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DISCUSSION

Alternative interpretation and scale-based context for "No evidence of recent (1995–2013) decrease of yellow-cedar in Alaska" (Barrett and Pattison 2017)[1]

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Abstract: In their analysis of resampled and remeasured plot data from the USDA Forest Service Forest Inventory and Analysis (FIA) program, Barrett and Pattison (2017, Can. J. For. Res. **47**(1): 97–105, doi:10.1139/cjfr-2016-0335) suggest that there is neither evidence of a recent regional decrease in yellow-cedar (*Callitropsis nootkatensis* (D. Don) Oerst. ex D.P. Little) live tree basal area nor a decrease in the species' extent in southeastern Alaska. Here, we identify substantial, broad-scale agreement between their estimated extent of concentrated yellow-cedar mortality and that resulting from a complementary, existing body of research into yellow-cedar decline spanning 35 years. However, we also discuss concerns that the FIA remeasurement data used did not match the spatial distribution of the decline (e.g., excluding areas of known active decline in wilderness areas) and that the temporal coverage of FIA data (1990s to 2000s) was inappropriately compared with a cumulative decline map that spans several decades, meshing recent mortality with mortality that occurred up to a century ago. We provide an alternative explanation of Barrett and Pattison's results in the context of ongoing yellow-cedar distribution and decline research in southeastern Alaska and support our interpretation by focusing on the temporal and spatial aspects of decline.

Key words: yellow-cedar decline, climate change, forest inventory, biomass monitoring, survey metholodology.

Résumé : Dans leur analyse des données de places échantillons rééchantillonnées et remesurées provenant du programme d'analyse et d'inventaire forestiers (AIF) du Service forestier des États-Unis, Barrett et Pattison (2017, Rev. can. rech. for. **47**(1): 97–105, doi:10.1139/cjfr-2016-0335) suggèrent qu'il n'y a pas d'indices d'une diminution régionale récente de la surface terrière des tiges vivantes de faux-cyprès de Nootka (*Callitropsis nootkatensis* (D. Don) Oerst. ex D.P. Little) ni d'une réduction de l'aire de répartition de l'espèce dans le sud-est de l'Alaska. Dans cet article, nous identifions une forte concordance à grande échelle entre leur estimation de l'étendue de la mortalité concentrée du faux-cyprès de Nootka et celle qui résulte des nombreux travaux de recherche existants et complémentaires sur le dépérissement du faux-cyprès de Nootka couvrant une période de 35 ans. Cependant, nous discutons aussi des préoccupations liées au fait que les données remesurées de l'AIF qui ont été utilisées ne correspondent pas à la distribution spatiale du dépérissement (p. ex., l'exclusion de zones où le dépérissement est connu pour être actif dans les régions sauvages) et que la couverture temporelle des données de l'AIF (des années 1990 aux années 2000) est inappropriée comparativement à une carte cumulative du dépérissement qui couvre plusieurs décennies, intégrant la mortalité récente et la mortalité survenue il y plus d'un siècle. Nous proposons une explication alternative aux résultats de Barrett et Pattison dans le contexte de la recherche en cours sur la distribution et le dépérissement du faux-cyprès de Nootka dans le sud-est de l'Alaska et nous supportons notre interprétation en mettant l'accent sur les aspects temporel et spatial du dépérissement. [Traduit par la Rédaction]

Mots-clés : faux-cyprès de Nootka, dépérissement, changement climatique, inventaire forestier, suivi de la biomasse, méthode d'inventaire.

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[1]Discussion of the paper by T.M. Barrett and R.R. Pattison (2017), Can. J. For. Res. **47**(1): 97–105. doi:10.1139/cjfr-2016-0335.

Introduction

Barrett and Pattison (2017) suggest that there is no evidence of a regional decrease in yellow-cedar (*Callitropsis nootkatensis* (D. Don) Oerst. ex D.P. Little) live tree basal area and extent in southeastern Alaska over an 18-year remeasurement period (1995–2013) of the USDA Forest Service (USFS) Forest Inventory and Analysis (FIA) plot network. This article has generated confusion among scientists and resource managers active in the region, as the conclusions appear contradictory to previous and ongoing research on yellow-cedar decline. We believe that this is due to a misunderstanding of the limitations of their FIA-only approach and overgeneralization of the data to nonsampled areas. The Barrett and Pattison (2017) results are quite useful when their context is clearly communicated, and we agree that the FIA program provides a valuable dataset for conducting regional assessments of changes in tree biomass and species composition. However, we believe that it is not justified to use the existing data to reach broad conclusions about the slow and spatially nonrandom phenomenon of yellow-cedar decline, a process that poses unique challenges to a dataset not fundamentally designed to assess this type of forest decline process.

