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Assessing Potential Development of Snags - Young Stand Thinning and Diversity Study

Final Report
6/11/99

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INTRODUCTION

Recent changes in forest-management policies in the Pacific Northwest (PNW) have motivated the exploration of new approaches to managing forested stands. Due to the vast extent of younger, managed forests which were initiated with timber-volume production in mind, efforts have been especially directed toward the design and testing of alternative prescriptions for these stands. Of special interest is understanding if and how younger stands (20+ yrs old) originating as managed plantations can be changed to more closely resemble naturally-initiated young stands or how to accelerate the development of attributes typical of older forests (Cascade Center for Ecosystem Management, 1998).

The Young Stand Thinning and Diversity Study (YST&D) was the first study initiated in the PNW region to evaluate alternative thinning regimes of young (ca. 40 yrs old) managed stands. Stand-level treatments in this study include a control (no treatment, ca. 620 TPH), a heavy thin (residual density ca. 123 TPH), a light thin (residual density ca. 296 TPH), and a light thin with gaps (residual density ca. 237 TPH) with 20% of a stand area in 0.2-ha gaps (i.e., areas with total removal of trees). Four sets of the four experimental treatments are located throughout the Willamette National Forest (Blue River, McKenzie, and Oakridge Ranger Districts). Specific objectives of the YST&D study are to determine relationships between varying residual densities and developmental rates of late-successional attributes, such as vertical diversity and tree-species diversity, and the influence of these attributes on abundance of other plants and of animal species (e.g., Bohac et al., in review; Hagar, 1996,98; Garman, 1998; Piltz et al., 1998).

Development of dead standing trees (snags) is of special interest in the YST&D effort for several reasons. Snags are an essential habitat feature for primary and secondary cavity-nesting bird species, many of which exhibit a positive numerical response to snag density (Schreiber and deCalesta, 1992; McComb et al., 1993). Also, branch and bole breakage during the early part of snag decay can contribute substantial amounts of woody debris to the forest floor, which is an essential habitat component for many ground-dwelling animal species and some plant species. Because current young managed stands originated from clearcut harvesting, they noticeably lack large live residual stems and have few, if any, large snags (Ohmann et al., 1994). Short-term deficiencies in snag densities are anticipated and can be ameliorated through artificial creation of snags (i.e., killing of live stems). However, before implementing a costly active snag-management program it is important to first understand snag recruitment due to natural and other processes. Snags will develop as stands pass through the stem-exclusion phase (Oliver and Larsen, 1990). Density-independent mortality stemming from small-scale natural disturbances such as windthrow and disease will have an important role in the development of snags throughout all stands. Also, trees extensively damaged during logging may serve as an important source of snags as they succumb to infections and decay prompted by damaged-related stresses. Estimating how each of these factors will influence temporal trends in density and size of snags in relation to the different thinning treatments is thus essential in determining both the need and extent of an active snag-management program.

Objectives of this study were to: 1) document current snag densities across all four experimental treatments, 2) assess future potential snag dynamics based on existing tree damage and stocking levels of stands, and 3) provide recommendations for an active snag-management program. The first objective was addressed through field sampling of snags and damaged trees. Computer simulation modeling of tree and snag dynamics was used to assess potential snag development. Management recommendations were based on findings from the first two objectives and from related studies.

METHODS

Field Study

Snags and damaged trees (i.e., boles with noticeable wounds or scars) were sampled in each of the 16 stands in November 1999. To facilitate spatial referencing of stems, sampling occurred along the transects used in the ground-dwelling vertebrate portion of the YST&D study (Garman, 1998). Transects in each stand were located in order to establish 100 trapping stations with an inter-station and inter-transect distance of 30 m. Also transects had to be >50-m from a stand edge. Thus, the number of transects and length of each varied with the shape and size of a stand. In general, however, stands contained >4 transects and >10 stations per transect, and transects collectively spanned the full extent of a stand. Snags and damaged trees were sampled within a 4-m wide belt transect centered on the vertebrate-sampling transects. On average, the belt transect sampled ca. 7% of the area of a stand. Recorded information for each snag or damaged tree encountered included location (i.e., transect number and the number of the two adjacent trap stations on the transect - transect and trap station numbers are noted on wire flags at each trap station), diameter at breast height (dbh) to within 10 cm, and life-form (conifer, hardwood). Only snags ≥3-m tall were recorded. Snag height was recorded as 3-6, 6-10, or >10-m tall. Decay class was estimated using standard criteria (i.e., Cline et al. 1980). Wildlife use of snags was noted by recording numbers of nesting cavities and foraging excavations along the full extent of the bole. Live trees with wounds or scars originating from any type of physical disturbance or with broken tops were classified as damaged. Canopy status (intermediate, suppressed, co-dominate, dominate) and life-form (i.e, conifer, hardwood) of damaged trees were recorded in addition to the status of the top (i.e., broken or intact), number of scars, and size of scars in terms of approximate percent circumference and depth. Only scars greater than ca. 440cm^2 in size were recorded. Vigor of a damaged bole was qualitatively estimated on the basis of foliage and branch characteristics, and the status of the top. Trees with noticeable loss or discoloration of foliage or with >10% of the top broken were assigned low vigor. Trees with noticeable loss of branches and with <10% of the top broken but without loss or discoloration of foliage were assigned medium vigor. Otherwise, vigor was recorded as high. Assessing foliage characteristics of hardwood species was problematic given the time of year of sampling. For these species, branch and top condition were the primary features used to assess vigor. Based on preliminary assessments of vigor categories, it became apparent that the ability to distinguish between medium and high vigor classes was highly variable among field technicians, due to the subjectivity in assessing degree of branch loss. Thus, vigor categories effectively were reduced to low and other (i.e., medium + high).

Simulation Modeling

The ZELIG.PNW (ver. 3.0) gap model was used to estimate future potential snag production. Descriptions of model logic, empirically-based enhancements for the PNW region, and model corroboration can be found in Hansen et al. (1995), Urban (1993), Urban et al. (1993), Garman et al. (1992, 1999). In short, ZELIG simulates the annual establishment, diameter growth, and mortality (ambient and stress-related) of individual stems on a small model plot (0.04 ha) corresponding in size to the zone of influence of a canopy-dominant stem. Dynamics are based on species' maximum potential rates of demographic processes (i.e., growth, mortality, regeneration), which are subsequently reduced as current light conditions (due to shading), soil moisture, ambient temperature, and soil fertility deviate from optimum levels. Unlike typical growth and yield models, the gap model considers two forms of stem mortality, both of which are implemented as stochastic processes. Stress-related mortality results from resource limitations (i.e., shading, drought). Stems with a limited growth rate (i.e., dbh increment) for 3 consecutive years have an increased probability of mortality. Ambient mortality is independent of tree density and resource conditions, and accounts for tree death resulting from small-scale disturbances, such as windthrow and disease. However, ambient mortality processes are not modeled in an explicit manner; e.g., windfirmness of stems and disease susceptibility are not evaluated in determining mortality potential of a stem. Instead, ambient mortality is based on the maximum physiological longevity of a species. Thus, all stems of a species, regardless of size and growth potential, have an equal probability of dying each annual time step. Ambient mortality rates currently used in the model correspond to median values of older Douglas-fir stands (Acker pers. comm.). Coarse woody debris (CWD - i.e., snags and logs) dynamics are also a unique feature of the PNW version of the model, and were based on field observations by Graham (1982). When a tree dies, it converts immediately to either a log (based on a probability of falling) or a snag which later can break and create log pieces. Over time, each CWD piece is advanced through the standard decay classes (Cline et al., 1980) using a probability function based on maximum residence time (which varies by orientation, decay resistance, and stem size) and actual residence time in a decay class. The mass, dbh or large end diameter, height or length, and decay class are tracked for each CWD piece. Spatial pattern of a forested stand is simulated using a grid of interacting model plots, where the stature of trees on neighboring plots is considered in calculating light levels on each model plot. Yearly weather conditions affecting live-tree dynamics are generated within the model using observed, long-term monthly values of precipitation, temperature, and solar radiation for a site. Because weather, certain demographic processes, and CWD dynamics are simulated as stochastic process, replicates of simulations are used to derive average trajectory of forest dynamics.

To evaluate general trends in snag production, initial stand conditions of simulations were based on average post-treatment conditions of each of the thinning treatments, and averaged conditions of control stands (Table 1). Underplanting (740 stems/ha - 70% Psme, 30% Tshe) by year 3 of a simulation and pre-commercial thinning of the planted stems (thinning from below to 494

Table 1. Initial stand conditions used in the simulation analyses of potential snag production.

Treatment	Basal Area (m2/ha)	Density (no./ha)	Mean dbh (cm) & SD	Leaf area index
Control	40.0	635	27.5 (8.39)	6.886
Heavy thin	14.0	192	27.2 (16.08)	2.058
Light thin	25.8	302	28.8 (14.80)	3.338
Light thin with gaps	16.8	219	29.1 (15.07)	2.287

stems/ha) 12 yrs later were implemented in the heavy thin and light thin with gaps stands. Environmental information used in all simulations typified the 600-800 m elevational zone of the west-central Oregon Cascade Range. A stand size of 9 ha (i.e., 15 x 15 model plots) and five replications were used in all simulations. In the light thin with gap simulations, seven 0.24-ha gaps (3 x 3 model plots with all trees removed) were evenly distributed throughout a stand. Three simulation scenarios were performed for each stand treatment:

1) To estimate of minimal natural snag recruitment, simulations were performed with ambient mortality turned off (i.e., stem exclusion exclusive process of snag recruitment);

2) Simulations were performed using the existing logic for ambient mortality (i.e., random selection of trees that die due to 'natural' causes). These simulations illustrated the potential importance of small, scale natural disturbances in the production of snags;

3) The third set of simulations was an extension of the second scenario but included snag creation to examine short- and long-term implications. For all stands, two of the largest live boles were converted to snags at stand age 45 and 50 (each stand was assumed to be 40-yrs old at the initiation of a simulation).

