Longevity and dynamics of fatally and nonfatally topped Douglas-fir in the Coast Range of Oregon

Tristan D. Huff and John D. Bailey

Abstract: Worldwide, snags are an important, but often lacking, component of forest ecosystems. We revisited artificially topped Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) trees 16–18 years after treatment in a replicated experiment in western Oregon. Some trees had been topped such that no live crown was retained (fatally topped), while others retained some portion of their live crown after topping (nonfatally topped). Topped trees were created under three different silvicultural regimes: clearcut, two story, and group selection. Twenty-three percent (61 of 262) of nonfatally topped trees remained living 16–18 years after treatment; 4% (19 of 482) of fatally topped trees had broken at some point up the bole by 16–18 years after treatment. Silvicultural regime, post-treatment height, stem diameter, stem lean, and ground slope were considered as potential explanatory variables in logistic regression models explaining mortality and breakage. A nonfatally topped tree's odds of surviving 16–18 years after treatment was greater in the mature matrix of group selection stands than in clearcuts or two-story stands. A fatally topped tree's odds of breaking within 16–18 years of treatment decreased as DBH increased. If carefully created, artificially topping trees can be a useful silvicultural tool to increase structural heterogeneity.

Résumé : Les chicots sont une composante importante, mais souvent manquante, des écosystèmes forestiers partout dans le monde. Nous avons revisité des douglas taxifoliés (*Pseudotsuga menziesii* (Mirb.) Franco) artificiellement étêtés il y a 16 à 18 ans dans le cadre d'une expérience répétée dans l'ouest de l'Oregon. Certains arbres ont été étêtés de façon à ce qu'il ne reste plus de cime vivante (fatalement étêtés) alors que d'autres avaient conservé des portions de leur cime vivante après l'étêtage (non fatalement étêtés). Les arbres ont été étêtés sous trois régimes sylvicoles différents : coupe à blanc, peuplement à deux étages et jardinage par groupe. Vingt-trois pourcent (61 arbres sur 262) des arbres non fatalement étêtés étaient toujours vivants 16 à 18 ans après le traitement. Quatre pourcent (19 arbres sur 482) des arbres fatalement étêtés étaient cassés à un certain endroit le long du tronc 16 à 18 ans après le traitement. Le régime sylvicole, la hauteur après le traitement, le diamètre de la tige, l'inclinaison de la tige et la pente du terrain ont été retenus comme variables explicatives potentielles dans des modèles de régression logistique expliquant la mortalité et la rupture de la tige. Les chances de survie d'un arbre non fatalement étêté 16 à 18 ans après le traitement étaient meilleures dans la matrice mature des peuplements jardinés par groupe que dans la coupe à blanc ou les peuplements à deux étages. Les chances de rupture d'un arbre fatalement étêté 16 à 18 ans après le traitement diminuaient avec l'augmentation du DHP. S'il est fait avec soin, l'étêtage artificiel des arbres peut constituer un outil sylvicole utile pour augmenter l'hétérogénéité structurale.

[Traduit par la Rédaction]

Introduction

Standing dead trees (snags), living trees with decay, and hollow trees are all important structural components of forest ecosystems worldwide. Snags are used by various taxa for nesting, denning, or foraging (Thomas et al. 1979; Mannan et al. 1980; Nappi et al. 2003). In British Columbia, Keisker (2000) identified 79 vertebrate species associated with dead and decaying trees. Snags also serve as growth substrates for lichen and fungi, and some plants are adapted to use the decaying wood of snags as a germination bed (Harmon et al. 1986). Living trees with decay exhibit structural complexities such as multiple tops and hollow chambers that are used by various forest species (Bull et al. 1997; Keisker 2000). Hollow trees provide roosting sites for Vaux's swifts (*Chaetura vauxi* Townsend) and denning sites for black bears (*Ursus americanus* Pallas) and American martens (*Martes Americana* Turton). In Australia, around 300 vertebrate species have been identified as using hollows in trees (Gibbons et al. 2002).

