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Abundance and Characteristics of Snags in Western Montana Forests

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Abstract

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Plot data from the U.S. Forest Service's Forest Inventory and Analysis program was used to characterize the abundance and selected characteristics of snags from forests in western Montana. Plots were grouped by whether they had a history of timber harvest, and the U.S. Forest Service classifications of forest type, habitat type, and potential vegetation group were used to characterize plot conditions. Snag abundance was classified by d.b.h. class and species. On uncut plots (no evidence of previous timber harvest or other mechanized human activity), total snag (9 inches or greater) density varied from under three per acre on dry Ponderosa pine (*Pinus ponderosa*) types to approximately 21 per acre on mesic spruce and fir types as well as warmer sites supporting grand fir (*Abies grandis*) and western redcedar (*Thuja plicata*). Higher snag densities occurred in dry subalpine types (over 30 per acre), but these figures may be anomalous because of recent, uncharacteristically high mortality of whitebark pine (*Pinus albicaulis*). Abundance of large (21 inches or greater) snags was much lower, but showed similar trends, varying from as low as 0.4 per acre on dry ponderosa pine sites and 0.2 per acre on lodgepole pine (*Pinus contorta*) dominated sites to 2 per acre on warm, mesic sites. Similar trends were observed when stands were categorized by habitat type groups and potential vegetation groups. Snag abundance on young, recently disturbed stands was only slightly lower than on older, sawtimber stands, and in general, snag dynamics differed from those of live trees during the process of stand aging. Stands lacking a history of timber harvest had significantly higher snag abundance than those with a history of timber harvest. The generally higher snag abundances in uncut stands reflect not only an unharvested condition, but also a lack of fire and probably an attendant excess of mortality from insects and disease, which would be manifested more strongly in smaller d.b.h. classes. Snag abundances in larger d.b.h. classes of uncut stands should closely mimic natural conditions on the landscape in the absence of timber harvest if accounting for a small upward bias caused by fire suppression. These estimates for larger d.b.h. classes can be used as rough targets for landscapes where managing for biodiversity or emulating natural disturbance patterns is an important objective.

Keywords: cover type, habitat type, logging, snag, snag abundance

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Abundance and Characteristics of Snags in Western Montana Forests

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Introduction

Snags (standing dead trees) are recognized as a vital component of wildlife habitat and a normal and necessary part of forested landscapes (Bull and others 1997; Thomas and others 1979). During the past two decades, considerable research has been devoted to characterizing the numerous relationships among various wildlife species and snags (Martin and Barrett 1983; Marzluff and Lyon 1983; Raphael and White 1984). Much of this research has been motivated by the concern that silvicultural practices aimed solely at maximizing wood production would, in time, produce entire forests deficient in snags, particularly large-diameter snags. The most frequently articulated result of such a condition would be extirpation of snag-dependent species (often woodpeckers), although the long-term effects on other aspects of the forest ecosystem of snag loss remain largely unknown.

Because earlier forestry practices often removed snags without such an awareness, and because even modern forestry practices can easily reduce snag abundance further, the question arises: How many snags should we target for our landscapes? This question has recently been brought into sharper focus by the involvement of the Federal Occupational Safety and Health Administration (OSHA) in the safety aspects of snag management. In short, the pressures on both "sides" of the snag management issue—more snags suggested by wildlife or ecosystem integrity concerns, fewer snags suggested by human safety concerns—have intensified, clarifying the need for better data on current and desired snag abundance.

Wildlife researchers have taken principally a "species-centered" approach to this question. They have studied the life-history requirements of individual species known to be dependent on, or associated with, snags and estimated the number and type of snags needed by individuals of these species. Then, they have combined these results with theory from the population dynamics literature to estimate the abundance and characteristics of snags needed on a landscape scale to ensure persistent populations (Menasco 1983; Neitro and others 1985; Thomas and others 1979).