In all simulations, temporal trends in density of snags >5-m tall were recorded by three size classes: 20-50cm dbh, >50-70cm dbh, >70 cm dbh.

Analyses

Snag and damaged tree densities, and wildlife-use of snags were averaged by treatment and compared. Measures for individual stands are additionally presented in appendices for reference. A fixed-effects ANOVA was used to compare treatment means. The Least Significant Difference (LSD) method was used for all pairwise comparisons of means. Temporal trends of simulation results were graphed for comparisons.

RESULTS

Snags

Two trends in snag densities were evident across all treatments. Stands had few soft snags (<2.55/ha) and few snags >50-cm dbh (<1.61/ha) (Table 2), reflecting both the age of the stands and previous management practices. The majority of recorded snags for each treatment type was relatively small (10-20cm), recent (i.e., decay classes 1 & 2), and >6-m tall. Combining across decay and height classes, mean densities of small snags (Figure 1A) and of snags >20-cm dbh (Figure 1B) reflected thinning intensity. For both size classes of snags, control plots had the highest mean density of snags followed by the light thin, light thin with gaps, and heavy thin treatments. For snags 10-20cm dbh, mean density of the heavy thin treatment was statistically different ($P < 0.05$) from mean density of the control and of the light thin treatments. Also, mean density was statistically different ($P < 0.05$) between the control and light thin with gaps treatments. For snags >20-cm dbh, means were not significantly different ($P > 0.05$) among treatments due to the high degree of among-stand variability.

Wildlife use of snags varied with decay class (Table 3). Although soft snags were limited, almost all soft snags had nesting cavities or evidence of foraging excavations. All larger (>50-cm dbh) soft snags had evidence of wildlife use. Across treatments, the mean percentage of soft snags 10-50cm dbh with evidence of wildlife use ranged from 58-100%. The percentage of hard snags with cavities and excavations varied from 12 to 24% among treatments excluding the heavy thin. The 67% use rate in the heavy thin treatment was relatively high compared to other treatments, but this reflected the relatively low mean density of snags of the intensively thinned stands (mean of 2.09/ha for the heavy thin compared to >11/ha for the other treatments). There were no clear trends in wildlife use among height classes of hard snags. Also, there were no significant differences ($P > 0.05$) among treatments in mean percentage of snags with evidence of wildlife use based on all snags 10-20cm and all snags >20cm dbh (Figure 2A,B). However, on average, mean percentage of snags with evidence of wildlife use was higher for >20-cm dbh snags compared to smaller snags.

Tree Damage

Damage levels recorded in this study were lower compared to those reported by Han and Kellogg (1997), who employed a more intensive survey method of logging damage in the thinned stands. Mean damage levels (%) in this study, which includes both scars and broken tops (ca. <0.5% damage level), were 4.2% for the heavy thin treatment, 1.8% for the light thin treatment, and 6.2% for the light thin with gaps treatment. Han and Kellogg reported mean damage levels based on scar sizes >465cm^2 and >929cm^2 of 5.3-2.1%, 5.2-3.2%, and 7.6-5.4%, for the heavy thin, light thin, and light thin with gaps treatments, respectively. For all except the light thin treatment, mean damage levels of this study fell within the previously reported ranges for medium and large scar sizes (after adjusting for broken tops). Given the rapid assessment method of this study, it is most likely that a significant portion of smaller scars were overlooked.

Table 2. Mean (se) snag density (no./ha) for each stand treatment, by height and dbh class, and by decay group. Averages based on four replications. (See Appendix A for snag density measures of individual stands).

		Hard snags (decay classes 1 & 2) by dbh classes				Soft snags (decay classes 3-5) by dbh classes				
Treatment	Height class	10-20cm	>20-50cm	>50cm	Total	10-20cm	>20-50cm	>50cm	Total	Total
Control										
	3-6m	**3.37**	**1.96**	**0.00**	**5.33**	**0.85**	**0.00**	**0.42**	**1.27**	**6.50**
		(1.05)	(1.84)	(-)	(1.97)	(0.57)	(-)	(0.48)	(0.92)	(1.85)
	>6-10m	**8.13**	**0.83**	**0.00**	**8.96**	**0.00**	**0.00**	**0.00**	**0.00**	**8.96**
		(2.97)	(0.96)	(-)	(2.90)	(-)	(-)	(-)	(-)	(1.90)
	>10m	**14.75**	**7.36**	**0.00**	**22.11**	**1.28**	**0.00**	**0.00**	**1.28**	**23.39**
		(3.19)	(4.23)	(-)	(2.56)	(0.96)	(-)	(-)	(0.96)	(6.89)
	Total	**26.25**	**10.15**	**0.00**	**36.40**	**2.13**	**0.00**	**0.42**	**2.55**	**38.95**
		(5.22)	(6.43)	(-)	(5.21)	(1.49)	(-)	(0.48)	(1.70)	(58.34)
Heavy thin	3-6m	**0.00**	**0.87**	**0.00**	**0.87**	**0.00**	**0.00**	**0.37**	**0.37**	**1.24**
		(-)	(1.00)	(-)	(1.00)	(-)	(-)	(0.43)	(0.43)	(0.95)
	>6-10m	**0.61**	**0.00**	**0.00**	**0.61**	**0.00**	**0.00**	**0.00**	**0.00**	**0.61**
		(0.71)	(-)	(-)	(0.71)	(-)	(-)	(-)	(-)	(0.71)
	>10m	**0.31**	**0.31**	**0.00**	**0.61**	**0.00**	**0.00**	**0.00**	**0.00**	**0.61**
		(0.36)	(0.36)	(-)	(0.71)	(-)	(-)	(-)	(-)	(0.71)
	Total	**0.92**	**1.17**	**0.00**	**2.09**	**0.00**	**0.00**	**0.37**	**0.37**	**2.47**
		(1.06)	(0.94)	(-)	(1.44)	(-)	(-)	(0.43)	(0.43)	(1.25)
Light thin	3-6m	**3.43**	**0.00**	**0.00**	**3.43**	**0.00**	**0.41**	**0.00**	**0.41**	**3.84**
		(1.43)	(-)	(-)	(1.43)	(-)	(0.47)	(-)	(0.47)	(1.49)
	>6-10m	**2.28**	**0.31**	**0.00**	**2.59**	**0.00**	**0.00**	**0.82**	**0.82**	**3.41**
		(1.26)	(0.36)	(-)	(1.04)	(-)	(-)	(0.94)	(0.94)	(1.13)
	>10m	**9.86**	**3.41**	**0.31**	**13.57**	**0.00**	**0.00**	**0.00**	**0.00**	**13.57**
		(6.68)	(1.55)	(0.36)	(7.87)	(-)	(-)	(-)	(-)	(7.87)
	Total	**15.57**	**3.72**	**0.31**	**19.59**	**0.00**	**0.41**	**0.82**	**1.23**	**20.82**
		(6.52)	(1.61)	(0.36)	(7.06)	(-)	(0.47)	(0.94)	(1.41)	(8.35)

Table 2. Cont'd

Treatment	Height class	Hard snags (decay classes 1 & 2) by dbh classes				Soft snags (decay classes 3-5) by dbh classes				
		10-20cm	>20-50cm	>50cm	Total	10-20cm	>20-50cm	>50cm	Total	Total
Light thin w/gaps	3-6m	**1.97**	**0.00**	**0.00**	**1.97**	**0.00**	**0.00**	**1.19**	**1.19**	**3.16**
		(0.87)	(-)	(-)	(0.87)	(-)	(-)	(0.87)	(0.87)	(1.48)
	>6-10m	**2.82**	**0.00**	**0.00**	**2.82**	**0.00**	**0.00**	**0.00**	**0.00**	**2.82**
		(0.47)	(-)	(-)	(0.47)	(-)	(-)	(-)	(-)	(0.47)
	>10m	**5.89**	**0.39**	**0.00**	**6.29**	**0.00**	**0.39**	**0.43**	**0.82**	**7.11**
		(4.08)	(0.45)	(-)	(4.26)	(-)	(0.45)	(0.49)	(0.55)	(4.21)
	Total	**10.69**	**0.39**	**0.00**	**11.09**	**0.00**	**0.39**	**1.61**	**2.00**	**13.09**
		(5.05)	(0.45)	(-)	(5.24)	(-)	(0.45)	(0.74)	(0.44)	(5.54)