There is concern that forests managed for timber production may be lacking in snags. Wilhere (2003) showed how self-thinning in Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) forests can result in the creation of large snags; however, self-thinning only occurs when there exists competition-induced mortality, which is generally minimized through the use of carefully timed thinnings when managing for timber objectives (Tappeiner et al. 2007). Additionally, any snags resulting from broken tops, fire, insects, disease, or other natural mechanisms can be hazardous to workers if they are left standing during harvest operations (US Department of Labor 2006). Indeed, researchers working in various forest ecosystems have concluded that forests managed for timber production have

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T.D. Huff.[1] Oregon State University Extension Service, 631 Alder Street, Myrtle Point, OR 97458, USA.
J.D. Bailey. Forest Engineering, Resources and Management, Oregon State University, 204 Peavy Hall, Corvallis, OR 97331, USA.

[1] Corresponding author (e-mail: tristan.huff@oregonstate.edu).

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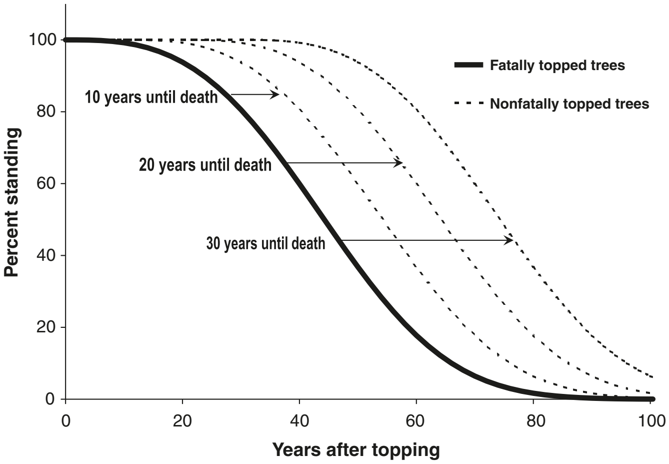
Fig. 1. Conceptualization of the persistence of fatally and nonfatally topped trees through time. Arrows indicate the variable shift resulting from the corresponding lag time needed for nonfatally topped trees to die.



significantly reduced quantity and (or) quality of snags and living trees with decay than their unmanaged counterparts (Cline et al. 1980; Kirby et al. 1998; Hale et al. 1999; Wilhere 2003; Koch et al. 2008; Lombardi et al. 2008).

As an alternative to relying upon naturally occurring snags to meet the needs of wildlife, some managers artificially create snags. When snags are purposefully created, they can be "placed" where they will be out of the way of current and future harvest operations. Various methods have been used to kill live trees for the purpose of creating snags (Lewis 1998). Trees can be girdled, inoculated with fungus, injected with herbicide, or treated with pheromones to encourage insect attack. These methods all retain the tree's full structure and may help encourage heart rot, which could increase a snag's value as wildlife habitat (Bull et al. 1997). However, none of girdling, inoculation, herbicide, or insect pheromones guarantee tree death, and furthermore, snags with an intact top but wounded base may be more susceptible to uprooting and stem breakage than ones that have had their tops removed (Bull and Partridge 1986). As an alternative to the above-described options, trees can have their crowns fully or partially removed by topping with a chainsaw or dynamite. When all live branches are removed, tree death is guaranteed and rapid, whereas death may be greatly delayed if some live branches are retained (Bull and Partridge 1986).

While the decomposition and fall rates of naturally occurring snags are relatively well understood (Cline et al. 1980; Chambers and Mast 2005; Garber et al. 2005; Russell et al. 2006), the dynamics of artificially topped conifer trees in an operational context are not. The fall rate of natural snags is approximated by a sigmoidal pattern, where rapid fall rates follow a significant lag time, during which newly killed snags decompose and weaken (Cline et al. 1980; Harmon et al. 1986; Garber et al. 2005). However, when healthy live trees are topped and live branches remain (nonfatally topped), the time between when the tree is topped and when the tree dies is extended (Fig. 1). Two other differences exist between natural snags and topped trees: natural snags are generally taller with correspondingly larger height/diameter ratios, and topped trees have a large wound that can serve as an entry point for decay-causing fungi such as *Fomitopsis cajanderi* (Karst.) Kotl. & Pouz. and *Fomitopsis pinicola* (Swartz: Fries) Karst. Because of these differences, it is important to differentiate between natural snags, fatally topped trees (FTTs), and nonfatally topped trees (NFTTs) when modeling snag dynamics. NFTTs, for the purpose of this study, are trees that retain live branches after topping, and FTTs are topped trees that have all live branches removed. Additionally, the structure of the surrounding forest is likely to have an effect on a snag's longevity. Garber et al. (2005) considered a stand's silvicultural prescription when modeling natural snag longevity, but differences in stand structure were most likely overridden by the mechanical damage resulting from harvest activities.