Our response first outlines Barrett and Pattison's major findings and then summarizes pertinent, complementary yellow-cedar research that spans the last 35 years (Shaw et al. 1985; Hennon et al. 1990*a*, 2012, 2016; Hennon and Shaw 1997; D'Amore et al. 2009; Oakes et al. 2014, 2015; Buma et al. 2017). We discuss agreement between the estimated extent of concentrated yellow-cedar mortality in Barrett and Pattison (2017) and the existing body of research, clarify where the FIA data were inappropriately matched (temporally and spatially) to forest health aerial survey data, and then provide an alternative explanation of the study's results in the context of ongoing yellow-cedar distribution and decline research in southeastern Alaska. We offer alternative interpretations for the following Barrett and Pattison findings from the 1995–2013 FIA plot remeasurements: the increase in yellow-cedar live tree basal area; high levels of yellow-cedar recruitment into larger diameter classes; limited active decline based on equivalent yellow-cedar live tree to snag ratios between declining and nondeclining forests; no evidence of overall range contraction; and a lack of congruence between existing mapped decline and FIA-observed decline. We support our interpretation by focusing on the long and episodic temporal scale of yellow-cedar decline compared with the limited FIA remeasurement period and the spatial scale of cumulative versus active decline as it pertains to the limited spatial coverage of the FIA data in areas of known recent mortality.

In sum, we wish to clarify that (*i*) the remeasured FIA dataset is limited in spatial extent and not spatially unbiased, as the authors claim — in fact, the remeasurement data exclude substantial areas of recently mapped decline, (*ii*) mixing declining and post-decline recovering stands by ignoring the temporal component of the decline process can lead to erroneous results regarding net basal area change, (*iii*) comparisons between mapped decline and FIA plots were made without appropriate understanding of spatial accuracy in survey data, and (*iv*) the results of Barrett and Pattison (2017) are nonetheless quite valuable if their context and limitations are accurately communicated.

"No evidence" findings

Barrett and Pattison (2017) analyzed changes in yellow-cedar growth and mortality across southeastern Alaska using FIA plots established in 1995–1998 (n = 671) and remeasured in 2004–2013 (n = 564; interval of 6–18 years, mean 12.2 years). Eighty-four of the 671 initial plots overlapped with yellow-cedar decline areas mapped by USFS Forest Health Protection, while only 57 of 564 plots from the 2004–2013 remeasurement period overlapped with mapped decline areas. Plots were distributed across 13.4 million ha of land within the Coastal Rainforest Level 2 ecoregion (Nowacki et al. 2001) but excluded Glacier Bay National Park and Preserve and most Forest Service wilderness areas. From the remeasured plot network, Barrett and Pattison calculate an increase in yellow-cedar live tree basal area of 0.3 to 3.3% (95% CI) across the 13.4 million ha over the FIA plot remeasurement period. They also suggest that a relatively large increase in small trees (2.5 to 12.7 cm diameter class) indicates high levels of regeneration and recruitment during the sampling window.

Based on the 2004–2013 inventory only, Barrett and Pattison (2017) conclude that equivalent live tree to snag ratios among declining and nondeclining areas of the forest (as mapped in aerial surveys conducted by USFS Forest Health Protection) indicate little to no active decline and that snags originated from prior mortality events. They further argue that the small percentage of plots (3.1%) with 100% yellow-cedar mortality in the FIA plots suggests that yellow-cedar range contraction has not occurred. Finally, the authors estimate approximately 175 000 ha of yellow-cedar forest across southeastern Alaska with >70% of yellow-cedar basal area in snags but emphasize that only 4000 to 12 000 ha of that occurs within previously mapped decline areas.