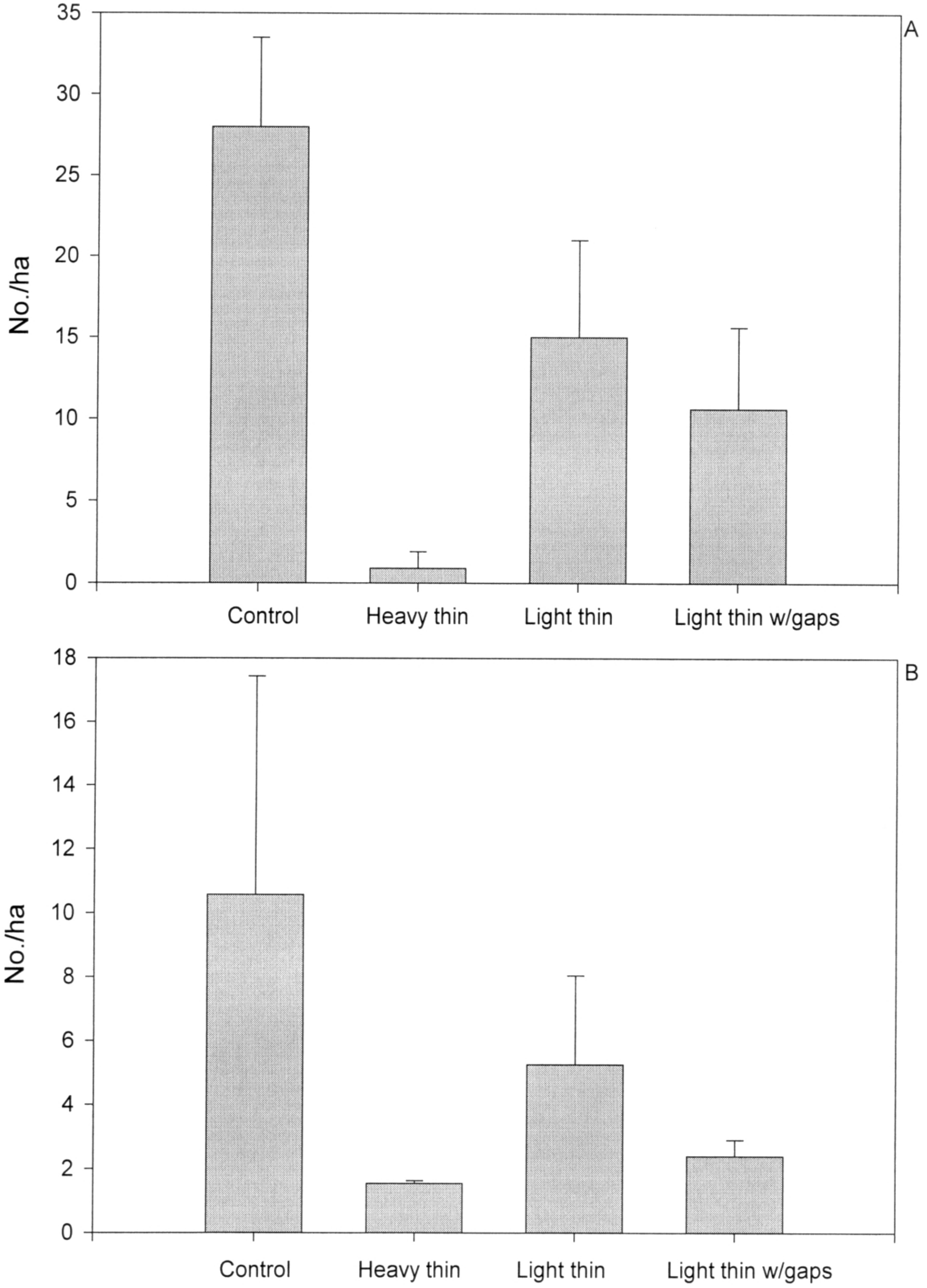

Figure 1. Mean density of snags $\geq$3-m tall by treatment. A - snags 10-20cm dbh (all decay classes); B - snags >20-cm dbh (all decay classes). Error bar = 1 se.

Table 3. Mean (se) percentage of snags with evidence of wildlife use, by height, dbh, and decay class. Averages based on four replications. "-" indicates no recorded snags. "(-)" indicates standard error could not be calculated. (See Appendix B for percentage values by individual stands).

		Percentage of hard snags (decay classes 1 & 2) by dbh class				Percentage of soft snags (decay classes 3-5) by dbh class				
Treatment	Height class	10-20cm	>20-50cm	>50cm	Total	10-20cm	>20-50cm	>50cm	Total	Total
Control	3-6m	**30.00**	**50.00**	-	**33.33**	**50.00**	-	**100.00**	**75.00**	**42.75**
		(27.49)	(70.71)	-	(27.22)	(70.71)	-	(0.00)	(35.36)	(23.40)
	>6-10m	**21.87**	**0.00**	-	**21.87**	-	-	-	-	**21.87**
		(14.88)	(-)	-	(14.88)	-	-	-	-	(14.88)
	>10m	**20.09**	**52.38**	-	**25.76**	**25.00**	-	-	**25.00**	**25.94**
		(7.65)	(35.48)	-	(10.41)	(35.36)	-	-	(35.36)	(10.55)
	Total	**20.32**	**43.77**	-	**24.64**	**53.66**	-	**100.00**	**58.50**	**26.35**
		(7.67)	(12.29)	-	(9.12)	(8.67)	-	(0.00)	(5.44)	(9.45)
Heavy thin	3-6m	-	**0.00**	-	**0.00**	-	-	**100.00**	**100.00**	**50.00**
		-	(-)	-	(-)	-	-	(0.00)	(0.00)	(70.71)
	>6-10m	**100.00**	-	-	**100.00**	-	-	-	-	**100.00**
		(0.00)	-	-	(0.00)	-	-	-	-	(0.00)
	>10m	**100.00**	**0.00**	-	**50.00**	-	-	-	-	**50.00**
		(0.00)	(-)	-	(0.00)	-	-	-	-	(0.00)
	Total	**100.00**	**0.00**	-	**67.23**	-	-	**100.00**	**100.00**	**72.25**
		(0.00)	(-)	-	(8.98)	-	-	(0.00)	(0.00)	(7.82)
Light thin	3-6m	**18.75**	-	-	**18.75**	-	**100.00**	-	**100.00**	**22.92**
		(13.82)	-	-	(13.82)	-	(0.00)	-	(0.00)	(18.16)
	>6-10m	**38.89**	**0.00**	-	**29.17**	-	-	**100.00**	**100.00**	**45.83**
		(24.53)	(-)	-	(19.84)	-	-	(0.00)	(0.00)	(18.22)
	>10m	**2.78**	**19.44**	**0.00**	**10.64**	-	-	-	-	**10.64**
		(3.40)	(12.27)	(-)	(5.75)	-	-	-	-	(5.75)
	Total	**12.66**	**13.01**	**0.00**	**12.72**	-	**100.00**	**100.00**	**100.00**	**17.12**
		(1.84)	(5.07)	(-)	(1.77)	-	(0.00)	(0.00)	(0.00)	(2.76)

Table 3. Cont'd

Treatment	Height class	Percentage of hard snags (decay classes 1 & 2) by dbh classes				Percentage of soft snags (decay classes 3-5) by dbh classes				
		10-20cm	>20-50cm	>50cm	Total	10-20cm	>20-50cm	>50cm	Total	Total
Light thin w/gaps	3-6m	**50.00**	-	-	**50.00**	-	-	**100.00**	**100.00**	**66.67**
		(35.36)	-	-	(35.36)	-	-	(0.00)	(0.00)	(20.41)
	>6-10m	**0.00**	-	-	**0.00**	-	-	-	-	**0.00**
		(-)	-	-	(-)	-	-	-	-	(-)
	>10m	**5.56**	**100.00**	-	**12.70**	-	**0.00**	**100.00**	**50.00**	**41.20**
		(7.86)	(0.00)	-	(2.24)	-	(-)	(0.00)	(70.71)	(36.01)
	Total	**16.41**	**100.00**	-	**18.08**	-	**0.00**	**100.00**	**88.97**	**25.05**
		(2.7)	(0.00)	-	(3.61)	-	(-)	(0.00)	(7.44)	(3.34)

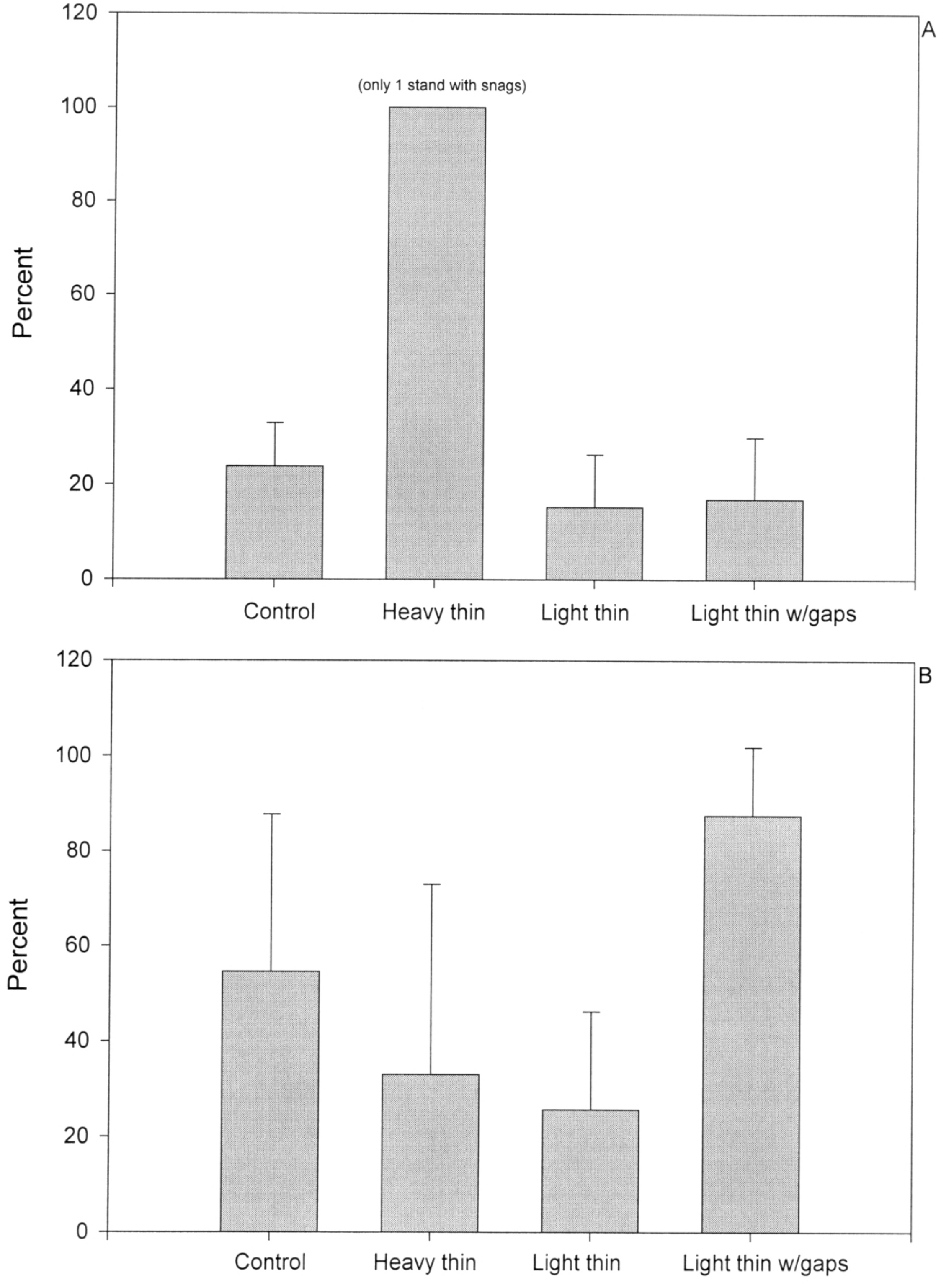

Figure 2. Mean percentage of snags $\geq$3-m tall with evidence of wildlife use by treatment. A - snags 10-20cm dbh (all decay classes); B - snags >20-cm dbh (all decay classes). Error bar = 1se.