Our study investigated the long-term dynamics of both FTTs and NFTTs created during the implementation of three different silvicultural regimes. Specifically, we sought to quantify how individual stem characteristics including height, DBH, lean from vertical, and silvicultural regime (clearcut, two story, or group selection) are associated with the mortality rates and fall rates of fatally and nonfatally topped Douglas-fir trees 16–18 years after their creation in the Coast Range of Oregon.

Methods

Study context

FTTs and NFTTs were created as part of the College of Forestry Integrated Research Project (CFIRP) initiated by Oregon State University's College of Forestry in 1989 (Maguire and Chambers 2005). CFIRP was designed to compare costs and biological and human responses among an uncut control and three silvicultural alternatives to traditional clearcutting. Each silvicultural regime was designed to retain some structural features associated with old-growth forests while allowing for commercial timber harvest. The three alternative silvicultural regimes were clearcut with green tree retention, two story, and group selection. Thirty stands comprising 297 ha were designated across three geographically distinct sites (Saddle, Peavy, or Dunn) within Oregon State University's 4550 ha McDonald–Dunn Research Forest (123°15′W, 44°35′N). Each of the stands was assigned to one of the three silvicultural regimes: clearcut, two story, and group selection. Under each regime, commercial timber harvests were carried out with the pattern and amount of retention varying by regime. Under the clearcut regime 1.2 green trees were retained per hectare, under the two-story regime 75% of the volume was removed resulting in 20–30 green trees/ha, and under the group selection regime 33% of the volume was removed in 0.2–1.0 ha circular, square, or strip-shaped gaps. Stands were harvested in 1989 (Saddle site), 1990 (Peavy site), and 1991 (Dunn site), and all harvested areas were planted with Douglas-fir seedlings.

Concurrent with the harvesting of the clearcuts, two-story stands, and group selection stands described above, both FTTs and NFTTs were topped with a chainsaw by climbing the trees. In total, 804 Douglas-fir trees were topped (288 nonfatally and 516 fatally). Topped trees had a mean height

Table 1. Stem and site variables used in logistic regression on proportion of topped trees that are alive and proportion that are broken 16–18 years after topping.

Variable	Description	Variable type	Categories
Silvicultural regime	Alternative silvicultural regime the NFTT or FTT was created within	Categorical	1. Clearcut 2. Two story 3. Group selection
Creation year	Year the tree was topped (covaries with site)	Categorical	1. 1989, Saddle 2. 1990, Peavy 3. 1991, Dunn
Height	Height of the stem after topping (m)	Continuous	
DBH	Diameter at breast height of stem (cm)	Continuous	
Slope	Percent slope of the ground at the topped tree (only considered for FTT group)	Continuous	
Lean	Percent lean from vertical of the topped tree (only considered for FTT group)	Continuous	

Note: NFTT, nonfatally topped trees; FTT, fatally topped trees.

of 16.9 m (range of 12.2–23.5 m) and a mean DBH of 86 cm (range of 33–198 cm). In the group selection treatments, all topped trees were created within the uncut, mature forest matrix. Topped trees were individually numbered using aluminum tags, and their locations were later recorded using a GPS receiver. Additionally, the following measurements were taken on each topped tree after being cut: DBH, height, percent lean from vertical, and slope of ground.

The McDonald–Dunn Research Forest is located on the east flank of the Coast Range as it transitions into the Willamette Valley. Elevation ranges from approximately 120 to 400 m. Slope and aspect both vary by stand. Soils across the three sites are predominantly (93%) composed of the Dixonville, Jory, Philomath, Price, and Ritner series, which are generally deep, well-drained silty clay loams derived from basalt parent material. About 7% of the area making up the CFIRP sites is composed of the Abiqua and Waldo soil series, which are alluvial soils associated (on these sites) with terraces and fans of small seasonal streams.

