

Dynamics of snags in aspen-dominated midboreal forests

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Abstract

This research focuses on the dynamics of snags within aspen-dominated (*Populus tremuloides* Michx.) boreal forests within Alberta. Data from Alberta Lands and Forest Service permanent sample plots (PSP) were analyzed to determine densities, size distributions, input rates, falldown rates, and longevity patterns of snags (≥ 10 cm DBH). The mean density of snags in 20 to 39-yr-old stands was 18.1 snags per ha increasing to 61.6–99.8 snags per ha in stands up to 100 + yrs. In general, size distributions of trees and snags exhibited a reversed J-shaped size distribution. In stands < 40 yrs of age, size distributions of snags lagged behind trees. However, as the stand aged and self-thinning of small trees was supplemented by the death of canopy codominants, the size distribution of snags began to increasingly overlaps with that of trees. Overall snag input rates varied from 0.08–8.2% of trees per annum, larger values were associated with older stands and/or smaller trees. Snag falldown rates varied from 9–21% of snags per annum depending upon stand age. Falldown rates exhibited a U-shaped pattern with rates decreasing in 60 to 79-yr-old stands. Snag longevity patterns exhibited a negative sigmoidal shape with an initial period of relative stability for approximately 5 yrs after death, afterwards the probability of falldown increased with a greatest falldown occurring between 10 to 20 yrs after death. © 1998 Elsevier Science B.V.

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1. Introduction

Over the last few decades there has been an increasing recognition of snag resources as critical elements in the function of forest ecosystems (Harmon et al., 1986). Standing dead trees or snags serve as habitat for birds (Connor, 1980; Gibbs et al., 1993) and mammals (Connor et al., 1975; Barclay et al., 1988). In the boreal forests of Alberta, approximately 25% of the vertebrate wildlife species are

dependent upon snags as critical habitat (Scheick and Roy, 1995). For forest managers to ensure the supply and maintenance of critical snag habitats, they must understand the dynamics of snags within forests and the impact of forest age upon these dynamics.

Snag dynamics are driven by four parameters: (1) initial standing crop, (2) input rates, (3) decay rates, and (4) falldown rates (Bull et al., 1980; Cimon, 1983). To date, most studies have concentrated on the standing crop of snags. Examples include oak (*Quercus*) and oak–hickory (*Quercus*–*Carya*) forests in southwest Virginia (Rosenburg et al., 1988), Pacific coast Douglas fir–hemlock (*Pseudotsuga*–

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Tsuga) forests (Cline et al., 1980), and hemlock–hardwood forests of Wisconsin and northern Michigan (Tyrell and Crow, 1994).

There is a much poorer understanding of rate functions underlying snag dynamics. In part, this is due to the lack of datasets with snag input/falldown rates and patterns of individual snag longevity. Mortality rates of trees can usually be obtained from the standard long-term sampling plot data used in growth–yield estimations. However, to estimate snag input, the data must indicate whether the tree remained standing after death or was downed. Also, as snags decay, they change in form and function. At different decay stages, snags become available to different wildlife species while no longer being used by other species. Snags have been classified under a number of decay classification criteria (e.g., Tyrell and Crow, 1994) but the time period within a decay stage is poorly understood in most forest types (however see Cline et al., 1980). Keen (1955) marked and remeasured beetle-killed Ponderosa pine (*Pinus ponderosa*) in northern California. Both Dahms (1949) and Lyon (1977) followed fire-killed Ponderosa pine and lodgepole pine (*Pinus contorta*), respectively, in Oregon. Complete dynamics have been modeled for ponderosa pine and lodgepole pine snags in north-eastern Oregon (Bull et al., 1980; Cimon, 1983). Such data are lacking for virtually all other forest types.