But, given the likelihood that small scars have a low potential to lead to decay and death of a bole, bias in estimates of near-term snag development of damaged trees should be nominal. However, tree-damage results should be viewed with some caution.

The majority of damaged trees had little indication of reduced growth potential, at least based on our assessment method (Table 4). Mean number of damaged trees of low vigor were limited, with the light-thin with gaps treatment having the highest incidence (<1.57/ha). Just considering the thinned stands, <15% of damaged stems were scored as low vigor and >75% of these stems were small (10-20cm dbh). Small (10-20cm dbh) damaged stems of medium/high vigor only accounted for 18-30% of the total stems of this vigor class. The majority of damaged stems were scored as medium/high vigor, were >20-50cm dbh, and were in the upper portion of the canopy (codominat and dominant). However, mean densities of this majority across thinning treatments ranged from 3.58 to 8.34/ha. Stems >50-cm dbh only comprised 5.3-9.3% (0.28-1.20/ha) of total damaged-stem densities across thinning treatments. Combining across canopy and size classes, mean density of damaged stems of medium/high vigor clearly corresponded to intensity of thinning (Figure 3A), although means were not significantly different ($P < 0.05$) among thinning treatments. Damage levels for the untreated control stands provided a 'background' measure of naturally occurring scars and wounds. Compared to the control, mean density of damaged trees of thinning treatments was 5-13 times greater. Trends among thinning treatments in densities of just larger stems (>20-cm dbh) were similar (Figure 3B).

Simulation of Snag Development

In the absence of ambient mortality, densities of snags >20-50cm dbh increased over time in relation to the initial density of the stand (Figure 4A). Crowding on the simulated control stand resulted in a substantial increase in density of smaller snags (20-50cm dbh) over the next 40 yrs. Snags of this size began to develop in the light thin stand at age 60 but never exceeded 12 stems/ha over the course of the 120 yr simulation. Snags in the more intensively thinned stands did not begin to appear until stand age 90-100, then increased considerably due to stem exclusion in the cohort which developed under the relatively open canopies. Residual snags >50-cm dbh of the initial stands only last for 40-50 yrs (Figure 4B). Limited development of snags of this size across all stands reflected low levels of resource competition among overstory stems (Figure 4B-C). Due to extensive stem exclusion early on in the control stand, stems surviving to 50+cm were sufficiently spaced to limit competition (i.e., shading effects) among stems. Densities of large snags in the thinned stands corresponded to initial residual density and growth rates. More large snags occurred in the simulated light thin stand due to higher initial stem densities; large snags developed later in the heavy thin and light thin with gaps stands. After stand age 130, the density of large snags was only slightly higher in the heavy thin stand compared to the gap treatment, reflecting in part faster development of stems.

Simulations with ambient mortality illustrated the importance of small scale disturbances in the development of snags. Trends in densities of small snags (20-50cm dbh) among treatments were similar to those when ambient mortality was turned off (compare Figure 4A, D). However, for similar treatments, densities increased faster, and generally peaked sooner and were lower at the

Table 4. Mean (se) density (no./ha) of live, damaged stems by vigor, dbh, and canopy class. Canopy class codes: S - suppressed, I - intermediate, C/D - codominant & dominant. Averages based on four replications. (See Appendix C for damaged-tree data by individual stands).

		Low vigor by dbh class				Medium-high vigor by dbh class				
Treatment	Canopy class	10-20cm	>20-50cm	>50cm	Total	10-20cm	>20-50cm	>50cm	Total	Total
Control	S	**0.44**	**0.00**	**0.00**	**0.44**	**0.42**	**0.00**	**0.00**	**0.42**	**0.86**
		(0.50)	(-)	(-)	(0.50)	(0.48)	(-)	(-)	(0.48)	(1.00)
	I	**0.44**	**0.00**	**0.00**	**0.44**	**0.42**	**0.00**	**0.00**	**0.42**	**0.86**
		(0.50)	(-)	(-)	(0.50)	(0.48)	(-)	(-)	(0.48)	(0.57)
	C/D	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
		(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
	Total	**0.88**	**0.00**	**0.00**	**0.88**	**0.85**	**0.00**	**0.00**	**0.85**	**1.72**
		(1.00)	(-)	(-)	(1.00)	(0.56)	(-)	(-)	(0.56)	(1.41)
Heavy thin	S	**0.00**	**0.00**	**0.00**	**0.00**	**0.37**	**0.00**	**0.00**	**0.37**	**0.37**
		(-)	(-)	(-)	(-)	(0.42)	(-)	(-)	(0.42)	(0.48)
	I	**0.00**	**0.00**	**0.00**	**0.00**	**1.17**	**0.30**	**0.00**	**1.47**	**1.48**
		(-)	(-)	(-)	(-)	(0.84)	(0.31)	(-)	(0.71)	(0.71)
	C/D	**0.00**	**0.00**	**0.00**	**0.00**	**0.37**	**5.05**	**0.75**	**6.17**	**6.16**
		(-)	(-)	(-)	(-)	(0.42)	(1.17)	(0.86)	(2.33)	(2.33)
	Total	**0.00**	**0.00**	**0.00**	**0.00**	**1.92**	**5.35**	**0.75**	**8.02**	**8.02**
		(-)	(-)	(-)	(-)	(1.62)	(0.89)	(0.86)	(3.30)	(3.30)
Light thin	S	**0.00**	**0.00**	**0.00**	**0.00**	**0.28**	**0.00**	**0.00**	**0.28**	**2.85**
		(-)	(-)	(-)	(-)	(0.32)	(0.50)	(-)	(0.32)	(0.33)
	I	**0.00**	**0.00**	**0.00**	**0.00**	**0.43**	**0.00**	**0.00**	**0.43**	**0.43**
		(-)	(-)	(-)	(-)	(0.50)	(-)	(-)	(0.50)	(0.50)
	C/D	**0.69**	**0.00**	**0.00**	**0.69**	**0.28**	**3.30**	**0.28**	**3.86**	**4.57**
		(0.47)	(-)	(-)	(0.47)	(0.32)	(2.60)	(0.33)	(2.76)	(2.62)
	Total	**0.69**	**0.00**	**0.00**	**0.69**	**1.00**	**3.30**	**0.28**	**4.58**	**5.29**
		(0.47)	(-)	(-)	(0.47)	(0.68)	(2.66)	(0.33)	(1.57)	(2.44)

Table 4. Cont'd

		Low vigor by dbh class				Medium-high vigor by dbh class				
Treatment	Canopy class	10-20cm	>20-50cm	>50cm	Total	10-20cm	>20-50cm	>50cm	Total	Total
Light thin with gaps	S	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
		(-)	(-)	(-)	(-)	(-)	(-)	(-)	(0.98)	(-)
	I	**0.00**	**0.00**	**0.00**	**0.00**	**0.42**	**0.00**	**0.00**	**0.42**	**0.42**
		(-)	(-)	(-)	(-)	(0.49)	(-)	(-)	(0.49)	(0.49)
	C/D	**1.18**	**0.39**	**0.00**	**1.57**	**3.65**	**7.14**	**1.20**	**11.99**	**13.17**
		(0.45)	(0.45)	(-)	(0.74)	(0.94)	(4.90)	(0.89)	(4.84)	(5.40)
	Total	**1.18**	**0.39**	**0.00**	**1.57**	**4.08**	**7.14**	**1.20**	**12.42**	**13.59**
		(0.45)	(0.45)	(-)	(0.74)	(1.29)	(4.93)	(0.89)	(4.70)	(7.35)