Precipitation averages 104 cm annually with most occurring as rain in the winter and spring (July monthly rainfall averages only 1 cm). This is on the low end of the Coast Range's precipitation gradient. Low temperatures in January average 0.5 °C, while August highs average 27 °C (Western Regional Climate Center, http://www.wrcc.dri.edu/). Site index (50 year base age) across the sites range from 28 to 40 m (King 1966).

Study areas occur within two plant association types: Douglas-fir/hazel/brome-grass (*Pseudotsuga menziesii*/*Corylus cornuta* var. *californica*/*Bromus vulgaris*), and Douglas-fir/vine maple/salal (*Pseudotsuga menziesii*/*Acer circinatum*/*Gaultheria shallon*) (Franklin and Dyrness 1973). Vegetation was generally similar across sites prior to treatment. Total basal area of stands ranged from 24 to 76 m^2/ha, of which hardwoods represented between 5% and 26%. Douglas-fir dominated the overstory, although there was a small component of grand fir (*Abies grandis*). Stands ranged in age from 45 to 144 years, and the average height of the 40 largest tress per stand ranged from 29 to 54 m (Maguire and Chambers 2005).

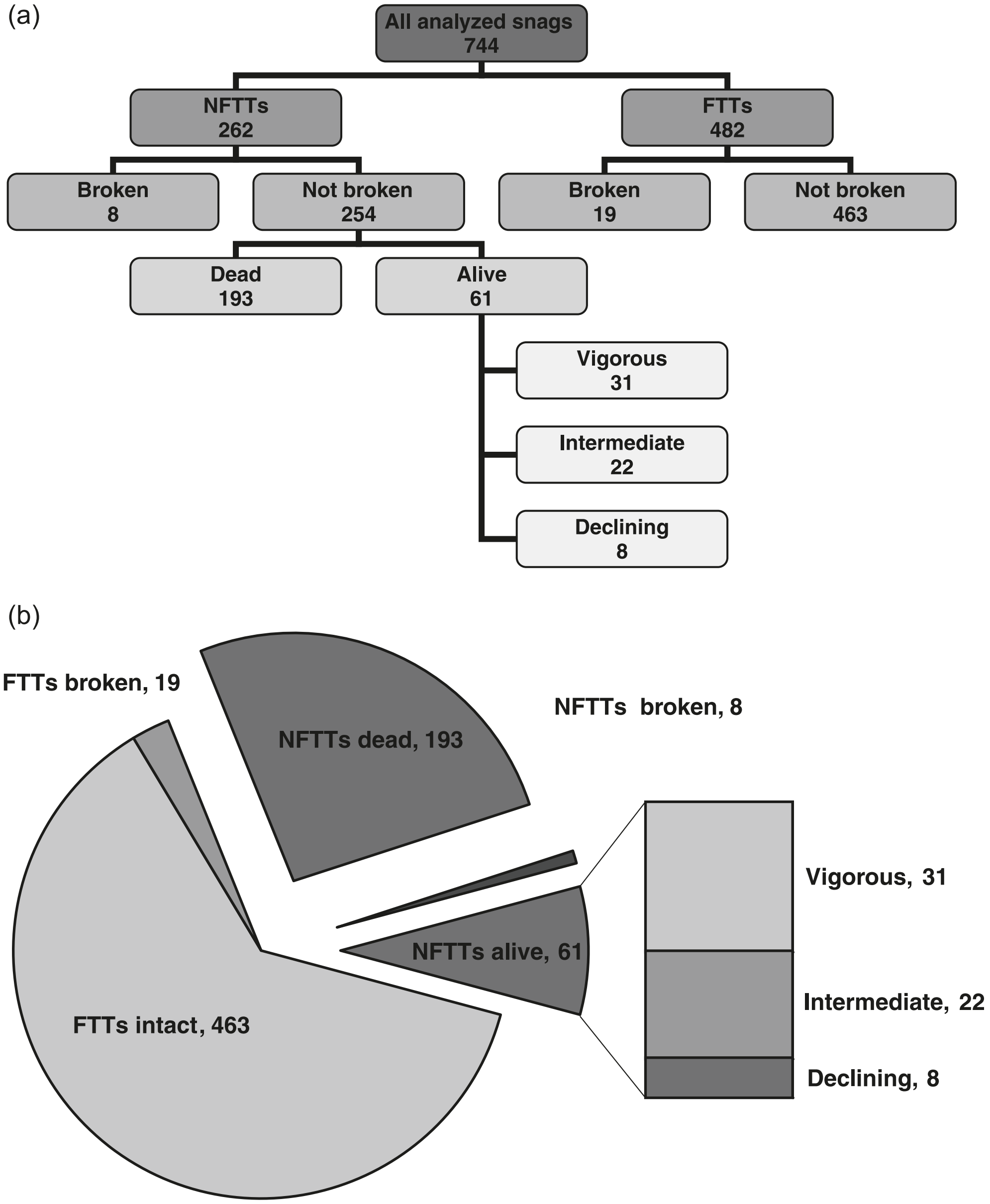
Data collection

Topped trees (both NFTTs and FTTs) were revisited during the winter of 2007–2008, 16–18 years after their creation. If a NFTT was still alive, it was recorded as such and assessed for relative vigor: declining, intermediate, or vigorous. "Declining" trees showed no signs of height growth, since the tree had been topped. Branches on "declining" trees had not converted to leaders, and the trees as a whole appeared to be declining in health. "Intermediate" trees showed signs of height growth, since treatment and some branches had converted to leaders, but these NFTTs also exhibited poor general health as evidenced by chlorotic needles and reduced needle retention. Trees marked as "vigorous" showed significant signs of height growth since the trees were topped, and their crowns were healthy looking with dark green foliage and a full complement of needles. Dead NFTTs and FTTs were marked as either standing or broken. Standing topped trees retained their original flat-cut top, while broken topped trees were ones that had either been uprooted or were missing their cut top. Broken topped trees were measured for height; a value of zero was assigned to trees that uprooted or broke at the base. Twenty-six topped trees could not be located because of missing GIS data and were removed from consideration in the analyses. Additionally, 34 topped trees were missing initial assessment data and were not analyzed, leaving a total sample size of 744.

Statistical analyses