Currently, there exists relatively little data on snag dynamics within deciduous boreal forests. Lee et al. (1997) compared the size profiles in standing snag crops within 20–30, 50–60, and 120 + yr old deciduous stands. Densities of snags (< 10 cm DBH) tended to be lower in young stands than in older stands. The size profiles and decay patterns of snags revealed a significant biological legacy of large sized snags from the prefire stand that were still detectable in the 50 to 60-yr-old stands. That study provided only a snapshot of snag profiles and densities. To fully understand the dynamics of snags it is important to understand the input and falldown rates of snags.

Estimation of rates and patterns of snag input and falldown requires long term marking and remeasurement of trees and snags. Permanent sample plots (PSP) are one of the methods by which forest resources have been enumerated. Traditionally, PSP

data have focused on the regeneration/mortality and growth/yield of canopy trees and biophysical variables associated with growth of canopy trees, e.g., soil moisture or understory cover. PSPs, however, may also be useful for describing snag dynamics. Data are repeatedly collected within the same plot and so provide a record of the changes to single elements, e.g., trees, and changes in the profile of the stand as a whole.

This paper examines the Alberta Lands and Forest Service PSP database over the midboreal ecosystem (Strong and Leggat, 1992) and evaluates its use in describing the dynamics of snags. The analysis was restricted to the deciduous land base (i.e., > 80% deciduous by cover), however, some of the methodology and basic recommendations are applicable to other cover types. Specifically this report will examine (1) standing crop of snags, (2) snag input, (3) snag falldown, and (3) snag longevity. Unfortunately, the PSP database does not classify snags according to decay stage, hence, no estimations of transition times/rates between decay stages will be possible.

2. Materials and methods

The Alberta Lands and Forest Service (LFS) permanent sample plot (PSP) database contains 68 deciduous-dominated plots established after 1960. PSPs prior to 1960 were excluded due to the lack of data on deadwood resources. Deciduous PSPs < 60 yrs or > 100 yrs are scheduled for resampling every 5 yrs while those between 60 and 100 yrs are resampled every 10 yrs. PSP stands were aged at the time of establishment. The detailed measurement protocol is described in Anonymous (1994).

All PSPs were located within midboreal mixed-wood ecoregion of Alberta (Strong and Leggat, 1992). In this ecoregion, forests consist mainly of trembling aspen (*Populus tremuloides* Michx.), balsam poplar (*Populus balsamifera* L.), paper birch (*Betula papyrifera* Marsh.), white spruce (*Picea glauca* Moench.), and balsam fir (*Abies balsamea* L.). The typical successional trajectory moves from *Pop. tremuloides* and *Pop. balsamifera* to conifer species, however, stands are frequently deciduous-dominated even after several hundred years. Eleva-

tion of all PSPs varied between 286–880 m above sea level. The climate features cold winters (daily mean (± 1 S.D.) temperature; $-15.2^{\circ}\text{C} \pm 4.8$) and warm summers (daily mean temperature $14.9^{\circ}\text{C} \pm 1.2$) with moderate amounts of precipitation (annual mean 513.5 mm ± 110.6) (unpublished data from Atmospheric Environmental Service, Environment Canada).

Two methods were used to establish plots. Prior to April 1981, each plot was a cluster of four subplots. Each subplot was placed along a cardinal direction 50.3 m from the group centre. Subplot sizes were set to enclose a minimum of 100 living trees per ha. Most subplot sizes were either 1012 m² or 2023 m². The sizes of subplots varied among PSPs but were the same within a plot. After April 1981, a single plot was used for each PSP. Plots encompassed at least 50 trees and were usually 1000 m². However, in low density stands plot size increased to 1500 or 2000 m². The plot boundaries were oriented along cardinal directions. Buffers were established around each PSP. To ensure the independence of PSPs and to compare plots of similar size, a single random subplot was chosen from the pre-1981 data to estimate snag densities. For all other analysis, trees and snags were used from all subplots. Pre- and post-1981 PSPs were well dispersed among the stand-age categories, and hence were not biased towards any particular stand age.