Understanding of decline dynamics

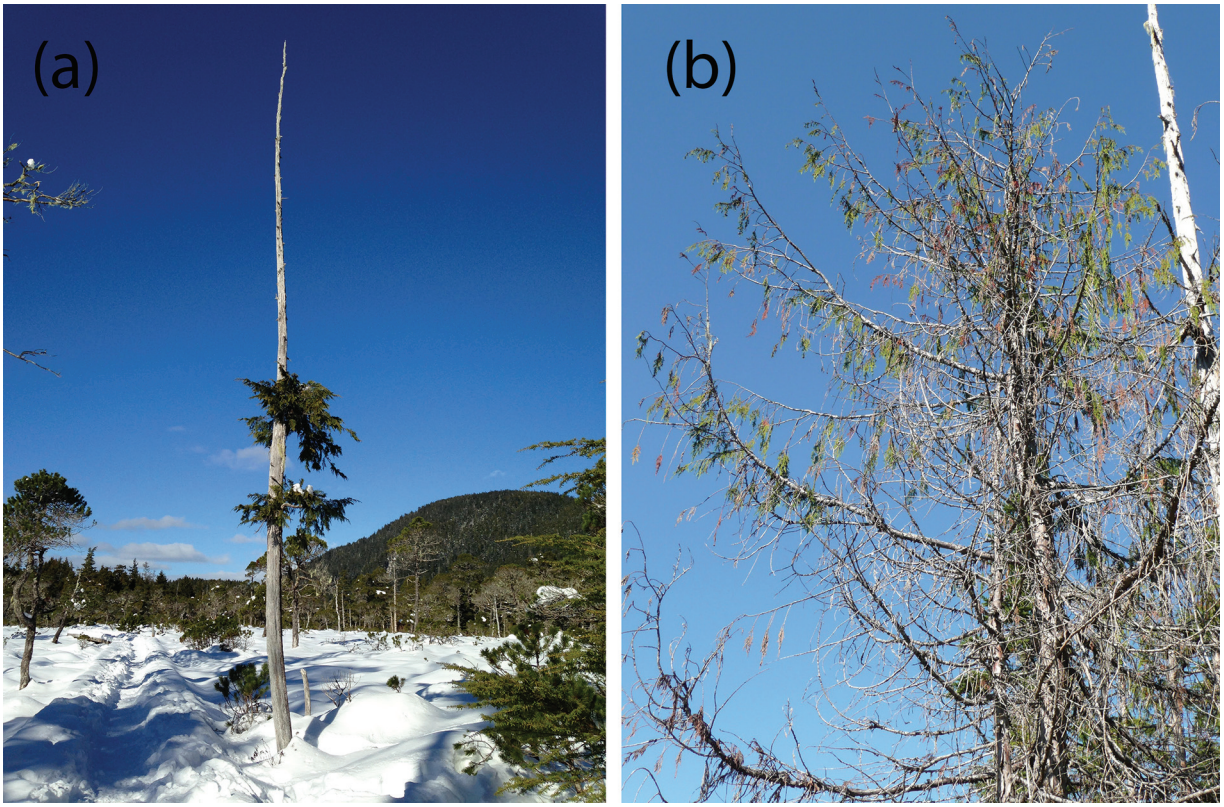
Forest decline, defined as the loss of tree vigor and eventual mortality triggered by complex biotic and abiotic factors (Manion and Lachance 1992), is slow and episodic in forests composed of long-lived yellow-cedar trees (Hennon et al. 2016), and the application of this term does not necessarily imply a decline in biomass or population extent. Yellow-cedar decline has been observed across southeastern Alaska for over a century (Sheldon 1912; Hennon et al. 1990*a*), but until recently, the causal mechanism remained a mystery (Hennon et al. 2012). Climate change induced loss of snow cover, combined with earlier dehardening, makes yellow-cedar trees susceptible to root injury from sudden, extreme cold events (D'Amore and Hennon 2006; Hennon et al. 2012, 2016).

Research to date provides the following insight into yellow-cedar population dynamics and decline in southeastern Alaska and other parts of its range.

Decline is episodic and temporally complex, especially relative to the short FIA remeasurement window

- Yellow-cedar decline is episodic because of the confluence of climate factors needed to initiate mortality (Beier et al. 2008), often occurring with significant lag time (10–15 years) between symptom onset and tree death (Hennon and Shaw 1997) for this extraordinarily long-lived species (lifespan can exceed 1000 years and averages 500–750 years; Laroque and Smith 1999). Individual-tree canopy dieback of up to 95% of the crown, followed by a long period before final death, is not uncommon (Hennon et al. 1990*a*, 2016; Figs. 1*a* and 1*b*).
- Yellow-cedar is extremely decay resistant (Kelsey et al. 2005), and snags may stand for 80 or more years following death (Hennon et al. 1990*b*). Applying a species-specific snag classification system developed using plot data allows researchers to reconstruct spatial and temporal patterns of mortality dating back to the early 1900s (Hennon et al. 1990*a*; Oakes et al. 2014).
- Concentrations of yellow-cedar mortality were first observed in the late 1800s to early 1900s (Sheldon 1912), with the greatest pulses of death in the 1970s and 1980s (Hennon and Shaw 1994). These mortality events correspond to the end of the Little Ice Age and warmer periods of the Pacific Decadal Oscillation, followed by a relative lull in decline in the 1990s and 2000s (Hennon et al. 2016).

Fig. 1. (*a*) "Rope trees" are yellow-cedar with a dead top and most of the circumference of the bole also dead except a narrow strip of cambium connecting a live root to a single branch cluster (photo by Paul Hennon, Sika, Alaska). (*b*) An actively dying yellow-cedar with sparse foliage (photo by Paul Hennon, Wrangell Island, Alaska). Both of these examples of partially live trees are common in declining yellow-cedar forests (Hennon et al. 1990*b*; Hennon and Shaw 1997) and demonstrate the often slow decline of individual trees, with crowns thinning for 15 years or longer before tree death.