Three separate stepwise logistic regressions were conducted to determine whether stem characteristics and (or) silvicultural regimes were significantly associated with: (*i*) the proportion of fatally topped trees that were broken, (*ii*) the proportion of nonfatally topped trees that were broken, and (*iii*) the proportion of nonfatally topped trees that were dead 16–18 years after treatment. The four independent stem characteristics considered included height, DBH, slope of ground, and percent lean (Table 1). These variables were chosen because they are commonly considered predictors of natural snag fall rates (Keen 1955; Cline et al. 1980; Morrison and Raphael 1993). Silvicultural regime was in-

Fig. 2. Fates of all analyzed nonfatally topped trees (NFTTs) and fatally topped trees (FTTs) displayed by count in hierarchical form 16–18 years after treatment in Oregon's Coast Range. Accompanying pie chart shows the same data proportionally.



cluded as a categorical variable so that pairwise comparisons could be made between the clearcut, two-story, and group selection treatments (Table 1). Since creation year covaries with site, it was included as a categorical variable solely to control for variation as a result of age and geographic location. Beginning with a model containing no independent variables, independent variables were added one at a time with only the most significant (smallest *p* value) variable added to the model. Additionally, if a variable's parameter estimate was not significant at $\alpha = 0.05$ it was not included, and if, after the inclusion of other variables, a parameter estimate was not significant at $\alpha = 0.10$ it was removed from the model. The final step in model selection was to check for independence of explanatory variables by testing the significance of their interaction terms. Once a model was selected, comparisons between silvicultural regimes and different levels of the continuous variables were made. Comparisons were presented as a ratio of odds.

Results

Nonfatally topped trees

The majority of the 262 revisited NFTTs (76.7%) died at some time during the 16–18 years since they were created. Of the 61 that remained living, 50% were classified as vigorous, 37% were classified as intermediate, and only 13% were classified as declining (Fig. 2). All of the NFTTs classified as vigorous exhibited candelabra structures in which multiple branches convert to leaders (Figs. 3 and 4). While not found to be statistically significant, there were absolute differences by silvicultural regime in the proportion of NFTTs that were classified as vigorous. Fourteen percent

Fig. 3. Vigorous nonfatally topped Douglas-fir exhibiting considerable height growth since treatment.

of all NFTTs created under the group selection treatment were classified as vigorous as compared with 10% under the clear-cut regime and 7% under the two-story regime.