Within each plot, all standing trees (live and dead) > 9.1 cm DBH were tagged, measured, and tallied. A tree or snag was considered 'in' if more than half of the stem was within the plot at breast height (1.3 m). All snags were able to withstand a firm push before being measured. Stand age was calculated by felling, sectioning, and counting rings from three or more codominant/dominant trees in the buffer zone of each plot.

3. Analysis

For most analyses, trees and deadwood were classified into size classes 10–19 cm, 20–29 cm, 30–39 cm, and ≥ 40 cm DBH, and within stand-age classes 20–39 yrs, 40–59 yrs, 60–79 yrs, 80–99 yrs, and 100+ yrs. Snag densities and proportions of species were based on the mean of all PSPs within an age

class. With a remeasurement interval of 5–10 yrs, there were often two or more measurements from a single PSP within an age class. In those cases, the PSP was represented by the mean of these measurements to prevent biasing PSPs with repeated measurements. In all, 18 077 trees were analyzed for size distributions and 3417 snags were analyzed for densities and size distributions. A $\log(x)$ transformation was used to normalize snag densities and a one-way ANOVA was used to compare densities with a Student–Neuman–Kuels posthoc test for multiple comparisons. A significance level of $P = 0.05$ was used for all analysis.

The measurement protocol for PSPs in Alberta makes it possible to determine snag input and fall-down rates for stand ages. At the time of death, each tree was classified as missing, cut down, dead and down, or standing dead. Unnatural and unexplained losses from PSPs were very small with only 95 trees cut down and one missing tree recorded in the entire dataset. Only trees and snags ($n = 17\,456$ and 2692 , respectively) counted prior to the last measurement can be used in the estimation of rates. Deadwood input and snag falldown rates were based on dividing the number of trees becoming snags or downed woody materials (DWM) by the total number of trees or snags in the previous measurement. Overall estimates of mean and variance were calculated from rates estimated within each plot. The annualized probabilities of mortality were transformed using a $\log(x + 1)$ transformation prior to ANOVA and posthoc Student–Neuman–Kuels multiple range testing.

A profile for the longevity of snags depending upon DBH and species was developed through failure-time analysis (Fox, 1993). Briefly, failure-time analysis involves the handling of time sequenced data taken from repeatedly observing a unique individual. The classical approach (Muenchow, 1986) for analysis of this data type usually involves the assessment of failures of a fixed number of individuals over a fixed time. The cumulative numbers of failures at a fixed time are then compared between groups. Failure-time analysis differs in establishing the survival distributions then comparing distributions among groups. This method has several advantages when analyzing the PSP dataset. The primary advantage is the ability to combine and analyze

datasets in different stages of monitoring, PSP data varies in age depending upon the time plot establishment. Also, individual trees within a PSP may have different periods of monitoring since a lower size criteria of 9 cm DBH is required before a tree is marked and remeasured. Unlike ANOVA approaches which focus on mean failure-time and assumes homogeneity of variances, failure-time analysis compares whole survival distributions. Lastly, failure-time analysis can compare survival distributions with multiple periods of high hazard. The mathematical details of failure-time analysis are presented in detail by Kalbfleisch and Prentice (1980) and will not be presented here.

The measurement periods of 5–20 yrs for each PSP recorded a large proportion (~70%) of snags with complete records (uncensored data). Snags with unknown establishment dates (left censored data) were not included in analysis but snags with known dates of establishment that had not fallen yet (right-censored data) was used in analysis. Estimates of snag longevity functions were based on the product-limit method (Kalbfleisch and Prentice, 1980). A total of 2311 snags were evaluated in all snag size and species categories. A minimum sample size of at least 60 snags within a category was required before

continuing with analysis. All four size categories and four species were analyzed. Differences within size and species categories were examined using a log-rank test (Fox, 1993). Posthoc multiple comparisons were based on Z-statistics constructed from log-rank scores (Fox, 1993).

4. Results

4.1. Densities and species

Only snag densities within 20 to 39-yr-old stands were different (Fig. 1; $df = 4$, $F = 4.48$, $P = 0.004$). The mean density (± 1 S.E.) of snags in 20 to 39-yr-old stands (18.1 ± 3.7 snags per ha) was lower than other older age groups which ranged from 61.6–99.8 snags per ha.