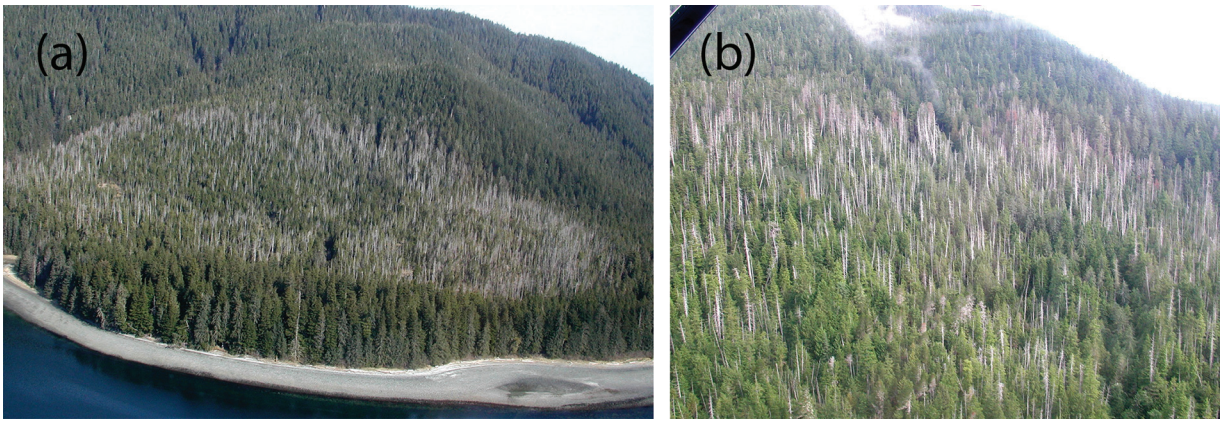


Decline is spatially nonrandom, and recent decline does not align with FIA remeasurement data

- Decline occurs nonrandomly as a function of microclimate, landscape position, ecosystem type, and regional climate influence (Hennon et al. 2012, 2016; Fig. 2*a*).
- While broadscale regional mortality has slowed in recent decades, yellow-cedar decline proceeds locally on sites already affected by decline. Tree death can positively feed back to increase risk factors in adjacent yellow-cedar forests: dying trees open the forest canopy, allowing increased solar radiation to further diminish protective snowpacks (see Hennon et al. 2012). As precipitation shifts from snow-dominated to rain-dominated in the later winter (University of Alaska Fairbanks, Scenarios Network for Alaska and Arctic Planning (SNAP), http://www.snap.uaf.edu/, accessed 2015), decline is predicted to progress to relatively higher latitudes and elevations (Oakes et al. 2015; Fig. 2*b*).
- Recent concentrations of yellow-cedar decline are located in remote, designated-wilderness areas (Oakes et al. 2014) that are mostly excluded from the FIA plot-based remeasurement inventory used by Barrett and Pattison (2017).
- Many areas of yellow-cedar decline occur in low-volume forests with poor soil drainage (Hennon et al. 2012), which appear to be rare in the FIA plot network that excludes forested wetlands with <10% tree cover.
- Yellow-cedar is a cross-boundary species. The greatest extent of its range, as well as substantial areas of decline, lies in British Columbia, Canada; therefore, any long-term assessments of the species' population stability and predicted risk should occur at the range-wide scale (Buma et al. 2017).
- There are large areas of yellow-cedar forest in coastal Alaska outside of the range of forest decline (Hennon et al. 2016), and vegetation plots reveal few dead trees and exceedingly low mortality rates for the species (Hennon and Trummer 2001; Oakes et al. 2015; J. Krapek and B. Buma, unpublished), consistent with extremely low mortality rates in nondeclining areas farther south in the range (Lertzman 1995; Hille Ris Lambers et al. 2015).

Multiple lines of evidence (Hennon et al. 2012; Buma et al. 2017; including Barrett and Pattison 2017) demonstrate that yellow-cedar decline is a widespread, yet episodic and patchy, phenomenon. Several studies, including Barrett and Pattison (2017), estimate 175 000 to 275 000 ha of declining yellow-cedar forests and significant mortality in Alaska alone, generally with >70% basal area dead (Hennon et al. 2016; Barrett and Pattison 2017; Buma et al. 2017; USDA Forest Service 2016). Snow model predictions based on future climate scenarios indicate that decline is expected to emerge in new portions of the landscape as snow cover is reduced at higher elevations and latitudes (see University of Alaska Fairbanks SNAP (http://www.snap.uaf.edu/) and Wang et al. (2012) snow modeling used in Hennon et al. (2016)). Barrett and Pattison suggest a pause in live tree basal area loss over the past two decades within the portion of the region represented by the FIA data; however, yellow-cedar decline continues to affect forests (USDA Forest Service 2016) and remains an important conservation and forest management concern. The most recent Forest Health Protection aerial survey that covered about 15% of the forested area of the state documented 16 000 ha of active yellow-cedar decline (USDA Forest Service 2016).

