acknowledgements

Thank you to everyone who helped collect bud scar counts in the field (Eli Berman, John Byrne, Jessie Dodge, Andrew Hudak, and Sean McNeal) and to Penelope Morgan for first teaching us this method. Emily Mangini helped with field sampling, completed the majority of the lab work, and presented this work at two conferences as well as providing illustrations.

Abstract

Determining the age of natural conifer regeneration following wildfires is crucial to understanding ecological trajectories and predicting post-fire effects in conifer forests. However, traditional methods of determining seedling age via growth ring counts requires killing desirable seedlings, while the validity of non-destructive alternatives is undetermined in many species. In 2016 and 2017 we sampled ponderosa pine (*Pinus ponderosa*) in central Oregon (dry ponderosa) and southeast Washington (dry mixed conifer), grand fir (*Abies grandis*) in southeast Washington, and black spruce (*Picea mariana*) in Interior Alaska (boreal spruce). Seedlings were sampled within wildfires that had burned in either 2004 (Alaska), 2005 (Washington), or 2007 (Oregon) as well as from unburned areas within or immediately outside the fire perimeter. Seedling age was estimated in the field by counting terminal bud scars, after which seedlings were cut at ground level. The "true" age was then determined by counting basal growth rings using WinDENDRO software. The precise accuracy (where bud scar age was equal to ring count age) was 17% for ponderosa, 18% for grand fir, and 27% for black spruce, which increased to 49%, 45%, and 56% accuracy at +/- one year accuracy. Bud scar counts underestimated age by an average of 1.8 years for ponderosa, 1.6 for grand fir, and 0.84 for black spruce. For all species our results show that accuracy was best for seedlings younger than ~15 years, likely due to bark formation in older seedlings that covers early bud scars, and on non-suppressed seedlings, i.e. seedlings that were relatively tall for a given age. In general our findings agree with those of previous studies on non-destructive aging methods, that these non-destructive methods can be accurate enough for some applications but are likely inappropriate for applications requiring high precision of seedling aging.

Final Report

Objectives
The objective of this project was to improve the accuracy and inference of post-wildfire seedling recovery studies by quantifying the validity of a commonly used field aging method: terminal bud scar counts. To do so, we destructively sampled seedlings of three major Western U.S. conifers and compared field age estimates based on terminal bud scar counts to laboratory age estimates based on basal growth ring counts. The accuracy of bud scar counts were determined by comparing them with growth ring counts.

Background
The age and timing of conifer regeneration in many post-wildfire landscapes is a critical factor in the ecological trajectory of a site and in tracking and predicting post-fire effects. The ability to accurately age conifer seedlings has wide-ranging applications in post-fire and other post-disturbance management and research since dating the establishment of seedling cohorts progresses our understanding of forest regeneration dynamics and future ecosystem trajectories (Morin & Laprise 1997; Murphry et al. 1999; Girardin et al. 2002; Stevens- Rumann et al. 2015; Harvey et al. 2016). Other management applications include calculation of growth rate and factors that affect it, such as disease (e.g. Maguire et al. 2002) or climate (e.g. Hankin et al. 2019), as well as improved understanding of how activities such as the removal of grazers (e.g. Miller & Halpern 1988) affect seedling establishment. This project will evaluate the accuracy of a non-destructive aging method (terminal bud scar counts) for post-wildfire regeneration of three important western U.S. conifer species (black spruce [*Picea mariana*], ponderosa pine [*Pinus ponderosa*], and grand fir [*Abies grandis*]).

Methods for measuring ages of seedlings fall into two main categories: destructive and non-destructive. Destructive methods consist of using serial sectioning (League & Veblen 2006; Daniels et al. 2007) or longitudinal splitting (Nigh & Love 1999) to locate the root-shoot interface and then counting the number of annual growth rings at that location in the stem. Though these methods are generally considered the most accurate (Telewski & Lynch 1991) there are disadvantageous in that they are labor intensive, can be very difficult or impossible to conduct accurately in the field, and they kill desirable seedlings.