Not surprisingly, *Pop. tremuloides* and *Pop. balsamifera* were the dominant species of snags within these stands (Fig. 1) with percentages varying from 69–91% for stand ages. However, proportions of different snag species varied among stand ages ($\chi^2 = 334.7$, $df = 12$, $P < 0.0001$). In general, a higher proportion of secondary species, *B. papyrifera* (>

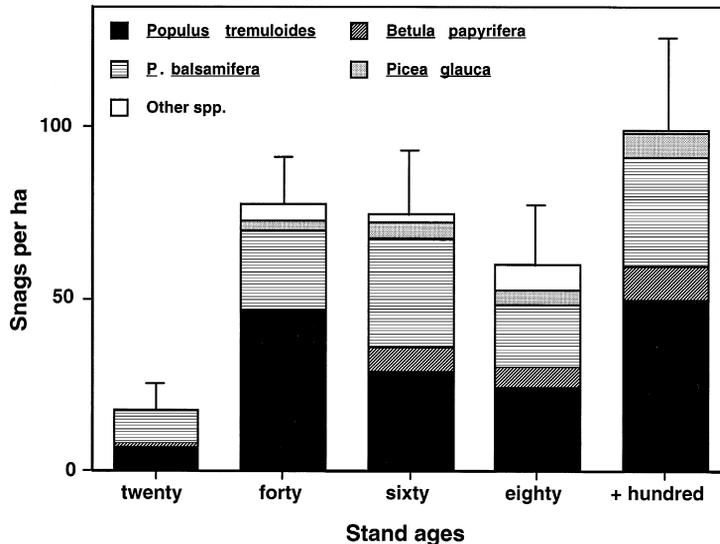


Fig. 1. Relationship between mean density of snags (± 1 S.D.) and stand age within *Pop. tremuloides*-dominated stands of Alberta's midboreal ecoregion.

10%) and *Pic. glauca* (> 7%), were found in stands > 80 yrs. of age ($P < 0.001$).

4.2. Size distributions

Trees and snags generally exhibited a reverse J size distribution. Stands between 40–59 yrs of age had the steepest reverse J distribution (Fig. 2). However, there was a pulse of both trees and snags at the larger sizes (≥ 35 cm DBH). For both distributions, the pulse of larger tree and snags accounted for 4–5% of trees and snags. As a stand ages, the tree distribution spread into the larger size classes generally producing a more even distribution of individuals across all size classes (Fig. 2). There was also a continual reduction in the density of trees within the smaller size categories. The leading edge of large residual trees was indistinguishable from the current cohort of trees within stands beyond 60 yrs. of age.

As the mortality pattern in trees switches from self-thinning to death of the canopy, the size distribution of snags reflects this pattern (Fig. 2). In 60 to 79-yr-old stands, the distribution of snags is domi-

Table 1

Summary of two-way ANOVA on the effects of stand age and DBH on the annual snag input and falldown rates (per 100 trees per yr) within *Pop. tremuloides*-dominated stands of Alberta's midboreal ecoregion. Data from 20 to 39-yr-old stands were excluded because they did not have data in all size categories

Source of Variation	df	MS	F-value	P
<i>Snag input</i>				
Stand age	4	0.001	6.243	0.0001
DBH	3	0.003	15.74	0.0001
Stand age \times DBH	9	0.00047	2.171	0.0246
Error	247	0.00022		
<i>Snag falldown</i>				
Stand age	4	0.149	6.405	0.0002
DBH	3	0.020	0.844	0.4743
Stand age \times DBH	7	0.023	1.002	0.4371
Error	71	0.023		

nated by smaller DBH snags and lagged behind the tree size distribution. As stands exceed 80 yrs of age, the distributions of trees and snags have the same range.