While this approach has great merit and has undoubtedly contributed to more enlightened snag management than in the past, it suffers from at least three drawbacks:

1. Estimates of population sizes needed to ensure persistence can only be developed through mathematical models, but species-specific data to parameterize the extremely detailed and complex models needed to estimate population viability are nearly always inadequate.
2. Even if the abundance and characteristics of snags required for a chosen "indicator" or "umbrella" species are known with precision, questions remain about how many snags are required to ensure persistence of the entire range of snag-dependent species.
3. Focus on individual species is inconsistent with the recent move toward focusing on general ecosystem patterns and processes (Franklin 1993). This "coarse-filter" approach has the advantage that, at least theoretically, it lends itself to management objectives that, while including the needs of individual wildlife species, embrace a more fundamental concept of ecosystem integrity.

For example, in considering the closely related (and even more contentious) issue of "old-growth," most research has been devoted to elucidating the natural processes that create and eliminate old-growth (Johnson and others 1995; Lesica 1996), and on the resultant natural patterns present on the historical landscape (Losensky 1993, 1996), rather than on questions of how much old-growth any given species needs for persistence. These general patterns of forest age are highly correlated to patterns among local indigenous fauna (Bunnell 1995), providing additional confidence that maintaining a similar abundance and pattern of age classes should generally support all species, and obviating the (clearly impossible) task of calculating the individual needs of hundreds or perhaps thousands of such species.

The same ecological knowledge that allows us to draw general conclusions about "natural" age distributions within differing forest types can be used to make similar broad statements about snag abundance and dynamics (USFS n.d.). Although we can analyze historical records in the Northern Rockies with respect to age distribution (Losensky 1993, 1997), no such comparable data exist with respect to snags. Foresters working during the initiation of the era of large-scale logging and fire suppression (about 1900 to 1930) documented ages and species mixes of stands in ways we can now use, but they did not keep similar records about snags. Thus, we have no way to go back in time to examine the "naturally" occurring abundance and pattern of snags. (Although see the recent work of Harrod and others 1998, for an estimate of historical snag densities in an assumed steady-state system.)

Fortunately, we have access to modern data that allow estimation of snag abundances in various forest types and in forests subject to varying levels of human intervention. We can gain some insight into the patterns of snags that "should" characterize our forests by careful examination of current conditions, even if we are unable to determine exactly what "would" have been on the landscape some 100 years ago.

This report is a preliminary attempt to examine those patterns. I have used data obtained from the U.S. Forest Service's Rocky Mountain Research Station, Ogden, UT, as part of the Forest Inventory and Analysis (FIA) program to estimate abundance and characteristics of snags in western Montana forests, with the objectives of:

1. Estimating abundance of snags in various forest types in the absence of timber harvesting.
2. Comparing these data with those obtained from forest stands already subject to logging.
3. Suggesting possible management approaches to snag management that follow a coarse-filter philosophy, rather than a species-specific one.

Methods

Data used in this report came from the most recent (generally 1988 through 1995) periodic forest inventory developed and administered by the Forest Service's Western FIA program, in Ogden, UT. Briefly, these were permanent, systematically located point clusters encompassing approximately 0.5 to 1 acre (0.2 to 0.4 ha) on which trees were sampled. For all tallied trees, attributes such as species, size, age, and condition were documented. Plots were sampled on all forested land, regardless of ownership or forest condition, and constituted an objective representation of forests on unsampled locations. Clusters (plots) consisted of up to 10 points. Only point centers were fixed (that is, plot boundaries were not fixed), and a variable radius was used to select individual trees for sampling. For trees of diameters that are the focus of interest in this report, a basal-area-factor 40 prism was used. The raw data entering these analyses were not number of trees tallied per plot, but rather trees-per-acre projections based on the diameter of each tallied tree and its distance from the point center. During some years, the FIA program additionally estimated snags counted within circular 0.5 acre plots superimposed on the center of the cluster, with the rationale that variable basal-area-factor 40 plots dealt ineffectively with the clumpy distribution typically characterizing snags. I elected, however, to use the point-cluster data in preference to the snag count estimates because the estimation procedures used in these additional fixed plots were prone to measurement errors (Harris, unpublished data), species was not recorded for snags counted, and the area effectively sampled by the cluster of basal-area-factor 40 plots was equal to or larger than 0.5 acre for the larger diameter snags of interest here (table 1). For information on sampling and documentation procedures used in the FIA program, see Woudenberg and Farrenkopf (1995) and USDA (1988).