We identified silvicultural regime, creation year, and DBH as being significantly associated with the probability of nonfatally topped Douglas-fir trees surviving 16–18 years after being topped (Table 2). Percent survival under each of the silvicultural regimes, as well as mean values of the previously described tree and site characteristics for living and dead NFTTs are all shown in Table 3.

Table 2. Test statistics and *p* values for significance of association with Logit(survival) of nonfatally topped trees in Oregon's Coast Range 16–18 years after topping.

Effect	df	Wald χ^2	*p* value
Silvicultural regime	2	9.317	0.010
Year created	2	8.212	0.017
DBH	1	6.357	0.012

NFTTs created under the group selection regime are more likely to remain living 16–18 years after topping than those in clearcuts and two-story treatments. After accounting for the effects of DBH, the odds of survival (remaining alive) for a NFTT created under the group selection regime are estimated to be 3.5 times (95% CI: 1.0–7.1 times) the odds of survival for NFTTs in a clearcut and 3.3 times (95% CI: 1.3–8.3 times) the odds of survival under the two-story regime. Smaller diameter NFTTs were more likely to survive than larger NFTTs. For each 10 cm increase in DBH, the odds of dying within 16–18 years of creation for NFTTs are increased 1.2 times (95% CI = 1.0–1.4 times). Test statistics

Fig. 4. Candelabra-shaped crown created when the branches of a nonfatally topped Douglas-fir converted into leaders.

and odds ratios for all model variables and comparisons within the groups of each are summarized in Table 4. Only 8 of the 262 revisited nonfatally topped Douglas-fir trees (3.1%) were broken (i.e., did not retain their full height); consequently, logistic regression on the proportion with breakage was not feasible with the NFTT group.

Fatally topped trees

Only 19 of the 482 revisited fatally topped Douglas-fir trees (3.9%) had broken at some point along their bole 16–18 years after topping. Most broke at some point along the bole as opposed to breaking off at the base or uprooting (Fig. 5). We identified DBH as the only significant variable significantly associated with the probability of fatally topped Douglas-fir trees breaking within 16–18 years of being topped (Wald χ^2, 1 df = 14.39, p value = 0.0001). For each 10 cm increase in DBH, the odds of breaking within 16–18 years of creation for FTTs are decreased 1.2 times (95% CI = 1.0–1.4 times).

Discussion

Artificial snags within the size range we considered are very unlikely to break within the first 16–18 years after their creation (3%–4%). This very low rate of breakage agrees with the findings of Cline et al. (1980) who found that, for larger natural Douglas-fir snags, the lag time before snags begin to fall is around 20 years. Our finding that larger stem diameter resulted in lower rates of breakage also agrees with the findings of past studies of natural snags. Cline et al. (1980) found that with natural Douglas-fir snags, fall rate lag time increases with increasing diameter. In a recent review of the natural snag fall rate literature, 8 of the

Table 3. Percent living and percent broken of fatally and nonfatally topped trees by silvicultural regime, creation year, and spatial arrangement 16–18 years after treatment as well as mean values of stem characteristics and each mean's standard deviation (in parentheses).

	Nonfatally topped		Fatally topped	
	Dead	Alive	Broken	Unbroken
Silvicultural regime				
Clearcut	86.3%	13.7%	5.8%	94.2%
Two story	90.1%	9.9%	1.6%	98.4%
Group selection	66.4%	33.6%	4.2%	95.8%
Creation year (covaries with site)				
1989	74.4%	25.6%	5.1%	94.9%
1990	91.8%	8.2%	3.1%	96.9%
1991	70.3%	29.7%	4.2%	95.8%
Mean values				
Height (m)	16.9 (1.5)	16.7 (1.8)	16.7 (1.4)	17.0 (1.4)
DBH (cm)	89 (30)	72 (27)	87 (28)	62 (28)
Slope (%)	na	na	25 (16)	28 (15)
Lean (%)	na	na	1.5 (1.8)	1.9 (2.3)

Table 4. Test statistics and odds ratios for survival of nonfatally topped trees 16–18 years after treatment (with Wald 95% confidence intervals (CI)) for contrasts between silvicultural regimes and year topped.