Fig. 2. (*a*) Landscape-level patch of yellow-cedar decline near sea level at Poison Cove, Chichagof Island, Alaska. The green central zone in the decline patch represents early 1900s mortality (Hennon et al. 1990*a*, 1990*b*) that is now in recovery (gaining basal area), while recent morality (losing basal area) can be observed in a ring around the area in recovery. (*b*) Closer view of the same patch of mortality. Old yellow-cedar mortality low on the slope, with recent mortality (snags with branches) and dying trees (red tree crowns) emerging upslope as the snowline is reduced at elevation. The specific placement of FIA plots within the complex spatiotopographic nature of decline would influence the live tree basal area changes and forest shifts observed by Barrett and Pattison: an FIA plot located in the central zone would be expected to show gains in yellow-cedar during the remeasurement phase due to release of surviving yellow-cedar trees (Beier et al. 2008). (Photos by Paul Hennon.)



Important differences in interpretation and points of clarification

We agree that the FIA program provides a valuable, statistically unbiased dataset for conducting regional assessments of changes in live tree basal area and species composition. This dataset can augment, corroborate, or help refine regional estimates of the spatial extent of forest species' responses to climate, natural disturbance, and harvest over time, providing insight into ingrowth, mortality, and range shifts. However, we believe that the sampling scheme, spatial coverage, and remeasurement interval of FIA plots are not well-designed to capture the slow and spatially nonrandom process of yellow-cedar decline, which cannot be completely and properly assessed in terms of snag ratios and live tree basal area changes. Conclusions drawn from the FIA network, while valuable, must be made in recognition of those fundamental limitations. The primary discrepancies in interpretation relate to the following.

Temporal scale: Barrett and Pattison conclude that no major mortality or decline was observed during the time period of their study (1995–2013)

Live tree basal area changes do not capture the slow and site-specific decline process

The decline of individual trees is a slow process that we do not expect to be captured within the short remeasurement window of this FIA study (6–18 years, mean interval 12.2 years). Reductions in live canopy for individual trees can progress over the course of 15 years before trees ultimately die (Hennon and Shaw 1997; Figs. 1*a* and 1*b*). Averaging live tree basal area changes across the yellow-cedar range does little to inform our understanding of this highly spatiotemporal decline phenomenon. Active yellow-cedar decline continues to occur in southeastern Alaska, with thousands of hectares of dying trees observed and mapped annually (USDA Forest Service 2016). Gains in yellow-cedar biomass in currently healthy portions of its range, including higher elevations and latitudes, deeper soils, and north-facing slopes (Buma and Barrett 2015), may offset losses in decline-affected forests depending on the time scale considered. Therefore, the increase in basal area observed in Barrett and Pattison (2017) may come from gains in some areas and losses in others. Even in some forests with intense decline, short-term gains in biomass are expected among released yellow-cedar trees that remain alive after the main wave of decline has run its course in affected stands (Fig. 2*b*; Beier et al. 2008).

FIA surveys ignore live tree health status and therefore do not properly characterize severely injured yellow-cedar trees in declining forests

A variety of ground-based studies of yellow-cedar decline have observed mortality above 70% basal area, with 10% to 35% of yellow-cedar trees remaining alive and relatively healthy in severely affected forests (e.g., Hennon et al. 1990*a*; D'Amore and Hennon 2006; Oakes et al. (2014) reviewed in Hennon et al. 2016). Symptomatic larger trees tend to persist longer than smaller size classes in stands in which decline is still progressing (Hennon et al. 1990*a*; Hennon and Shaw 1997; D'Amore et al. 2009; Oakes et al. 2014). Severely damaged trees, some of which may have retained even as little as 1% live canopy foliage due to decline, were considered live in the FIA inventory. However, these physiologically compromised, "partially" live trees, which are common in decline areas (Hennon and Shaw 1997), are considered "entirely" live biomass in the FIA survey. In a recently installed (2015–2016) plot network in declining yellow-cedar forests on Kupreanof Island and Prince of Wales Island, Alaska, remaining live yellow-cedar trees >12.7 cm in diameter at breast height were estimated to have ~62% healthy crown foliage on average; one-quarter of surviving trees had <30% live foliage (authors' unpublished data). Because large symptomatic trees take longer to die, they may artificially inflate live tree biomass without informing our understanding of the decline status of individual trees or the stand as a whole. Thus, conclusions based on strict mortality, as opposed to a reduction in functional capacity, are potentially misleading.