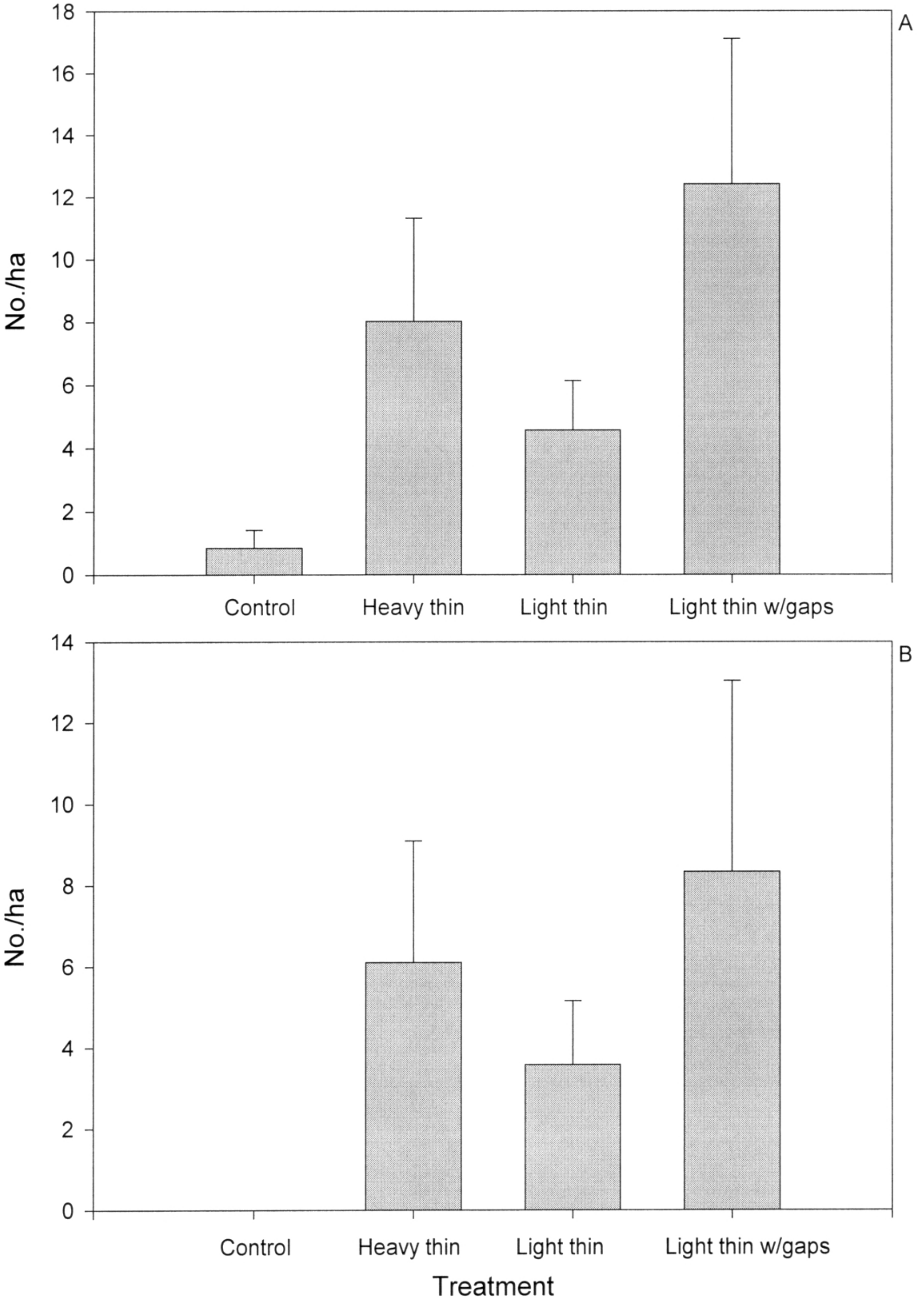

Figure 3. Mean density of live, damaged stems of medium-high vigor by treatment (all canopy classes combined). A - ≥10cm dbh; B - >20cm dbh. Error bar =1se.

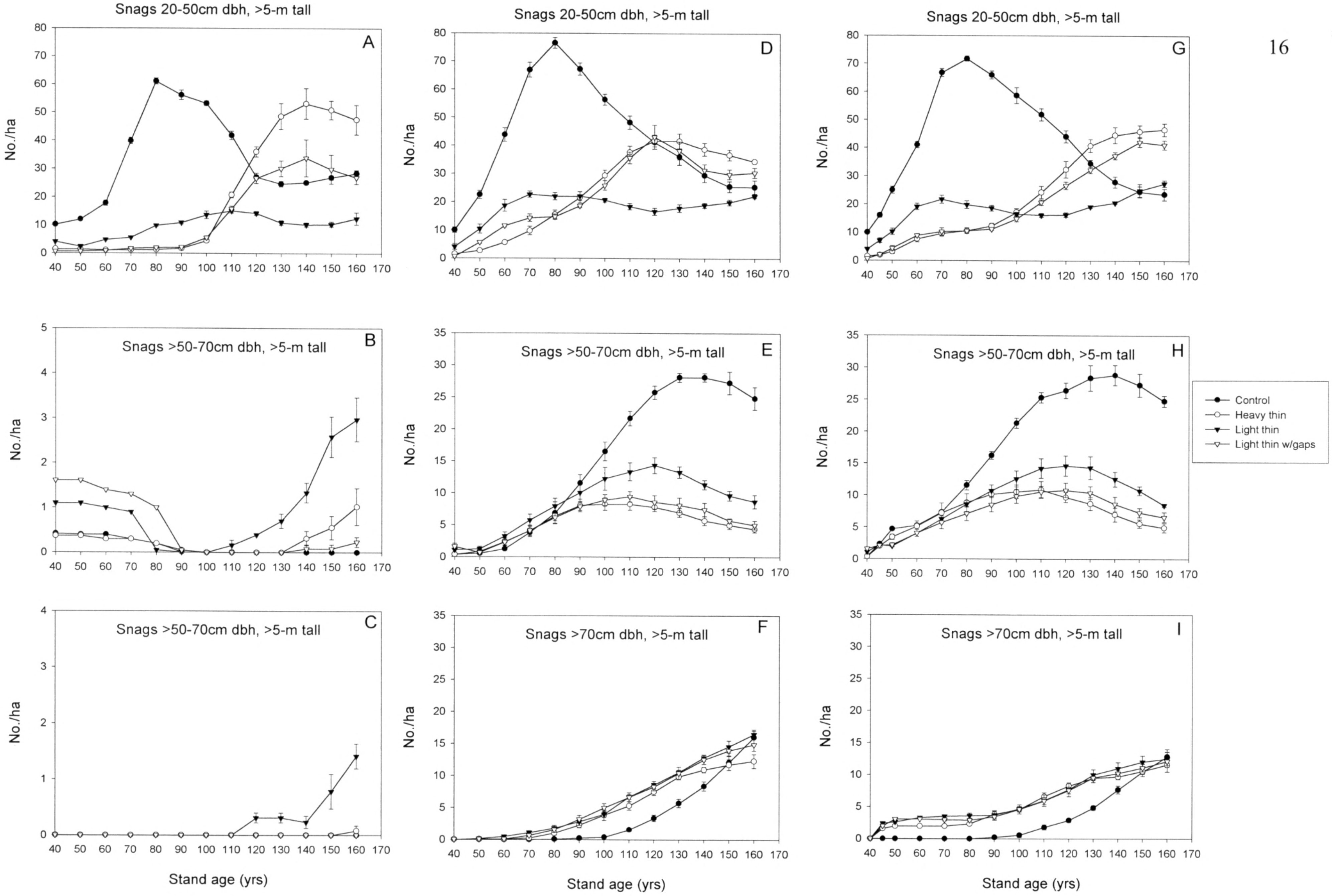

Figure 4. Simulated mean (se) densities of snags >5-m tall, by size class. A-C - without ambient mortality; D-F - with ambient mortality; G-I - with ambient mortality and artificial creation of 2 snags/ha at stand ages 45 and 50.

end of the simulation with ambient mortality compared to when this source of mortality was not invoked. Even with ambient mortality, simulated snag densities of the heavy thin and light thin with gaps treatments were less than 10/ha until stand age 60-70.

Development of large snags noticeably differed among the mortality scenarios. With ambient mortality, it took about 15-20 yrs before the recruitment of snags >50-70cm dbh in all stands (Figure 4E). Developmental trends of snags of this size class from stand age 40 to 80 reflected interactions between residual density and growth rates. Snag development was slowest in the control plot due to slower growth rates and thus development of large stems (Figure 5A-B). The initial density of the light thin stand resulted in faster growth rates compared to the control stand, and provided a greater source of snags compared to the other thinned stands. The density of stems >50-cm dbh on the control plot rapidly increased between stand age 60-80 (Figure 5A). After stand age 90, snag recruitment exceeded that of any other stand (Figure 4E). It took 30 years for larger snags (>70-cm dbh) to begin to develop on the thinned plots and 60 yrs for snags of this size to appear in the control stand (Figure 4F). Over time, the density of larger snags was similar among thinning treatments, but there was a slight positive correlation between residual density and snag recruitment.

Artificial creation of snags influenced both predicted short and long term snag densities. In the thinned stands, snags at stand age 45 were created from live stems >50-70 cm (Figure 4H) and at stand age 50 either from stems >50-70 or stems >70cm dbh (Figure 4I). All four snags on the control plot were derived from stems >50-70cm (Figure 4H). Across all stands, snag creation increased the density of large snags (>50-cm dbh) up to stand age 90-110 compared to simulations without snag creation (compare Figure 4E,H). However, with the breakage of the artificially created snags by this point in time, future densities of medium-sized snags (>50-70m dbh) were similar between the two mortality scenarios (compare similar treatments in Figure 4E,H). Compared to the no-snag creation scenario, converting four of the largest live stems to snags in the first decade resulted in slightly lower densities of larger snags (>70-cm dbh) after stand age 110-120 in the thinned stands (compare Figure 4 F,I). Also, removing just four live stems/ha reduced stress-related mortality (i.e., due to shading) of understory trees. This essentially decreased the recruitment of snags 20-50cm dbh in the control and light thin stands, and also extended the peak period of stem exclusion for the other two treatments (compare Figure 4 D,G).

DISCUSSION

An effective snag-management plan needs both functional target levels and understanding of natural snag recruitment. Target levels of snag densities for primary and secondary cavity-nesting bird species have been evaluated using both models derived from empirical studies and localized empirical data sets. Target levels are selected that will maintain a specified proportion of maximum population density or of maximum potential population (MPP) of cavity-nesting species. Assessments using the Snag Recruitment Simulator suggest that 4 snags/ha >38cm with