						95% Wald CI	
Effect	Contrast	df	Wald χ^2	*p* value	Odds ratio[a]	Lower	Upper
Silvicultural regime	Two story vs. clearcut	1	0.175	0.675	0.78	0.24	2.50
	Clearcut vs. group selection	1	3.503	0.061	0.29	0.14	1.04
	Two story vs. group selection	1	6.627	0.010	0.30	0.12	0.75
Creation year (covarying by site)	1990 vs. 1989	1	7.708	0.006	0.19	0.06	0.57
	1990 vs. 1991	1	8.805	0.003	0.23	0.08	0.65
	1991 vs. 1989	1	0.340	0.560	0.81	0.41	1.63
DBH (increase of 10 cm)	—	1	6.357	0.012	0.83	0.72	0.96

[a] The odds ratio of survival for an increase in stem DBH of 10 cm.

10 studies considered found that natural snags stand longer as their diameters increase; the other two studies didn't detect a significant relationship (Smith and Cluck 2007).

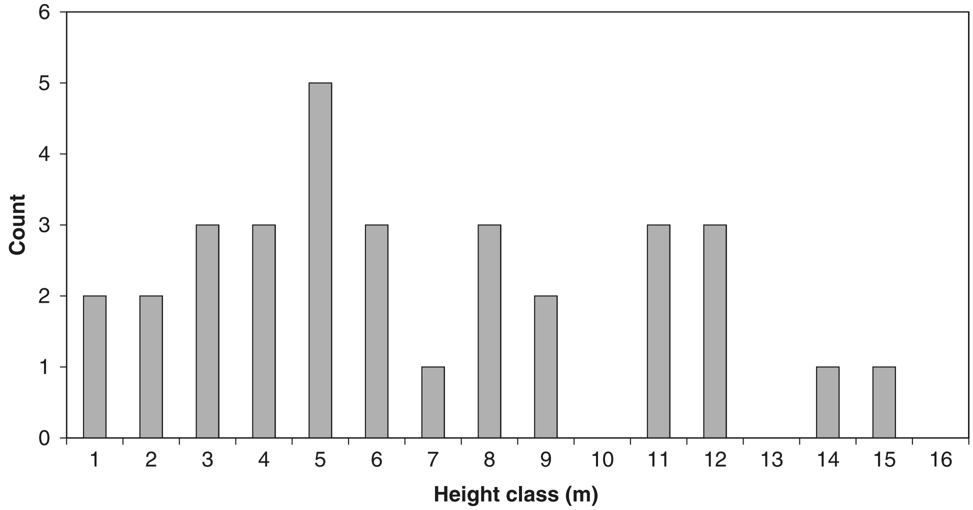
One might expect the height after topping to affect chance of breakage with taller topped trees being more likely to break. We didn't observe this association, most likely because of the small variability in height of topping in this study. The same reasoning most likely holds true for percent slope and percent lean.

Of the 32 FTTs that broke in our study, only four are currently too short (less than 1.8 m) to meet the needs of birds for nesting as defined by Thomas et al. (1979) (Fig. 5). Thus, nearly all of the artificially topped trees that died immediately after topping remain candidates for use by snag utilizing birds 16–18 years after their creation. While we didn't record avian use of FTTs, Chambers et al. (1997) and Walter and Maguire (2005) reported that FTTs in the CFIRP study were used extensively for nesting and browsing and that their use increased as snags decayed. Extensive bird use of artificially created snags has also been shown by Hallet et al. (2001).

In contrast with fatally topped trees, significant survival can be expected when Douglas-fir trees are topped in such a way that a portion of their live crown is retained; 23% of all NFTTs have survived 16–18 years. Walter and Maguire (2005) found that living NFTTs in the CFIRP study were rarely used for nesting or foraging, presumably because of their lack of decay. Anecdotal observations of cavity presence and absence during our remeasurements further support this conclusion. However, half of the 23% of NFTTs that survived 16–18 years exhibited a candelabra crown structure that is known to be a classic feature of many old-growth forest ecosystems (Franklin et al. 1981; Baker et al. 2005; Worrall et al. 2005). In the Pacific Northwest, a candelabra growth pattern results in large diameter branches that can be used as nesting platforms by, for example, the federally listed marbled murrelet (*Brachyramphus marmoratus* Gmelin) (Baker et al. 2006). Therefore, while the NFTTs that remain living may not be useful to snag dependent birds, they may still provide a valuable habitat for other species.