The key attributes in classifying plots were (1) stand history (for example, human intervention, fire, and insect damage); (2) forest cover type (by species); (3) habitat type group (Green and others 1992; Pfister and others 1977); and (4) stand-size class (for example, poletimber and sawtimber). Further description of grouped plots was made possible by reference to variables describing plot elevation, aspect, and slope.

Key attributes used in classifying individual trees within plots were (1) species; (2) diameter at breast height (d.b.h.); (3) tree history (for example, snag, live tree, and dead or down tree); and (4) trees per acre (that is, extrapolation factor) indicated for the species per d.b.h. per tree history combination.

Plots used in this report originated from three different land owners or managers:

1. Lands held in trust for educational beneficiaries of the State of Montana and managed by the Montana Department of Natural Resources and Conservation.

Table 1—Area effectively sampled by basal-area-factor 40 variable plots, assuming trees of various d.b.h. and differing numbers of points within each cluster. Number of points sampled at each plot are those used in the present analysis.

	Number of points sampled at each plot		
D.b.h.	**5**	**7**	**10**
inches	- - - - - - - - *Proportion of acre*	- - - - - - - -	
12	0.092	0.129	0.185
18	0.208	0.291	0.415
24	0.369	0.517	0.739
30	0.577	0.808	1.154
n	630	602	698

2. The Bitterroot, Flathead, Kootenai, and Lolo National Forests.

3. Nonindustrial private owners of forested lands.

Plots were grouped into two stand history categories: cut and uncut.

1. Plots were classified as "cut" if:

a. "…most important man-caused or natural action…on the sample acre" (USDA 1988:37) was any form of timber cutting.

b. The plot was identified as having been initiated through planting or seeding.

c. The most important action was documented as a separate human source (for example, road-building, chaining, land-clearing).

2. Plots were classified as "uncut" if none of the above characteristics were documented. The uncut classification included plots on which the "most important action" was fire, insect damage, disease, wind damage, and so forth (table 2). It also, necessarily, included plots influenced by fire-suppression. I use the word "uncut" throughout as a shorthand, but recognize that, even in the absence of timber harvest, human activities have influenced these stands and trees.

No attempt was made to alter or reclassify forest cover types from those assigned by the FIA program. These were generally in the form of single-species identifiers. For sparsely stocked locations (less than 6 live trees 5 inches or greater d.b.h. tallied), field workers were instructed to "Estimate which species has the plurality (highest amount) of basal area stocking...." For more densely stocked stands, cover-type designations were produced by automated, in-office programs that considered the entire documented tree tally for the plot. I did, however, lump together existing cover types to form aggregate types when sample sizes were obviously too small for meaningful analysis. A "mesic conifer" type was created consisting of the FIA's grand fir, western redcedar, western hemlock (*Tsuga heterophylla*), and western white pine (*Pinus monticola*) forest types; a "hardwood" type, consisting of the FIA's aspen, (*Populus tremuloides*), cottonwood (*P. trichocarpa*), and birch (*Betula* spp.) forest types; and a "subalpine" type, consisting of the FIA's whitebark pine, and limber pine (*Pinus flexilis*) forest types. Eleven plots originally coded as mountain hemlock (*Tsuga mertensiana*), accounting for about 3.5 percent of the resultant cover type, were included within the "spruce/fir" type.

Table 2—Proportion of plots in field location history categories, as recorded in the Forest Inventory Analysis data.

Category	Uncut	Cut
None	0.471	0.161
Animal damage	0.014	0.004
Insect damage	0.066	0.033
Disease	0.211	0.079
Weather	0.061	0.004
Wind	0.044	0.004
Fire	0.133	0.057
Clearcut	0.000	0.061
Selective cut	0.000	0.315
Other (selective) cut	0.000	0.193
Post/pole cut	0.000	0.004
Clearing	0.000	0.008
Road building	0.000	0.041
Type conversion	0.000	0.018
Other human alteration	0.000	0.018