Non-destructive methods are primarily coring for annual ring counts or counting terminal bud scar or branch whorls. While coring can provide the same information as destructive methods if the pith is intercepted at the base of the tree (Stokes & Smiley 1968), it carries a significant risk of killing smaller seedlings (DBH <2.5 cm) and thus may not be a viable option for aging seedlings when seedlings are young and a non-lethal method is needed. Branch whorls can be formed at the terminal bud and counted to estimate age (Figure 1) but branch loss or sprouting means that the accuracy of aging is very dependent on species (Husch et al. 2003) and age, which may make simple counting of branch whorls an imprecise method overall. However, for ponderosa pine and Douglas-fir (*Pseudotsuga menziesii*) the difference in accuracy between whorl and bud scar counts may be negligible (Hankin et al. 2018).

Though terminal bud scar counts have been shown to be a reliable method of aging, in some cases more accurate than counting growth rings in suppressed seedlings (Parent et al. 2001), the accuracy varies by species, age, and height of the seedling (Williams & Johnson 1990; Urza & Sibold 2013). Studies explicitly testing the accuracy of terminal bud scar counts via a comparison with destructive sampling have examined only a limited number of tree species (Williams & Johnson 1990; Urza & Sibold 2013; Hankin et al. 2018). Williams & Johnson (1990) reported no significant difference between age estimates from bud scar vs growth ring counts for table mountain pine (*Pinus pugens*) but did not provide any estimates of error. Urza & Sibold (2013) examined western larch (*Larix occidentalis*), lodgepole pine (*Pinus contorta*), Englemann spruce (*Picea engelmannii*), and Douglas-fir in Glacier National Park and found that for western larch and lodgepole pine the age and height of the seedling had a strong relation to accuracy and error due to the healing over of bud scars, with terminal bud scar counts underestimating seedling age by an average of 1.25 and 1 year respectively. Hankin et al. (2018) focused on whorl counts as their primary non-destructive method, however they found that the differences between bud scar counts and branch whorl counts were negligible and that both methods consistently underestimated the ring age of both ponderosa pine and Douglas-fir.

Materials and Methods

1. Study Sites

Study sites were located on three fires: the Taylor Complex, which consists of three main fires that burned 528,354 ha in 2004 in interior Alaska; the School Fire, which burned 21,000 ha in southeastern Washington in 2005; the Egley Fire, which burned 56,466 ha in 2007 in central Oregon. The Taylor Complex is north of Tok, AK, and burned in black and white (*Picea glauca*) spruce forests that have an average high of 22°C and low of -32°C, with annual precipitation of 25 cm falling mostly in the summer. The School Fire south of Pomeroy, WA, burned in dry mixed conifer and grasslands in the Umatilla National Forest with an average high of 30°C and low of -4°C, with annual precipitation of 43 cm falling mostly in the winter and spring. The Egley Fire is located northwest of Burns, OR, and burned primarily ponderosa pine in the Malheur National Forest with an average summer high of 29°C and average winter low of -9°C, with average yearly total precipitation of 28 cm falling mostly in the winter and spring.

2. Sampling Design

Plots were established for a pre-existing study using a random stratified by burn severity (high, moderate, low, and unburned; based on Monitoring Trends in Burn Severity product; (www.mtbs.gov), elevation (high and low), and transformed aspect (wet and dry). Based on prior sampling, plots were selected based on whether or not they had seedlings of the target species. For plots located in burned areas four to five seedlings of each species per plot were selected at random for destructive sampling following a field count of terminal bud scars, while unburned plots had six to seven seedlings selected at random in order to increase the range of seedling ages and heights sampled. A total of 70 ponderosa pine seedlings (35 from the Egley Fire and 35 from the School Fire), 38 grand fir seedlings, and 78 black spruce seedlings were sampled.

3. Field Measurements and Lab Methods

In the field the height above ground of each terminal bud scar was recorded, yielding a scar count as well as estimations of annual height growth, and then the seedling was cut down at ground level and a section of the base labeled and taken back to the lab. Seedlings were uprooted when possible to ensure accurate identification of the shoot-root boundary but when uprooting was not feasible the groundline was assumed as the shoot-root boundary (Urza & Sibold 2013). We chose to use only field counts of bud scars, rather than transporting whole specimens to the lab, because it best reflects the method that would be most useful for managers, as well as researchers, seeking to evaluate age and growth of seedlings in a non-destructive manner. Once seedlings were transported back to the lab, a cross-section of the base of each seedling was finely sanded and scanned using Regent WinDENDRO Software in order to count the rings and determine the "true" age of the seedling.