NFTTs created within the mature, closed-canopy matrix

Fig. 5. Distribution of breaking heights of all topped trees that broke within 16–18 years in the College of Forestry Integrated Research Project (CFIRP) study.



of a group selection harvest are likely to survive longer and may be more likely to develop a candelabra crown structure than NFTTs in clearcuts or in a two-story stand. This relationship may be due to the fact that NFTTs created in a mature forest are more sheltered from the wind and, thus, are able to retain more of their live branches following topping relative to the trees topped in more open settings (Schmid et al. 1985). Additionally, the lower level foliage that remains after topping is composed of shade needles, and these shade needles could experience fatal sunscald in the open conditions following harvest in the clearcut and two-story treatments. This effect is possibly similar to thinning shock as described by Harrington and Reukema (1983). These hypotheses on the causes of differences in survival, however, are speculative and beyond the scope of our study. Furthermore, it is important to note that our findings on NFTT survival are based on relatively short-term data, and other mechanisms may come into play as living NFTTs and the surrounding stand each develop. For example, it may be the case that NFTTs in the mature matrix of group selection stands may become less vigorous as they are increasingly overtopped by the surrounding trees. Conversely, living NFTTs in clearcuts and two-story stands may be more likely to persist in the long-term relative to NFTTs in the mature matrix of group selection stands because of lower levels of competition.

It is unclear why smaller diameter NFTTs were found to be more likely to survive than larger diameter individuals, but it is possible that smaller diameter NFTTs tended to have lower photosynthetic demands and, consequently, were more likely to persist with a reduced leaf area. It could also be the case that crown structure varied with diameter resulting in, perhaps, more live branches remaining after topping on smaller diameter NFTTs. It is unfortunate that data don't exist describing the amount of live foliage remaining after topping for each NFTT, as this variable would likely be a key predictor of probability of survival. While this lack of data does diminish the strength of our study somewhat, our findings on the general survival rates, influence of silvicultural regime, and resulting candelabra structures remain valid.

Conclusions

Topping trees, both fatally and nonfatally, is an effective way to create snags that will provide habitat for cavity nesting and browsing species for decades where they are lacking in stands or landscapes. Large diameter trees should be selected to ensure maximum longevity. If specific snag density goals are to be met, it is important to top trees in such a way that death is guaranteed. We have shown that if live branches are retained, a significant percentage of topped trees could remain living, thus making them unusable by cavity nesters and foragers. However, when overall objectives are to simulate the structural heterogeneity of old-growth forests, nonfatal topping of live Douglas-fir trees is a viable way to create a mix of snags and trees with structurally complex, candelabra crown structures. When the creation of these complex living structures is an objective, NFTTs should be created in mature stands or near intact trees to maximize survival, at least in the short term. Further research is needed to describe how the surrounding forest structure will affect living NFTTs in the long term. Additionally, the remaining live topped trees should be surveyed now and in the future for actual use by wildlife, especially for species of concern such as the marbled murrelet. These trees should also be assessed for decay, especially in their heartwood; Bull et al. (1997) discuss the importance of decay in living trees for use by wildlife. This decay, however, is likely to be a slow process occurring over several decades, so long term monitoring of these "living snags" is essential.

Our study is fundamentally limited in that it only considers one point in the life span of the topped trees. However, this snapshot in time provides some insight regarding how likely a topped tree is to either remain alive or remain unbroken 16–18 years following topping. While we were able to determine some key explanatory variables, further remeasurements will be necessary if models are to be built that predict a topped tree's useful life span. Our findings and the findings of Cline et al. (1980) suggest that these topped trees have not been dead long enough to have reached the end of their lag time and will experience greater fall rates in the next decade. Furthermore, some of the NFTTs remain alive and in various states of vigor. This suggests that there will be multiple sigmoidal trajectories for the NFTTs (depending on how long they remain alive) (Fig. 1). Therefore, it is essential that remeasurements are frequently taken in the next 10–15 years so that the life spans of both FTTs and NFTTs can be modeled with precision and accuracy.

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