4.3. Input rates

Both stand age and tree size (≥ 10 cm DBH) were related to the snag input rates (Table 1; Fig. 3). In general, rates of transition from live trees to snags increased with advancing stand age and with decreasing tree size class. Within trees of 10–19 cm

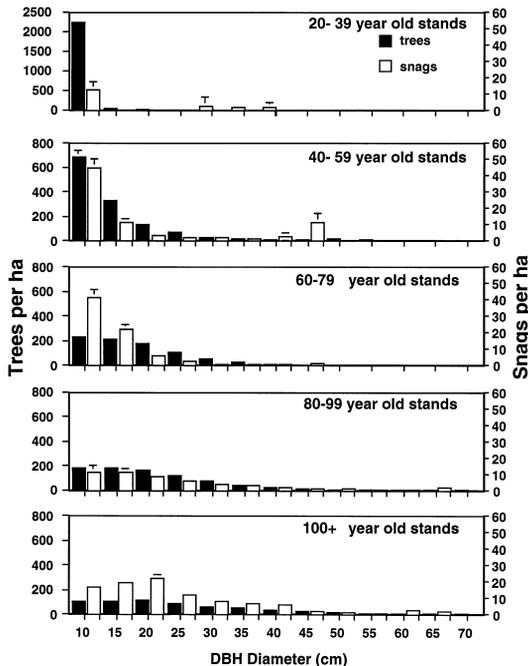


Fig. 2. Mean live trees and snag DBH (± 1 S.E.) densities in different stand age classes from within *Pop. tremuloides*-dominated stands of Alberta's midboreal ecoregion.

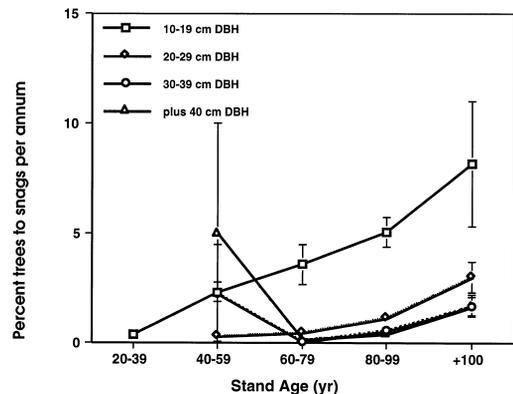


Fig. 3. Mean percentage (± 1 S.E.) of trees to snags per annum within stand age classes of *Pop. tremuloides*-dominated stands of Alberta's midboreal ecoregion.

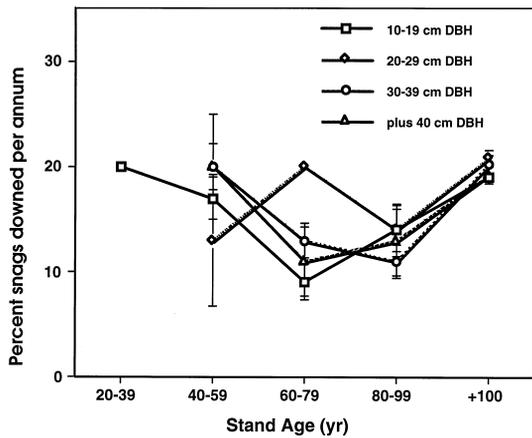


Fig. 4. Mean percentage (± 1 S.E.) of snags to be downed per annum within stand age classes of *Pop. tremuloides*-dominated stands of Alberta's midboreal ecoregion.

DBH, input rates increased from 0.4% per annum in 20 to 39-yr-old stands to 8.2% per annum in 100 + yr old stands. In comparison, input rates for trees ≤ 20 cm DBH ranged from 0.08% per annum in 60 to 79-yr-old stands increasing to 3.03% per annum in 100 + yr old stands. No differences were detected among size categories ≥ 20 cm DBH within a particular stand age (Posthoc SNK, $P > 0.05$). All input rates of snags ≥ 20 cm DBH were lower than snags < 20 cm DBH (Posthoc SNK, $P < 0.05$).