A bud scar on ponderosa pine

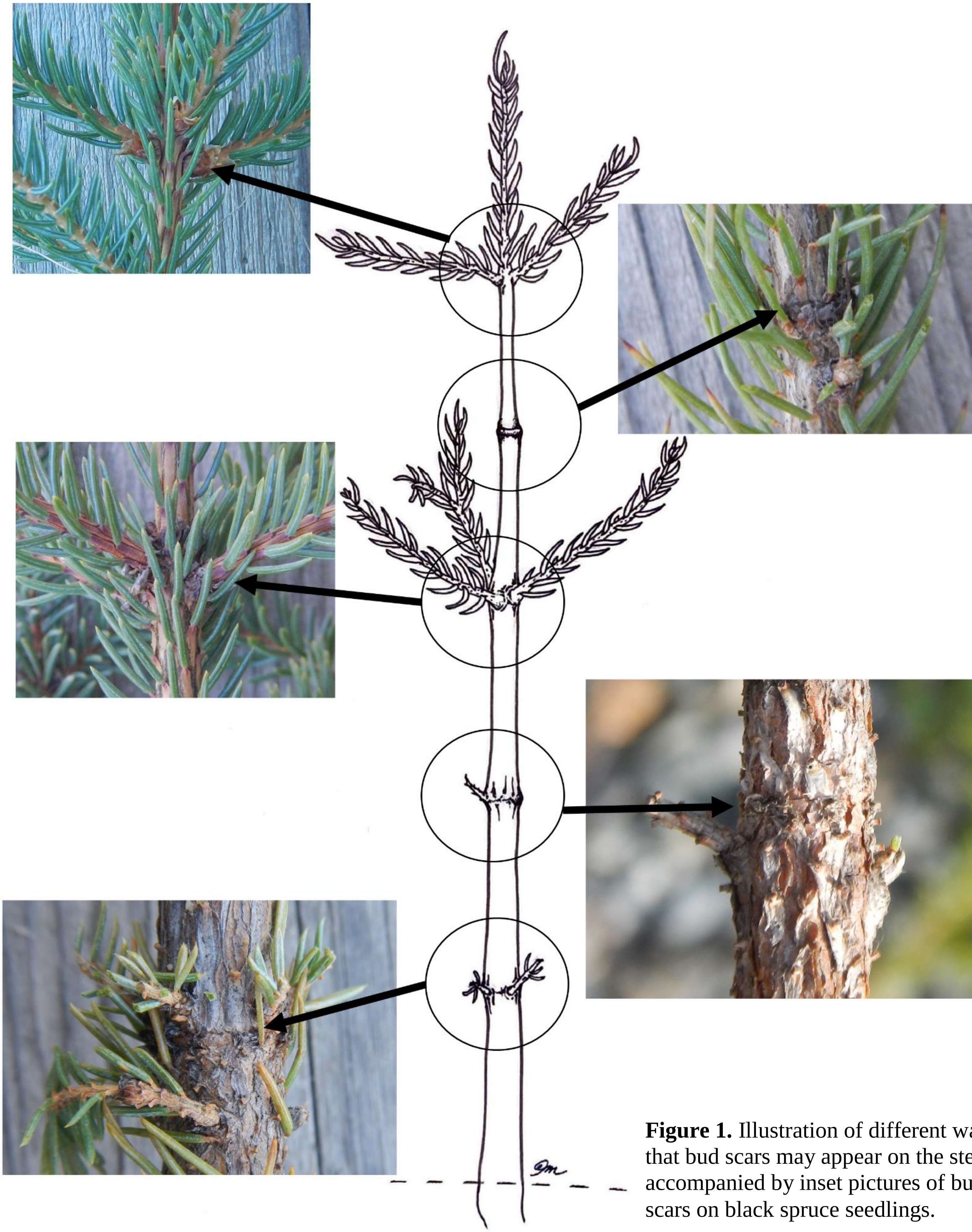

Figure 1. Illustration of different ways that bud scars may appear on the stem, accompanied by inset pictures of bud scars on black spruce seedlings.