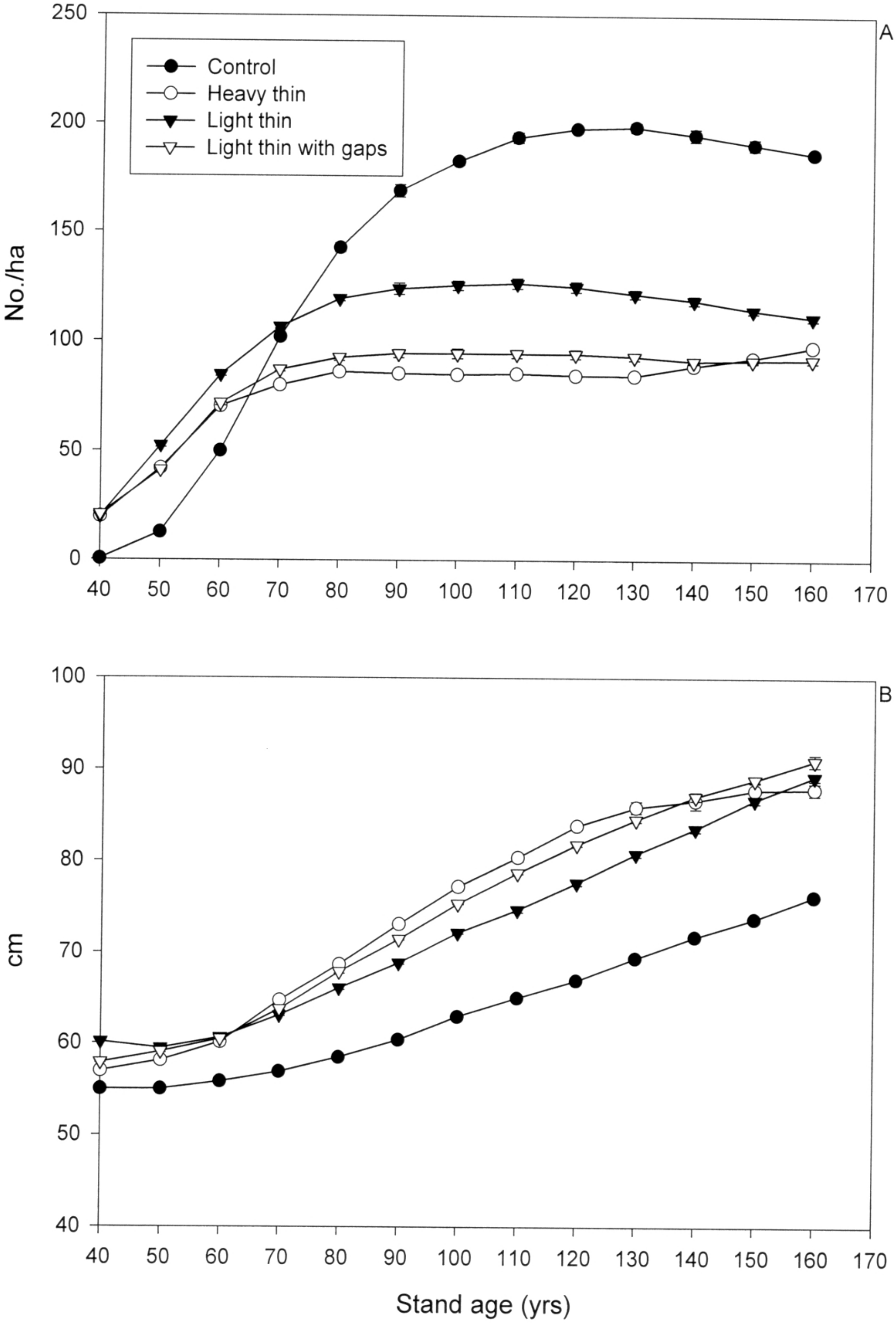

Figure 5. Simulated trends of live stems >50-cm dbh by treatment.
A - mean (se) density of live stems; B - mean (se) dbh of stems.

at least 1 snag/ha >43cm dbh is necessary for 100% of MPP of primary cavity-nesting species in coniferous forests in western Oregon (Ohmann et al. 1994). Recent federal forest-management guidelines suggest that snag densities should be sufficient to support cavity-nesting bird species at 40% of potential population levels (Interagency ROD-S&G Team, 1994). Based on an analysis of snag-bird relationships in clearcuts in the Oregon Cascades, McComb et al. (1993) suggested that 5 and 10 snags/ha >23m, >18-m tall were required to satisfy this target level for primary and secondary cavity-nesting species, respectively. Other recommendations for snag densities include 2 snags/ha >45 cm to satisfy nesting requirements of larger piciforms such as the pileated woodpecker (*Dyrocopus pileatus*). Although it is important to ascertain local snag-density requirements, the collective results of previous analyses suggest a minimum target of 5-10 snags/ha >23cm dbh with most being >38cm and 1-2 >43cm dbh in order to support 40% of potential population levels of cavity-nesting bird species.

The current snag densities in the thinned stands are below these levels. On average, densities of snags >20-cm range from 1.54 to 5.26/ha (Figure 1). Mean density of snags >50-cm dbh was especially low in the thinned stands (<1.61/ha), reflecting the historical practice of removing all standing boles for fiber and for safety concerns.

Recruitment of suitable wildlife snags from logging or naturally damaged stems likely will not be substantial in the near future. On average, few damaged stems (<1.57 stems/ha) in the thinned stands showed evidence of reduced growth potential, and most of these stems were small (10-20cm dbh). Damaged stems may be more susceptible to diseases which over time, may eventually kill these boles. Given extant snag densities and mean densities of damaged stems >20-cm dbh (3.58-8.73/ha), almost all stems would have to die in the very near future to immediately satisfy the 40% potential population level target. A potential short-term benefit of damage trees may result from localized decay. Rapid decay around existing wounds may provide sufficient substrate or nesting and feeding activity even though the bole will may not die for sometime.

Simulation experiments indicated the limits of potential natural snag recruitment. Without small scale disturbances, only snag >20-50cm dbh will develop over the next 60+ yrs and densities will be low. Even in the light thin stand, which was predicted to have the highest snag densities, snag levels will fall short of a 5-10/ha target level over the next 30-60 yrs. These predictions represent minimum potential densities since the YST&D stands will surely be affected by small-scale disturbances such as wildfire, windthrow, and diseases. Predictions with ambient mortality, however, still suggested potential near-term deficiencies in snag densities. Only the light thin treatment was predicted to satisfy the 40% potential population target level within a decade. For the other two thinning treatments, this target level would not be achieved for 2-3 decades. At best, results with ambient mortality represent an upper limit of snag development. As a useful simplification, ambient mortality is typically modeled as an annual rate even though actual natural disturbances and tree mortality occur at irregular intervals. An important implication of this simplification is that models may predict the death of large trees sooner than what would actually occur; thus, snag densities are most likely inflated. Another model simplification is the use of a constant annual mortality rate. Mortality rates change over time (e.g., Harcombe, 1986) and also are variable among stands. For instance, Acker found rates to vary from 0.2-1.0% in older Douglas-fir stands (Acker pers. comm.). In this study, the median mortality rate of 0.4% for Douglas-fir was used. Based on an analytical assessment, stochastic simulation of mortality rates using the distribution of rates reported by Acker likely would result in lower snag densities than just using a constant median value. Despite these limitations, the simulation results presented here at least provide some idea of lower and upper levels of potential, natural snag recruitment.

Both the benefits and costs of artificially creating snags were evident in simulation experiments. Creating just 4/ha resulted in satisfying wildlife-habitat objectives within 15 years in all treatments, but removing overstory stems can decrease recruitment of larger snags and delay development of smaller snags. Depending on the future management strategy of the YST&D stands, potential long-term effects will be insignificant if a rotation harvest is conducted 40-100 years from the present. Actual or anticipated deficiencies in snags densities in the subsequent stands could be ameliorated by creating a few large snags during the rotation harvest.

MANAGEMENT RECOMMENDATIONS

Target levels of snag densities should be commensurate with current regulations and our understanding of snag-wildlife relationships. Based on FEMAT guidelines (Interagency ROD-S&G Team, 1994) and empirical investigations (McComb et al., 1993), a minimum of 5-10 snags/ha >23cm dbh with 1-2 snags >43cm should be considered as a target level for all thinned stands (to achieve 40% maximum potential population levels). The current deficiencies of snags and the predicted deficiencies over the next 10+ years suggest that artificial creation of dead-standing trees will be required in order to meet wildlife-habitat objectives in the immediate future. Snags should be created from the largest possible stems to accommodate the full range of primary and secondary cavity-nesting species. Snags should be created as soon as possible. Depending on the method of snag creation, artificially created snags can provide important nesting habitat for bird species within 5 years (Chambers et al., 1997). The few studies investigating the spatial-arrangement implications of snags suggest that clumped or scattered patterns have no affect on use by cavity-nesting species (Chambers et al., 1997). Given these findings, artificially created snags should be evenly dispersed throughout a stand to decrease the chance of a localized disturbances wiping out clusters of artificially created snags. However, to protect against windthrow, snags should be located in areas protected from the prevailing winds or within 'dense' clumps of standing live stems of equal or greater stature.

Required densities of artificially created snags will vary by stand. Results of this study suggest that on average, more snags will be needed in the heavy thin and light thin with gaps than in the light thin stands. Current snag densities (see Appendix A) and potential levels of natural recruitment first should be evaluated to determine actual deficiencies in each stand. Predicted values of simulations should be reduced by at least 50% to guard against overestimation caused by model-parameter uncertainty (i.e., mortality rates). Thus, predicted maximum potential snag recruitment over the next decade is on average, 5 snags/ha 20-50cm dbh in the light thin stands, and 1.5-2.5 snags/ha of similar size in the heavy thin and light thin with gaps stands, respectively. At most 0.1-0.7 snags/ha >50-70cm could be expected to develop in any of the thinned stands over this time period. As a conservative approach, it should be assumed that trees damaged during logging will not be a significant source of snags in the near term.

Artificial creation of snags can be done with a range of methods (i.e., girdling, herbicide injections, topping, and inoculation of wood-rotting fungi). Short-term trends in snag development may vary among creation methods, but all tend to be effective in starting the development of snags (Newton and Filip, 1999). An important component of snag development in terms of wildlife habitat is the rate of decay of tissue layers. For instance, heartwood surrounded by a relatively solid sapwood layer provides the best nesting substrate for species such as the pileated woodpecker. The level of heartwood decay should be considered in selecting trees for snag creation. Also, snag creation methods which promote heartwood decay should be given greater consideration.

Monitoring of future snag development will be essential to ensure an effect snag-management program. Monitoring should encompass tracking conditions and wildlife use of artificially created snags. Monitoring protocols should be designed to evaluate the effectiveness of snag-creation methods and to validate the assumptions of target levels of snags (i.e., do 5-10snags/ha really maintain 40% of potential population levels of cavity-nesting species). Data currently being collected on bird-use of the stands will serve as base-line measures (Hagar, 1996; 1999). Remeasurement of relative abundance of bird species every couple of years after snag creation will be essential for validation purposes. Also, monitoring of natural snag development over time will be essential to elucidate the need for future snag-creation efforts.

Acknowledgments

I thank my Fall 1999 field crew for their efforts in this project, and J. Mayo and the Cascade Center for Ecosystem Management for funding this effort.