A significant stand age \times tree size interaction was also noted in the two-way model of input rates (Table 1). Most of this could be attributed to the relationships within stands 40 to 59-yr-old. In that age group, rates varied between 0.31–5.00% per annum with no differences among size classes (Posthoc SNK, $P < 0.05$). This was due to trees ≥ 20 cm DBH having much greater means and variances within the 40 to 59-yr age class than at other age classes (Fig. 3). In part the greater variation was caused by the relatively few numbers of ≥ 20 cm DBH trees ($n = 64$). The higher mean rates of input may reflect the death of predisturbance origin trees. Unfortunately, the lack of PSPs within the 20 to 39-yr-old stands prevented a further examination of this pattern.

At the time of death most trees remained standing as snags, rather than falling to the ground. The PSP data revealed the transition from tree to snag was the most common occurrence amongst all snag sizes and

stand ages. The ratio of tree to snag: tree to DWM transitions ranged from 2.8–15.1 for different size and stand age categories with a weighted mean ratio of 5.5 based on all categories. This value likely underestimates the actual ratio since five to ten years normally elapse between the last measurement of a tree and its subsequent remeasurement as a snag.

4.4. Falldown rates

In general, the falldown per annum of snags ranged from 9–20%. Stand age was associated with falldown rates ($P < 0.05$; Table 1; Fig. 4). Overall rates exhibited a U-shaped distribution decreasing from 13–17% in 40 to 59-yr stands to 9–13% in 60 to 79-yr-old stands and increasing to 9–20% snags downed per annum in 100 + yr old stands ($P < 0.05$; Posthoc SNK). No differences were detected amongst snag DBH ($P > 0.05$; Table 1). Also no interaction was detected between stand age \times DBH ($P > 0.05$; Table 1).

4.5. Longevity patterns

A comparison of longevity among snags of different size classes indicated no differences (Fig. 5; $df = 4$, $\chi^2 = 4.81$, $P = 0.31$). The weighted mean (± 1 S.E.) longevity was 19.2 ± 0.19 yrs. For the first 10 yrs after death, the falldown rate of snags relatively low with only with $< 25\%$ being lost. After 10 yrs there was a great increase in the rate of

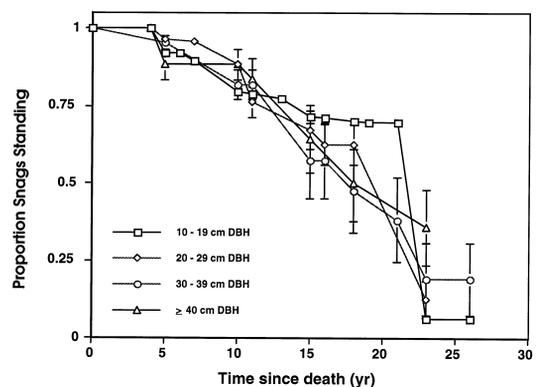


Fig. 5. Proportion of standing snags as a function of time since death for snags in 10–19 cm DBH ($n = 1850$), in 20–29 cm DBH ($n = 340$), in 30–39 cm DBH ($n = 101$), and ≥ 40 cm DBH ($n = 163$) size categories.

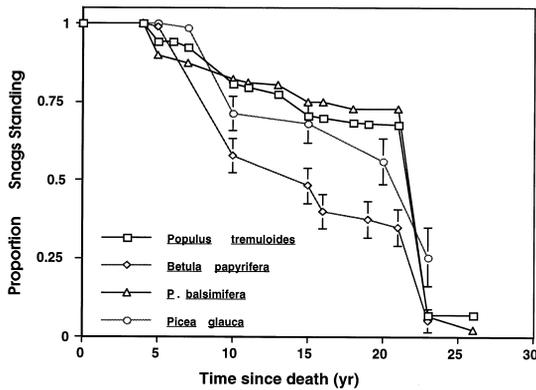


Fig. 6. Proportion of standing snags as a function of time since death for *Pop. tremuloides* ($n = 1278$), *Pop. balsamifera* ($n = 877$), *Pic. glauca* ($n = 67$), and *B. papyrifera* ($n = 89$) within *Pop. tremuloides*-dominated stands of Alberta's midboreal ecoregion.

falldown. After 20 yrs <25% remained for most size classes.