4. Data Analysis

A 20+ year old black spruce “seedling”

The difference between the age estimate obtained by terminal bud scar counts and ring counts was used to calculate percent accuracy, mean error, and root mean squared error for each species. Percent accuracy is the number of seedlings for which the counts match divided by the total number of seedlings sampled. Mean error is a directional measure of the average difference between bud scar estimates and ring count estimates, taken as bud scar count minus ring count. Root mean square error measures the average magnitude of the age differences between count methods. These measures of accuracy were then plotted against height and seedling age (based on ring count) to examine potential effects of height and age on accuracy of terminal bud scar counts.

A typical black spruce seedling under 10 years old, illustrating the difficulty of counting rings on young seedlings of slow-growing species.

Results and Discussion

Overall the mean error showed that the bud scar age underestimated the ring (true) age by one to two years depending on species (Table 1). Ponderosa pine (Figure 2) had the lowest perfect (+/- 0 years) accuracy at 16.67%, with an average underestimate of 1.8 years though grand fir (Figure 4) had similar results with 18.4% perfect accuracy and average underestimate of 1.6 years. However, ponderosa pine accuracy within +/- one year was higher than that of grand fir (49% vs 45%, respectively). Black spruce (Figure 3) was by far the most accurately aged using this method, with mean age underestimated by less than a year, 26.5% perfect accuracy, and 56.3% accuracy within one year. RMSE shows that the average magnitude of age difference between the two aging methods was about 4.2 years for ponderosa pine, and averaged about one year for grand fir and black spruce (Table 1). These results are generally similar to those of previously published work, although only ponderosa pine is duplicated between this study and previous work (Hankin et al. 2018).

Table 1. Root mean square error (RMSE) gave the magnitude of the error. Mean error is the raw average number of years the bud scar age differed from the ring age. Percent accuracy was calculated for samples with a difference of zero (bud scar age=ring age) and for a difference of +/- 1 year.

	Ponderosa pine	**Black spruce**	**Grand fir**
RMSE	4.2	0.92	1.3
Mean Error	1.8	0.84	1.6
% Accuracy	16.67%	26.5%	18.4%
% Accuracy +/- 1	48.72%	56.3%	44.7%

For all species, seedlings younger than 15 years (based on ring age) tended to be more accurately aged than older seedlings as can be seen by the narrower spread of points at younger ages (Figures 2-4). The non-destructive method is most accurate on dominant seedlings across all seedling species, as seen by the narrower spread of points for higher height to age ratio (Figure 4). Other work has found that seedling age is a primary driver of accuracy regardless of species, wherein older seedlings are consistently less accurately aged with non-destructive methods Urza & Sibold 2013; Hankin et al. 2018). Seedling height has been shown to impact accuracy for some species, but the effect is generally weaker than seedling age (Urza & Sibold 2013). Similar to our height:ring age ratio results, Hankin et al. (2018) found that bias of non-destructive methods decreased with higher growth rates.