The snag and damaged tree data collected in this study are stored in the Oregon State University Forest Science Data Bank as StudyId WExxx (Appendix D).

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Appendix A. Snag density (no./ha) for each stand, by height, dbh, and decay class.

Block/ Treatment	Height class	Hard snags (decay classes 1 & 2) by dbh class				Soft snags (decay classes 3-5) by dbh class				
		10-20cm	>20-50cm	>50cm	Total	10-20cm	>20-50cm	>50cm	Total	Total
Cougar Res./ Control	3-6m	3.47	0	0	3.47	1.74	0	0	1.74	5.21
	>6-10m	13.89	0	0	13.89	0	0	0	0	13.89
	>10-m	20.83	12.15	0	32.99	3.47	0	0	3.47	36.46
	Total	38.19	12.15	0	50.35	5.21	0	0	5.21	55.56
Heavy thin	3-6m	0	0	0	0	0	0	0	0	0
	>6-10m	2.45	0	0	2.45	0	0	0	0	2.45
	>10m	1.23	1.23	0	2.45	0	0	0	0	2.45
	Total	3.68	1.23	0	4.9	0	0	0	0	4.9
Light thin	3-6m	2.28	0	0	2.28	0	0	0	0	2.28
	>6-10m	2.28	0	0	2.28	0	0	0	0	2.28
	>10m	13.70	3.42	0	17.12	0	0	0	0	17.12
	Total	18.26	3.42	0	21.69	0	0	0	0	21.69
Light thin wtih gaps	3-6m	0	0	0	0	0	0	0	0	0
	>6-10m	3.4	0	0	3.4	0	0	0	0	3.4
	>10m	0	0	0	0	0	0	1.7	1.7	1.7
	Total	3.4	0	0	3.4	0	0	1.7	1.7	5.1
Mill Thin/ Control	3-6m	5.79	1.16	0	6.94	0	0	0	0	6.94
	>6-10m	9.26	0	0	9.26	0	0	0	0	9.26
	>10m	10.42	2.31	0	12.73	0	0	0	0	12.73
	Total	25.46	3.47	0	28.94	0	0	0	0	28.94

Appendix A. Cont'd

Block/ Treatment	Height class	Hard snags (decay classes 1 & 2) by dbh class				Soft snags (decay classes 3-5) by dbh class				
		10-20cm	>20-50cm	>50cm	Total	10-20cm	>20-50cm	>50cm	Total	Total
Heavy thin	3-6m	0	0	0	0	0	0	1.49	1.49	1.49
	>6-10m	0	0	0	0	0	0	0	0	0
	>10m	0	0	0	0	0	0	0	0	0
	Total	0	0	0	0	0	0	1.49	1.49	1.49
Light thin	3-6m	3.27	0	0	3.27	0	1.63	0	1.63	4.9
	>6-10m	1.63	0	0	1.63	0	0	3.27	3.27	4.9
	>10m	24.51	6.54	0	31.05	0	0	0	0	31.05
	Total	29.41	6.54	0	35.95	0	1.63	3.27	4.9	40.85
Light thin with gaps	3-6m	3.14	0	0	3.14	0	0	3.14	3.14	6.29
	>6-10m	3.14	0	0	3.14	0	0	0	0	3.14
	>10m	14.15	0	0	14.15	0	0	0	0	14.15
	Total	20.44	0	0	20.44	0	0	3.14	3.14	23.58
Christy Flats/ Control	3-6m	2.83	6.67	0	9.5	1.67	0	1.67	3.33	12.83
	>6-10m	8.00	3.33	0	11.33	0	0	0	0	11.33
	>10m	9.67	15	0	24.67	1.67	0	0	1.67	26.34
	Total	20.50	25	0	45.50	3.33	0	1.67	5	50.50
Heavy thin	3-6m	0	0	0	0	0	0	0	0	0
	>6-10m	0	0	0	0	0	0	0	0	0
	>10m	0	0	0	0	0	0	0	0	0
	Total	0	0	0	0	0	0	0	0	0

Appendix A. Cont'd

Block/ Treatment	Height class	Hard snags (decay classes 1 & 2) by dbh class				Soft snags (decay classes 3-5) by dbh class				
		10-20cm	>20-50cm	>50cm	Total	10-20cm	>20-50cm	>50cm	Total	Total
Light thin	3-6m	6.94	0	0	6.94	0	0	0	0	6.94
	>6-10m	5.21	0	0	5.21	0	0	0	0	5.21
	>10m	0	0	0	0	0	0	0	0	0
	Total	12.15	0	0	12.15	0	0	0	0	12.15
Light thin with gaps	3-6m	3.14	0	0	3.14	0	0	0	0	3.14
	>6-10m	3.14	0	0	3.14	0	0	0	0	3.14
	>10m	9.43	1.57	0	11.01	0	1.57	0	1.57	12.58
	Total	15.72	1.57	0	17.3	0	1.57	0	1.57	18.87
Side Walk/ Control	3-6m	1.39	0	0	1.39	0	0	0	0	1.39
	>6-10m	1.39	0	0	1.39	0	0	0	0	1.39
	>10m	18.06	0	0	18.06	0	0	0	0	18.06
	Total	20.83	0	0	20.83	0	0	0	0	20.83
Heavy thin	3-6m	0	3.47	0	3.47	0	0	0	0	3.47
	>6-10m	0	0	0	0	0	0	0	0	0
	>10m	0	0	0	0	0	0	0	0	0
	Total	0	3.47	0	3.47	0	0	0	0	3.47
Light thin	3-6m	1.23	0	0	1.23	0	0	0	0	1.23
	>6-10m	0	1.23	0	1.23	0	0	0	0	1.23
	>10m	1.23	3.68	1.23	6.13	0	0	0	0	6.13
	Total	2.45	4.9	1.23	8.58	0	0	0	0	8.58
Light thin with gaps	3-6m	1.6	0	0	1.6	0	0	1.6	1.6	3.21
	>6-10m	1.6	0	0	1.6	0	0	0	0	1.6
	>10m	0	0	0	0	0	0	0	0	0
	Total	3.21	0	0	3.21	0	0	1.6	1.6	4.81

Appendix B. Percentage of snags with evidence of wildlife use for each stand, by height, dbh, and decay class. "-" indicates no recorded snags.

Block/ Treatment	Height class	Hard snags (decay classes 1 & 2) by dbh class				Soft snags (decay classes 3-5) by dbh class				
		10-20cm	>20-50cm	>50cm	Total	10-20cm	>20-50cm	>50cm	Total	Total
Cougar Res./ Control	3-6m	0	-	-	0	100	-	-	100	33.33
	>6-10m	37.5	-	-	37.5	-	-	-	-	37.5
	>10-m	33.33	57.14	-	42.11	50	-	-	50	42.86
	Total	31.82	57.14	-	37.93	66.67	-	-	66.67	40.62
Heavy thin	3-60m	-	-	-	-	-	-	-	-	-
	>6-10m	100	-	-	100	-	-	-	-	100
	>10m	100	0	-	50	-	-	-	-	50
	Total	100	0	-	75	-	-	-	-	75
Light thin	3-6m	0	-	-	0	-	-	-	-	0
	>6-10m	50	-	-	50	-	-	-	-	50
	>10m	8.33	0	-	6.67	-	-	-	-	6.67
	Total	12.5	0	-	10.53	-	-	-	-	10.53
Light thin wtih gaps	3-6m	-	-	-	-	-	-	-	-	-
	>6-10m	0	-	-	0	-	-	-	-	0
	>10m	-	-	-	-	-	-	100	100	100
	Total	0	-	-	0	-	-	100	100	33.33
Mill Creek/ Control	3-6m	20	100	-	33.33	-	-	-	-	33.33
	>6-10m	50	-	-	50	-	-	-	-	50
	>10m	22.22	100	-	36.36	-	-	-	-	36.36
	Total	31.82	100	-	40	-	-	-	-	40

Appendix B. Cont'd

Block/ Treatment	Height class	Hard snags (decay classes 1 & 2) by dbh class				Soft snags (decay classes 3-5) by dbh class				
		10-20cm	>20-50cm	>50cm	Total	10-20cm	>20-50cm	>50cm	Total	Total
Heavy thin	3-6m	-	-	-	-	-	-	100	100	100
	>6-10m	-	-	-	-	-	-	-	-	-
	>10m	-	-	-	-	-	-	-	-	-
	Total	-	-	-	-	-	-	100	100	100
Light thin	3-6m	50	-	-	50	-	100	-	100	66.67
	>6-10m	0	-	-	0	-	-	100	100	66.67
	>10m	0	25	-	5.26	-	-	-	-	5.26
	Total	5.56	25	-	9.09	-	100	100	100	20
Light thin with gaps	3-6m	0	-	-	0	-	-	100	100	50
	>6-10m	0	-	-	0	-	-	-	-	0
	>10m	11.11	-	-	11.11	-	-	-	-	11.11
	Total	7.69	-	-	7.69	-	-	100	100	20
Christy Flats/ Control	3-6m	0	0	-	0	0	-	100	50	4.35
	>6-10m	0	0	-	0	-	-	-	-	0
	>10m	1.72	0	-	1.49	0	-	-	0	1.47
	Total	0.81	0	-	0.72	0	-	100	33.33	1.42
Heavy thin	3-6m	-	-	-	-	-	-	-	-	-
	>6-10m	-	-	-	-	-	-	-	-	-
	>10m	-	-	-	-	-	-	-	-	-
	Total	-	-	-	-	-	-	-	-	-