In contrast, a comparison of longevity among different species indicated some differences (Fig. 6; $df = 4$, $\chi^2 = 30.4$, $P < 0.0001$). Posthoc analysis indicated that *B. papyrifera* exhibited shorter longevity than *Pop. tremuloides*, *Pop. balsamifera*, and *Pic. glauca*. None of the latter species exhibited any differences amongst each other ($P = 0.94$). The weighted mean (± 1 S.E.) longevity of *B. papyrifera* was 15.9 ± 0.66 yrs while the combined longevity was 19.3 ± 0.51 yrs for all other species. The longevity function for *B. papyrifera* exhibits a much shorter period of stability ending after approximately 5 yrs. Thereafter, it exhibits a rapid decline to 20 yrs then another rapid decline to 23 yrs.

5. Discussion

Snag densities and the pattern of change over stand ages reported in this study were similar to those reported by Lee et al. (1997) in a previous study of stand age and snag density. Both studies indicated that snag densities (≥ 10 cm DBH) were lower in stands between 20 to 39 yrs of age. Mean densities (± 1 S.E.) ranged from 18.1 ± 3.7 for this study to 33.0 ± 6.8 snags per ha for Lee et al. (1997). These densities increased after 40 yrs to

61.6–99.8 snags per ha. Both studies indicated that there were no differences in density attributable to stand age among stands older than 40 yrs. The relative constancy of snag densities in older stands was produced by balancing increased tree mortality with increased snag falldown rates.

Size distributions of snags generally reflected different mortality processes operating within stands. Initially snags were derived from self-thinning and from trees killed by the stand initiating wildfire. Among 40 to 59-yr-old stands the majority of the snag distribution lagged behind the live tree distribution, however, there was a small pulse of large residual snags (4–5%) in the larger size categories. Unfortunately, there were only four PSPs within the 20 to 39-yr-old category. None of these PSPs exhibited any large residual trees or snags. This is unlikely to be a representative sample since Lee et al. (1997) found >30% of snags within this age group were derived from predisturbance residual trees and snags. The densities of snags in the 20 to 39-yr-old PSPs were about 45% lower than the previous study, i.e., 18.1 compared to 33.0 snags per ha suggesting that the few 20 to 39-yr-old PSPs may have been selected to avoid residual materials left after wildfire.

As the stand ages to 60 to 79 yrs residual snags have fallen and self-thinning becomes the dominant source of mortality. Beyond 80 yrs, self-thinning processes give way to a loss of larger canopy trees and the size distributions of trees and snags begin to cover the same range of sizes. The relative flatness of the tree and snag curves suggests that the size distribution of snags may remain relatively constant at older stand ages.

The overall falldown rates found in this study were higher than those found in other forest types. The values reported in this study ranged from 9–21% per annum. Keen (1955) reported annual rates of falldown to be 3.0% over 30 yrs among beetle-killed Ponderosa pine in northern California. Similarly, Dahms (1949) found an overall 2.6% falldown rate in fire-killed *P. ponderosa* in Oregon. Lyon (1977) found an attrition rate of 4.6% per yr over eight yrs within fire-killed *P. contorta*. Bull (1983) found annual rates between 2–4.5% among *P. ponderosa* and 7.8% among *P. contorta* in Oregon.