FIA data may not accurately capture the recruitment of this slow-growing tree

Yellow-cedar regeneration, recruitment, and migration are slow and episodic (Lertzman 1995; Krapek and Buma 2015; Hennon et al. 2016). Regeneration has been observed as uncommon in recent decades across southeastern Alaska, even where live yellow-cedar dominate the overstory (Pawuk and Kissinger 1989; DeMeo et al. 1992; Martin et al. 1995; Hennon et al. 2016; J. Krapek and B. Buma, unpublished). Although Barrett and Pattison (2017) speculate that an increase in the number of 2.5 to 12.7 cm diameter yellow-cedar trees over the remeasurement period indicates increased recruitment over the time period of the study, without detailed demo-

graphic data, there is no way to know if this was from advanced recruitment that was present prior to 1995. Yellow-cedar is a slow-growing tree, particularly in Alaska; suppressed trees ~15 cm in diameter at breast height can be over 300 years old (Burns and Honkala 1990). Furthermore, the data on yellow-cedar recruitment are unreliable, as the location of the FIA microplots in which yellow-cedar trees under 12.7 cm in diameter were measured shifted over the remeasurement period (Barrett and Pattison 2017). For all these reasons, it seems that no strong conclusions can be drawn on yellow-cedar recruitment based on this analysis of FIA plot remeasurement. More detailed knowledge of population dynamics and assessments of recruitment would be essential to evaluating the long-term trajectory of this long-lived, slow-growing species and warrants research.

Yellow-cedar snag identification and analysis is most reliable for resurveyed plots in which snags were previously live

Although yellow-cedar are extremely decay-resistant and may stand as snags for >80 years, dead trees lose bark and sapwood after about 30 years (Hennon et al. 1990*b*), complicating identification. After 50 years, the distinctive yellow heartwood color and aromatic compounds are diminished (Kelsey et al. 2005), both of which are key features for distinguishing yellow-cedar snags from dead trees of other species. Identification of older snags, therefore, can be challenging — even for seasoned field biologists — without careful and time-intensive examination. We believe that snag identification in original plot installation was affected by these challenges and that these data are less reliable than for identification of yellow-cedar alive at the time of plot installation but dead upon resurvey. However, information about the death of trees since plot installation is a major strength of the Barrett and Pattison study and the FIA plot network as a whole.

Spatial scale: investigation does not match patterns or extent of decline

The FIA network available for remeasurement analysis is not comprehensive or representative of the broader region

Key areas of recent mortality and low-productivity "decline habitat" are excluded from the FIA plot network (Oakes et al. 2014; Hennon et al. 2016; USDA Forest Service 2016). Bogs and wetlands with <10% tree cover are excluded from the FIA plot network; however, poor soil drainage in these areas causes yellow-cedar to root shallowly, making roots particularly vulnerable to freezing injury near the soil surface (Schaberg et al. 2011). Similarly, FIA remeasurement data are not generally available in southeastern Alaskan wilderness areas, which constitute a significant portion of federal lands in the region (~34%), limiting conclusions drawn from this remeasurement data. Because recent mortality is concentrated in wilderness areas (Oakes et al. 2014), this spatial limitation of the FIA dataset must be recognized.

Use of a cumulative decline layer introduces bias in interpretation

Barrett and Pattison (2017) used a cumulative decline layer, which captures mortality from the early 1900s to present, rather than an active (1995–2013) decline map for comparison with FIA plot network remeasurements. This choice did not allow them to focus on areas of active mortality coinciding with the remeasurement period. The cumulative aerial survey layer covers all yellow-cedar decline mapped in southeastern Alaska since the 1980s, including older decline (standing snags that have died since about 1900) and active mortality. We believe that comparing the FIA plots with a yellow-cedar decline layer from the same period (1995–2013) would have been a more appropriate methodological approach to characterizing differences between declining and nondeclining forests, likely yielding live tree to snag ratios and basal area numbers more consistent with existing yellow-cedar research (Buma et al. 2017; Hennon et al. 2016). By including older mapped mortality in their analysis, Barrett and Pattison may have been assigning plots located in areas of old decline (e.g., substantial mortality in the early 1900s) that are now in recovery (see Fig. 1*a*) to active decline status. This has the effect of reducing the amount of tree mortality observed in mapped decline areas of the study, as many of the plots in "decline" status may have been affected several decades prior with no further elevated yellow-cedar mortality expected. In fact, release of the surviving individuals in affected stands would be expected, as described earlier, resulting in a measurable increase in yellow-cedar biomass. Future studies of active decline at the plot scale should align with the active decline layer to ensure that older mortality does not bias results.