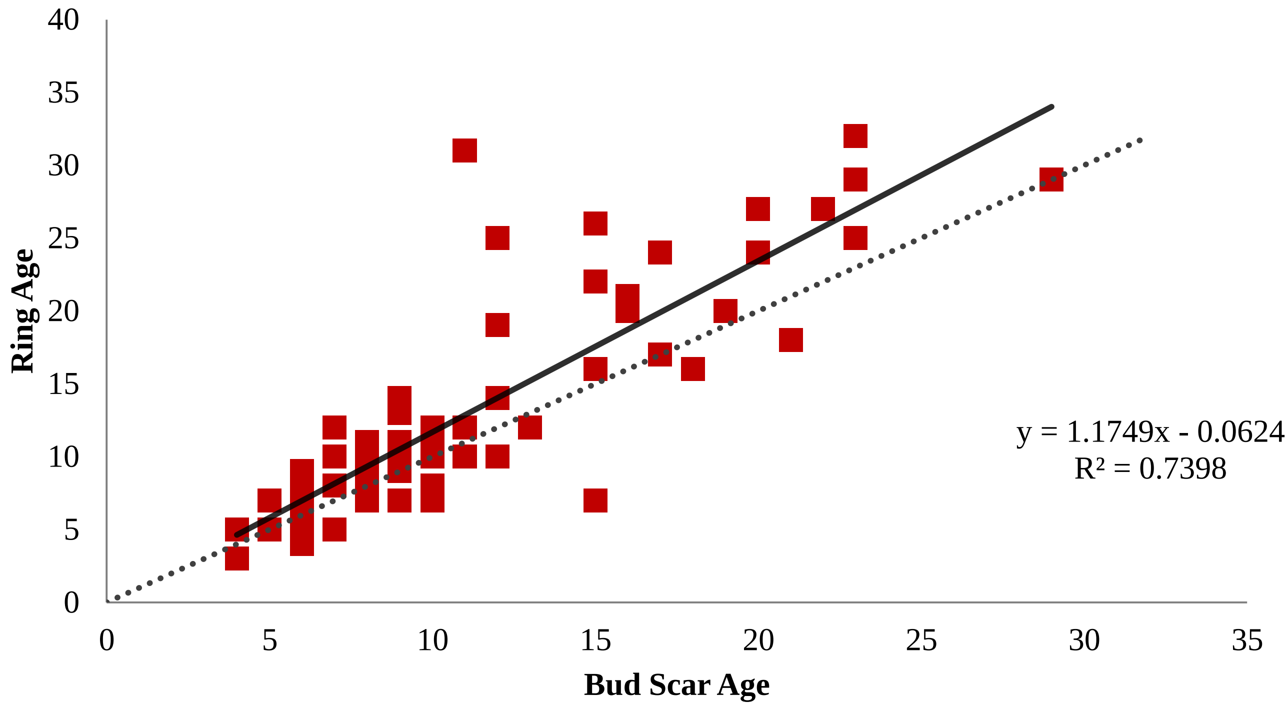

Figure 2. Ponderosa pine ring age plotted against bud scar age for seedlings from School Fire (WA) and Egley Fire (OR). Dashed line is a one-to-one line representing bud scar age=ring age.