Appendix B. Cont'd

Block/ Treatment	Height class	Hard snags (decay classes 1 & 2) by dbh class				Soft snags (decay classes 3-5) by dbh class				
		10-20cm	>20-50cm	>50cm	Total	10-20cm	>20-50cm	>50cm	Total	Total
Light thin	3-6m	25	-	-	25	-	-	-	-	25
	>6-10m	66.67	-	-	66.67	-	-	-	-	66.67
	>10m	0	-	-	0	-	-	-	-	-
	Total	42.86	-	-	42.86	-	-	-	-	42.86
Light thin with gaps	3-6m	50	-	-	50	-	-	-	-	50
	>6-10m	0	-	-	0	-	-	-	-	0
	>10m	0	100	-	14.29	-	0	-	0	12.5
	Total	10	100	-	18.18	-	0	-	0	16.67
Side Walk/ Control	3-6m	100	-	-	100	-	-	-	-	100
	>6-10m	0	-	-	0	-	-	-	-	0
	>10m	23.08	-	-	23.08	-	-	-	-	23.08
	Total	26.67	-	-	26.67	-	-	-	-	26.67
Heavy thin	3-6m	-	0	-	0	-	-	-	-	0
	>6-10m	-	-	-	-	-	-	-	-	-
	>10m	-	-	-	-	-	-	-	-	-
	Total	-	0	-	0	-	-	-	-	0
Light thin	3-6m	0	-	-	0	-	-	-	-	0
	>6-10m	-	0	-	0	-	-	-	-	0
	>10m	0	33.33	0	20	-	-	-	-	20
	Total	0	25	0	14.29	-	-	-	-	14.29
Light thin with gaps	3-6m	100	-	-	100	-	-	100	100	100
	>6-10m	-	-	-	0	-	-	-	-	0
	>10m	0	-	-	0	-	-	-	-	-
	Total	50	-	-	50	-	-	100	100	66.67

Appendix C. Density (no./ha) of live, damaged stems by vigor class for each stand, by vigor, canopy, and dbh class. Canopy class codes: S - suppressed, I - intermediate, C/D - codominant & dominant.

Treatment		Low vigor by dbh class				Medium, high vigor by dbh class				
area code	Canopy class	10-20cm	>20-50cm	>50cm	Total	10-20cm	>20-50cm	>50cm	Total	Total
Cougar Res./ Control	S	1.74	0	0	1.74	1.74	0	0	1.74	3.47
	I	1.74	0	0	1.74	0	0	0	0	1.74
	C/D	0	0	0	0	0	0	0	0	0
	Total	3.47	0	0	3.47	1.74	0	0	1.74	5.21
Heavy thin	S	0	0	0	0	0	0	0	0	0
	I	0	0	0	0	0	1.23	0	1.23	1.23
	C/D	0	0	0	0	0	2.45	0	2.45	2.45
	Total	0	0	0	0	0	3.68	0	3.68	3.68
Light thin	S	0	0	0	0	1.14	0	0	1.14	1.14
	I	0	0	0	0	0	0	0	0	0
	C/D	1.14	0	0	1.14	1.14	3.42	1.14	5.71	6.85
	Total	1.14	0	0	1.14	2.28	3.42	1.14	6.85	7.99
Light thin with gaps	S	0	0	0	0	0	0	0	0	0
	I	0	0	0	0	1.7	0	0	1.7	1.7
	C/D	0	0	0	0	5.1	1.7	0	6.8	6.8
	Total	0	0	0	0	6.8	1.7	0	8.5	8.5
Mill Creek/ Control	S	0	0	0	0	0	0	0	0	0
	I	0	0	0	0	0	0	0	0	0
	C/D	0	0	0	0	0	0	0	0	0
	Total	0	0	0	0	0	0	0	0	0

Appendix C. Cont'd

Treatment area code	Canopy class	Low vigor by dbh class				Medium, high vigor by dbh class				
		10-20cm	>20-50cm	>50cm	Total	10-20cm	>20-50cm	>50cm	Total	Total
Heavy thin	S	0	0	0	0	1.49	0	0	1.49	1.49
	I	0	0	0	0	2.98	0	0	2.98	2.98
	C/D	0	0	0	0	1.49	7.44	2.98	11.9	11.9
	Total	0	0	0	0	5.95	7.44	2.98	16.37	16.37
Light thin	S	0	0	0	0	0	0	0	0	0
	I	0	0	0	0	0	0	0	0	0
	C/D	1.63	0	0	1.63	0	0	0	0	1.63
	Total	1.63	0	0	1.63	0	0	0	0	1.63
Light thin with gaps	S	0	0	0	0	0	0	0	0	0
	I	0	0	0	0	0	0	0	0	0
	C/D	1.57	0	0	1.57	3.14	0	0	3.14	4.72
	Total	1.57	0	0	1.57	3.14	0	0	3.14	4.72
Christy Flats/ Control	S	0	0	0	0	0	0	0	0	0
	I	0	0	0	0	1.67	0	0	1.67	1.67
	C/D	0	0	0	0	0	0	0	0	0
	Total	0	0	0	0	1.67	0	0	1.67	1.67
Heavy thin	S	0	0	0	0	0	0	0	0	0
	I	0	0	0	0	0	0	0	0	0
	C/D	0	0	0	0	0	5.1	0	5.1	5.1
	Total	0	0	0	0	0	5.1	0	5.1	5.1

Appendix C. Cont'd

Treatment area code	Canopy class	Low vigor by dbh class				Medium, high vigor by dbh class				
		10-20cm	>20-50cm	>50cm	Total	10-20cm	>20-50cm	>50cm	Total	Total
Light thin	S	0	0	0	0	0	0	0	0	0
	I	0	0	0	0	1.74	0	0	1.74	1.74
	C/D	0	0	0	0	0	0	0	0	0
	Total	0	0	0	0	1.74	0	0	1.74	1.74
Light thin with gaps	S	0	0	0	0	0	0	0	0	0
	I	0	0	0	0	0	0	0	0	0
	C/D	1.57	1.57	0	3.14	1.57	18.87	1.57	22.01	25.16
	Total	1.57	1.57	0	3.14	1.57	18.87	1.57	22.01	25.16
Side Walk/ Control	S	0	0	0	0	0	0	0	0	0
	I	0	0	0	0	0	0	0	0	0
	C/D	0	0	0	0	0	0	0	0	0
	Total	0	0	0	0	0	0	0	0	0
Heavy thin	S	0	0	0	0	0	0	0	0	0
	I	0	0	0	0	1.74	0	0	1.74	1.74
	C/D	0	0	0	0	0	5.21	0	5.21	5.21
	Total	0	0	0	0	1.74	5.21	0	6.94	6.94
Light thin	S	0	0	0	0	0	0	0	0	0
	I	0	0	0	0	0	0	0	0	0
	C/D	0	0	0	0	0	9.8	0	9.8	9.8
	Total	0	0	0	0	0	9.8	0	9.8	9.8
Light thin wigh gaps	S	0	0	0	0	0	0	0	0	0
	I	0	0	0	0	0	0	0	0	0
	C/D	1.6	0	0	1.6	4.81	8.01	1.6	14.42	16.03
	Total	1.6	0	0	1.6	4.81	8.01	1.6	14.42	16.03

Appendix D. Meta-data for the Snag and Damaged-stem data base, Yound Stand Thinning and Diversity Study.

```
*************************************************************************************************
                              Variable Format and Definitions              WExx         6/2/99
*************************************************************************************************
Format 1
                                     Snag/Damaged Tree
```

Variable	Coded	Null	Format	Unit	Definition
TAC	Y		I2		Treatment Area Code
BLOCK	Y		I2		Block Code
TREATMENT	Y		I1		Treatment Code
TRANSECT			I2		Transect Number
STN1			I2		Trap Station Number (first reference)
STN2			I2		Trap Station Number (second reference)
DBH			I3	cm	Diameter at breast height (10-cm size classes)
SPECIES	Y		A2		Life form
LIVE_DEAD	Y		A1		Live/dead status
DECAY	Y		I1		Decay status
VIGOR	Y		A1		Estimate of vigor
DAMAGE	Y		I3		Damage estimate (broken top or measure of scar size)
DEPTH			I3	cm	Depth of scar(5-cm intervals)
CANOPY	Y		A3		Canopy status
CAVITYOLD			I3		Number of old cavities
CAVITYNEW			I3		Number of fresh cavities
FHOLEOLD			I3		Number of old feeding holes
FHOLENEW			I3		Number of fresh feeding holes
ID			I3		Acession number; used to indicate identify multiple damage records for an individual bole

```
*************************************************************************************************
                              Variable Code Definitions                    WExx         6/2/99
*************************************************************************************************
```

Variable:	BLOCK
1	Cougar Reservoir (Blue River RD)
2	Mill Creek (McKenzie RD)
3	Christy Flats (Oakridge RD)
4	Sidewalk Creek (Oakridge RD)

Appendix D. Cont'd

```
***************************************************************************************************
                              Variable Code Definitions                     WExx        6/2/99
***************************************************************************************************
Variable:      CANOPY
s              suppressed
i              intermediate
cd             co-dominant
d              dominant
#              for snags, an esimate of height by 3-m intervals (up to 10m)

Variable:      DAMAGE
-1             broken top
#              % of circumference of a scar (5% intervals)

Variable:      DECAY
               decay classes (Cline et al., 1980)
1              bole is solid, recently died
2              bark and sapwood is mined extensively and beginning to slough
3              sapwood decayed considerable and partly sloughed, branches no longer present
4              sapwood all sloughed off, no sound heartwood
5              wood is spongy,

Variable:      LIVE_DEAD
l              live
d              dead

Varaible:      SPECIES
c              conifer
h              hardwood
u              unknown

Variable:      TAC
               Cougar Reservoir
1              Control
2              Heavy Thin
3              Light Thin
4              Light Thin/gaps

               Mill Creek
5              Control
6              Heavy Thin
7              Light Thin
8              Light Thin/gaps

               Christy Flats
9              Control
10             Heavy Thin
11             Light Thin
12             Light Thin/gaps

               Sidewalk Creek
13             Control
14             Heavy Thin
15             Light Thin
16             Light Thin/gaps

Variable:      TREATMENT
1              Control
2              Heavy Thin
3              Light Thin
4              Light Thin/gaps

Variable:      VIGOR
               (only for live stems)
H              high, no noticeable abnormal growth potential
M              medium, loss of stems (e.g., broken tops, noticeable loss of branches)
L              low, noticeable loss of needles or predominance of brown needles
```