This study indicated that falldown rates were not related to snag DBH. This seems counter-intuitive

since the size of trees is often related to their longevity (Wood, 1995). In Oregon, both Keen (1955) and Bull (1983) found larger DBH *P. ponderosa* snags (> 49 cm DBH) and lower falldown rates than smaller snags. A number of possibilities exist for the lack of a similar finding in this study. The size range of DBHs were much narrower in this study, hence, a size effect may not have been detectable. Fire return intervals for the western boreal forest is relatively short usually less than 200 yrs (Murphy, 1987), hence, trees and snags > 49 cm DBH were relatively rare. Characteristic velocities and gust patterns of catastrophic winds and other stand effects that affect snag falldown may play a larger role than DBH at smaller sizes. Also, the PSPs were dominated by deciduous species. All these species predominantly regenerate from a large rootstock. The relative firmness of the attachment to the ground may have been a greater factor in wind firmness than DBH (Wood, 1995). In these species, wind pressure on the canopy often causes breakage along the bole. In turn, this would relieve the stress on the bole and reduce the chances of further falldown. Lee et al. (1997) found that approximately 40% of all snags within aspen forests had broken boles. Unfortunately, the Alberta PSP data does not indicate whether snags have broken boles or not.

Falldown rates also exhibited a negative sigmoidal shape with time since tree death. That is, snags were relatively stable for the first few yr after recruitment, then there was a period of rapid decline where many snags fall, then a period of relative stability. For *Pop. tremuloides*, *Pop. balsamifera*, and *Pic. glauca* snags the greater falldown rate lasted for 10–15 yrs but decreased after 15 yrs. Keen (1955) noted a similar trend among beetle-killed Ponderosa pine. After 4 yrs there was an increase in falldown rates which lasted up to 14 yrs after which the rate decreased. This general pattern points to an initial ability of snags to resist falldown after which there is greater rate.

The longevity of snags presents an interesting trade-off for cavity dwelling wildlife species. If snag longevity is an important issue for cavity dwelling wildlife, then animals may select snags on the basis of the age/decay. Trees, newly created snags, and oddly enough very old snags had the lowest annual probability of falldown, and hence maybe the most

desirable. However, trees and newly killed snags have the least decay and may not have suitable cavities while old very decayed snags may not have the structural integrity to support wildlife habitation. This leads to the argument that these types will be a limiting resource for cavity species, particularly those with long-term and/or reproductive biologies that require use of single or few cavities. The most common type of snags with cavities are likely to be middle-aged snags because of the higher presence of internal decay but these snags also have the higher falldown rates. These arguments lead to the hypothesis that cavity-dwelling species compete for snags on the basis of snag age/decay. Subsequently, the intensity of the competition and its effects on the reproductive success, social structure, and community mix of cavity dwellers are, at least partially dependent on the age/decay profile of snags.

6. Conclusion

Aspen-dominated forests have a very dynamic flow of snag recruitment and falldown. In part, the dynamic nature is a function of the large initial recruitment of snags after disturbance and the subsequent self-thinning of regenerating trees. The high rate of snag input is balanced by a relatively high rate of snag falldown. It follows that snag management must be done in the context of stand age and the underlying mortality/falldown processes operating within the stand at that time. In this forested ecosystem, it would seem unnecessary to consider practices such as mid-rotational thinning to create snags. Such practices are likely to only to produce snags for a relatively short period time afterwards, i.e., 10–20 yrs. Also, snag densities appear constant after stands reach 40 yrs of age and these are largely produced from the postdisturbance cohort of trees.

It would appear that the critical time for management of snags is at the time of harvest. In comparison to harvest stands, most stands of wildfire origin initially have the same density of snags as the prefire stand had trees and snags (unpublished data). Wildfires in aspen stands are generally not consumptive (Brown and Simmerman, 1986). It would be impossible to harvest in a similar manner to produce densities of snags similar to wildfire stands. How-

ever, the high density of immediately postfire snags (600–1200 snags per ha) declines to 18–33 snag per ha by 20–39 yrs. Through windfirm harvest strategies and selective leaving of an appropriate profile of trees and snags, it may be possible to produce a low but continuous recruitment of large snags during the early development of harvest stands. This would speed the convergence of wildfire and harvest stand development. Currently, data is being collected and analyzed from early successional harvest and wildfire stands and will be applied to this problem.

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