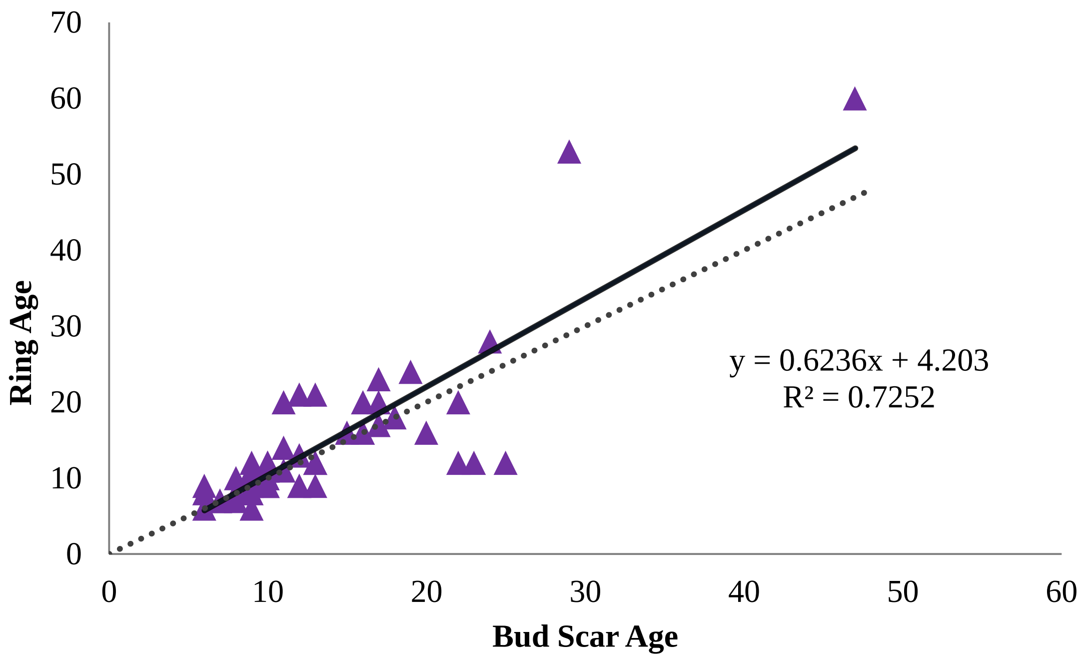

Figure 3. Black spruce ring age plotted against bud scar age. Dashed line is a one-to-one line representing bud scar age=ring age.

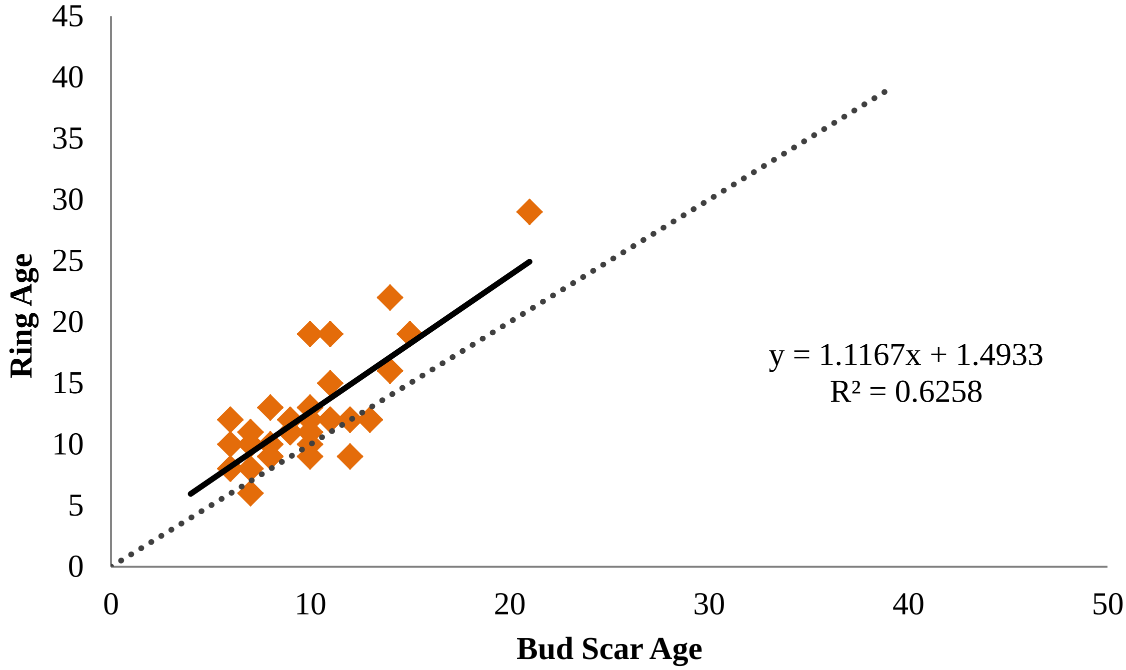

Figure 4. Grand fir ring age plotted against bud scar age. Dashed line is a one-to-one representing bud scar age=ring age.