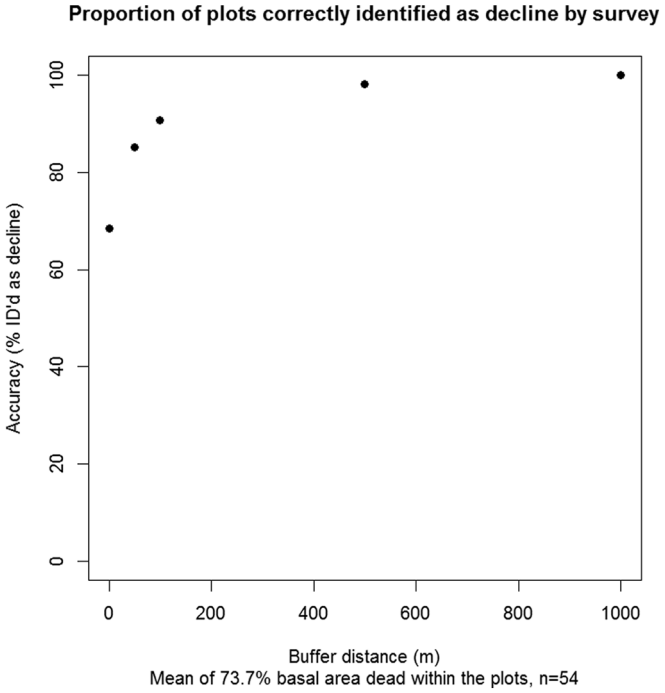
Coarse-scale aerial survey polygons of yellow-cedar decline should not be compared with fine-scale plot surveys without a robust error assessment

Barrett and Pattison assume that fine-scale plots can be overlaid with coarsely mapped aerially surveyed polygons of yellow-cedar decline for a perfect or near match despite substantial spatial differences between these forms of monitoring. Aerial survey data are collected and designed to be visualized at a scale of no closer than 1:63 000 (McConnell et al. 2000). It is not surprising then that Barrett and Pattison did not detect a difference in live tree to snag ratios between plots inside — as opposed to outside — the aerial survey decline layer, because the authors used an insufficient buffer size (±14 m) to test for the influence of location error between plots and aerial survey data. A much broader buffer (50–500 m) has been used to assess the difference in spatial scale between aerial and plot-level monitoring techniques in areas of mountain pine beetle mortality in the Rocky Mountains (Johnson and Ross 2008), where trees and forests tend to be killed uniformly, are easier to map, and can be accurately assigned a specific year of tree death. To assess the utility of buffers in comparing surveys of different scale, we compared a network of plots in which decline was known to occur (based on ground observations; $n = 54$) with cumulative aerially mapped decline at multiple scales. When accuracy was assessed using a 500 m buffer, positive accuracy (overlap between plots and mapped decline) was >90%, and even with a smaller buffer of 100 m, accuracy exceeded 80% (Fig. 3). Our assessment was conducted with decline plots designed for other purposes and, as such, is not as robust as a spatially random test. Because our healthy yellow-cedar plots are located in Glacier Bay National Park and Preserve, north of the main decline phenomenon, we were unable to perform buffer analysis on the healthy plots as a negative control. A similar test using the FIA datasets and a reasonable expectation of locational accuracy would be a valuable contribution to the literature. The grid-generated spatial distribution of FIA plots is a key strength of the FIA plot network, despite aforementioned limitations caused by the lack of remeasurement sampling in national parks and wilderness areas, and a good area for future collaboration.

No perfect method exists for detecting yellow-cedar decline at the landscape scale

Because there is currently no perfectly accurate method for detecting yellow-cedar decline over the vast, remote, and topographically varied region in which it occurs, combining and comparing monitoring approaches of differing scope and scale can improve our overall understanding of the phenomenon. Hennon and Wittwer (2013) compared digitized aerial photographs with cumulative mapped yellow-cedar decline at Kruzof Island and Peril Strait, areas with relatively complete aerial survey coverage. Barrett and Pattison (2017) summarize findings from this study as follows: "aerial survey overestimated areas of decline by 400% compared to the more detailed aerial photograph interpreted datasets, [and made] observations that the aerial survey misses areas of mortality in stands where yellow-cedar is a minor component

Fig. 3. Proportion of plots with decline within mapped decline areas, when different levels of accuracy are imposed on the decline map. At a buffer distance of 0 m, there is no allowance for spatial inaccuracy from the maps. At a 500 m allowance for inaccuracy in the map (as a result of known errors associated with sketch mapping), 97% of the plots overlapped mapped decline.