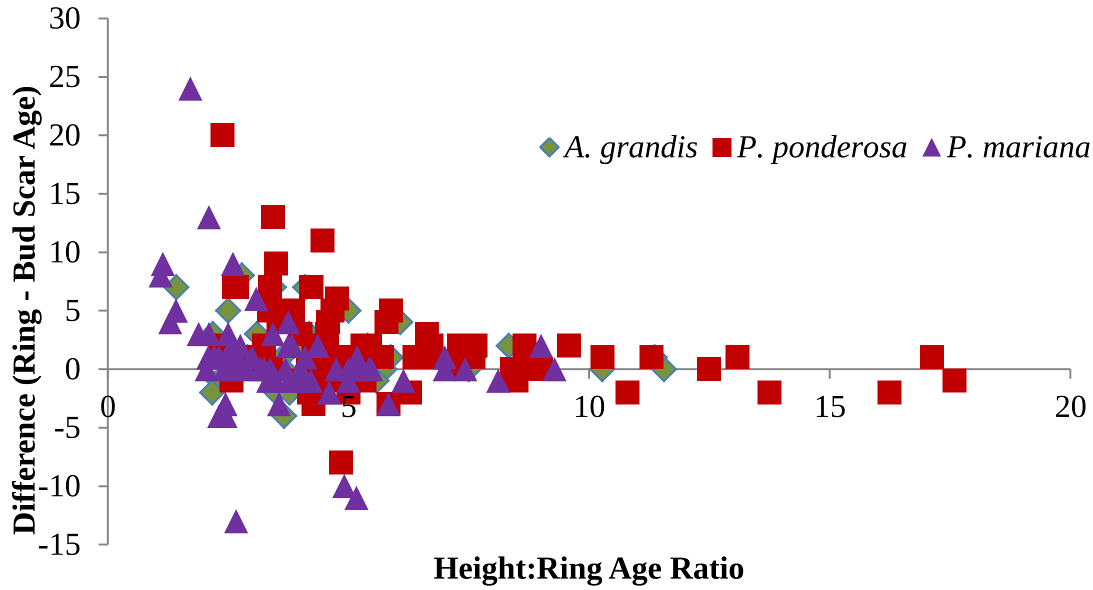

Figure 5 Accuracy of bud scar counts (shown as difference between ring and bud scar ages) plotted against height:age ratio, where low ratio values represent seedlings that are relatively short for a given age (suppressed).

Conclusions and Implications for Management and Future Research

Accuracy and error of non-destructive methods depends strongly on the individual species, as well as on the growing conditions and age of the seedling regardless of species. Therefore for activities requiring highly accurate identification of seedling age, non-destructive methods may not be suitable. This would be particularly true for species like ponderosa pine, sites containing mostly older (15+ years) seedlings, or sites containing mostly suppressed seedlings.

However, non-destructive methods such as bud scar counts may be an appropriate and useful tool for some applications and species. For example, black spruce seedlings were more accurately aged, and with lower error, than either ponderosa pine or grand fir. Anecdotally, based on our experience obtaining ring counts from black spruce seedlings in the lab, bud scar counts may potentially be more accurate than ring counts in young seedlings of this species due to the slow growth and resulting very small diameters of young seedlings. Future examination of the accuracy of identifying individual bud scars in multiple species across multiple regions would help managers and researchers assess the full accuracy of this method for determining yearly growth and age of seedlings.

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Appendix A: Contact information for project personnel

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Appendix B: List of delivery products

1. Article in prep for Journal of Forestry, to include undergraduate student (Emily Mangini) as co-author
2. A manager-oriented brief based on the article is in prep to highlight best practices and potential uses of this methodology.
3. Results will be included in student PI's dissertation (planned completion December 2019)
4. This work was presented at three conferences (presenting author listed first):
    a. Mangini, E., D.H. Hammond, E.K. Strand. Assessing post-wildfire conifer regeneration: Validation of a non-destructive seedling aging method. Poster at 2017 Association for Fire Ecology Congress in Orlando, FL.
    b. Mangini, E., D.H. Hammond, E.K. Strand. Assessing post-wildfire conifer regeneration: Validation of a non-destructive seedling aging method. Poster at 2018 AFE-IAWF Fire Continuum Conference in Missoula, MT.
    c. D.H. Hammond, E. Mangini, E.K. Strand. Validating a Non-Destructive Seedling Aging Method for Assessing Post-Wildfire Conifer Regeneration. Poster at 2018 Society of American Foresters National Convention in Portland, OR. **Poster won second place in student poster competition.**
5. Student PI presented this work 2018, June 11-13 as part of the "Long-term Vegetation Recovery and Reburn Potential" manager workshop (McCall, ID) organized by Northern Rockies Fire Science Network, USFS, and UI in cooperation with JFSP project 14-01-02-27.

Appendix C: Metadata

The metadata and full dataset will be archived and made available upon publication of the journal article.