of species makeup (Hennon et al. 2016)." This description of the study results implies that the color infrared photo-interpreted datasets represent the litmus test for the aerial survey data rather than acknowledging the limitations of both forms of assessment, with the true spatial extent of decline likely falling somewhere between the two estimates. Photo interpretation may greatly underestimate decline, as it only captures very concentrated tree death in higher volume forests due to the angle at which the photo is taken (Hennon et al. 2016). Remote-sensing tools and recent advancements in coverage and resolution of low-altitude imagery should be linked to ground-based measurements and used to improve estimates of the spatial extent of decline. As Barrett and Pattison correctly point out, studies of decline are often, and unsurprisingly, biased towards declining areas. However, these data provide an important counterpoint to FIA data. Active collaboration between FIA data specialists and the aerial survey team could resolve the discrepancies that we report here by considering several options for categorizing the FIA plots on the landscape based on known health status of yellow-cedar and approximate timing of decline onset.

Mortality threshold of 100% for range contraction ignores impacts on regeneration and future stand composition

Barrett and Pattison use FIA data to emphasize that yellow-cedar range contraction is not occurring based on a low number of plots with 100% yellow-cedar mortality. Complete mortality is not expected in affected forests (10%–35% of yellow-cedar trees typically survive; Hennon et al. 1990*a*; D'Amore and Hennon 2006; see Hennon et al. (2016) for further citations). However, the future of yellow-cedar in affected forests will hinge on its ability to regenerate and survive under site conditions that have already contributed to substantial mortality. Long-term population stability questions cannot be adequately addressed using this high mortality threshold for range contraction.

Yellow-cedar is a cross-boundary species, so population status outside of Alaska must be considered when commenting on the long-term viability of the species

British Columbia contains abundant yellow-cedar forests, as well as substantial decline-affected yellow-cedar. Therefore, broader regional and range-wide context for yellow-cedar decline that extends beyond the FIA network is required for a comprehensive, broad-scale assessment of the species (Buma et al. 2017). Barrett and Pattison suggest that their results contrast with perceptions of rapidly decreasing yellow-cedar populations described in the current petition to list yellow-cedar under the U.S. Endangered Species Act (ESA). Although areas of decline in British Columbia reside outside the domain of lands governed under the ESA, we believe that considering these transboundary population dynamics is essential to assessing range-wide population connectivity, status, and future viability.

Conclusions

There are inherent limitations to every inventory and monitoring approach or biological assessment. The strengths and weaknesses depend on the specific methodologies and metrics employed for data collection and analyses, as well as the spatial and temporal scales of the study. These factors must be considered for adequate interpretation. Various monitoring approaches can complement and independently corroborate one another; for example, Barrett and Pattison's estimate of the extent of yellow-cedar forest with greater than 70% yellow-cedar mortality is consistent with other estimates based on aerial surveys. Despite findings of no evidence of recent yellow-cedar decrease based on live tree basal area changes, snag ratios, and ingrowth of small trees in the remeasured FIA network, yellow-cedar decline continues to impact yellow-cedar forests throughout its range when properly contextualized (Buma et al. 2017). Live tree basal area may have increased on the FIA plots during the short sampling window (12.2-year mean) of the Barrett and Pattison study, and this data point is valuable. However, it is likely that yellow-cedar live tree basal area is increasing in certain areas where trees have persisted through the decline or where yellow-cedar remains healthy, while simultaneously decreasing in other areas where basal area of live yellow-cedar is lost through ongoing tree death. Many areas and habitats with recent, concentrated decline are not measured (bogs and wetlands with low tree cover) or remeasured by FIA (national forest wilderness areas). Equivalent snag ratios inside and outside the aerial survey map do not necessarily indicate that tree injury and mortality is not ongoing across the entire region. Given all lines of current evidence, as outlined above, yellow-cedar decline remains an active phenomenon, and climate models project that it is likely to emerge in new portions of the range in the future (Oakes et al. 2015; Hennon et al. 2016).

FIA data provide an excellent and valuable dataset if its spatial and temporal limitations are properly recognized, and there is great opportunity for constructive collaborations using FIA data, aerial survey data, field measurements in areas where FIA does not reach, and detailed plant community and regeneration data. Therefore, we believe that there is potential for yellow-cedar researchers to resolve monitoring discrepancies collaboratively, and we stress the need to do so given continuing threats to the species. By combining data from future FIA remeasurements, aerial mapping of yellow-cedar decline, and field-based observations that include metrics such as live tree health status, we can analyze yellow-cedar decline through a more comprehensive spatial, temporal, and statistically unbiased context and better predict where we expect future losses or persistence of this culturally and economically important tree on the landscape.

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