The "primary" habitat type designation (Pfister and others 1977) was retained for each plot as assigned by the field crew. Habitat types were then aggregated into habitat type groups, following Green and others (1992). I modified their classification system slightly by lumping all "Montana east-of-the-Continental-Divide" habitat types with their corresponding "west-of-the-Divide" reducing the total number of habitat type groups in Montana from 19 to 10. For example, habitat types designated by Green and others (1992) as "cool and moist" east of the Divide were grouped together with those designated "cool and moist" west of the Divide (appendix B). Habitat types coded by the FIA program were used to classify plots into six potential vegetation groups as suggested by M. Hillis (unpublished work). The objective of classifying plots into potential vegetation groups was to integrate underlying climatic and physical attributes with fire regimes and dominant cover types (for example, splitting out forests that are typically characterized by lodgepole pine, regardless of potential climax species) (appendix C).

To classify individual trees, I simply retained the species, d.b.h., and trees per acre provided by the FIA program for each tree record. Snags were classified as all trees designated with a tree-history code of either 4 (hard) "standing salvable dead...5.0 inches d.b.h. or larger with less than 67 percent rotten or missing volume" (USDA 1988 p. 55) or 6 (soft) "nonsalvable dead…5.0 inches d.b.h. or larger with 67 percent or more rotten or missing volume" that were not indicated by the damage-code field as being on the ground. Snags can also be categorized (Ohmann and others 1994) as being "remnant" (formed in a previous stand, usually from large old-growth trees) or "recruited" (originating in the current stand, usually from suppression mortality during the stem-exclusion stage of stand development) (Oliver and Larson 1990). I made no attempt at such a classification, but discuss this issue following presentation of the results.

Trees per acre for each plot were summarized by 6-inch d.b.h. classes, beginning with a d.b.h. of 9 inches (small = 9 to 14.99 inches; medium = 15 to 20.99 inches; large = 21 to 26.99 inches) plus an unbounded d.b.h. class (for example, more than 27 inches), as well as by snag/nonsnag status and tree species. All statistics and summaries reported here are by plot (sum of individual points); none are summarized on a by-tree basis.

Snag abundances and characteristics were examined among plots classified by cover type, habitat type groups, and potential vegetation groups. The most precise designation would have been to examine each cover type/habitat type group or cover type/potential vegetation group combination separately. However, sample sizes were too small in most cases to allow meaningful inference (I imposed a lower limit of 25 plots whenever possible) (see also Ohmann and others 1994), and the resultant matrix of snag-size distributions for 90 different types of forest may have produced more confusion than clarity.

The density from each plot represented a single sample, even though each consisted of cumulative data from 5 to 10 sample points within each cluster. I assumed that cover types, habitat type groups, potential vegetation groups and stand-size classes represented meaningful classifications, and thus did not test for significant differences in snag densities among them. I did not lump samples from different classes to enlarge sample sizes, even when it appeared that snag densities did not differ significantly between classes. To compare elevation and slope of plots that were classified as cut and uncut, standard 2-factor ANOVA (Norusis 1993) was used, using cover type as a covariate. The Mann-Whitney test was used to compare snag densities among samples classified as cut and uncut. To compare frequency distributions of snags per acre between cut and uncut plots, the Kolmogorov-Smirnov test was used (Norusis 1993). To compare snag and live tree densities among stand-size classes, standard one-way ANOVA was used, considering pairwise comparisons significantly different if $P < 0.05$ (Tukey's Honestly Significant Difference, Sokal and Rohlf 1981 p. 245).

Throughout this report, the English measurement system is used because raw data were reported using these units, and because American foresters and land managers continue to use it.

Results

Sample Plots and Trees

Data consisted of a total of 1,949 forested plots (Montana Department of Natural Resources and Conservation - 232 plots; National Forest - 1,237 plots; nonindustrial private owners of forested lands - 480 plots). These plots were classified as uncut (1,158 plots - 59 percent) and cut (791 plots - 41 percent). A history of fire, insect damage, disease damage, wind damage, and other factors characterized both cut and uncut plots with different frequencies (table 2). A total of 54,096 individual stems more than 5.0 inches d.b.h. were tallied on these plots, of which 5,167 (9.6 percent) were classified as snags. Of 23,955 stems more than 9.0 inches d.b.h., 3,279 (13.7 percent) were classified as snags.

The most common forest type among the 1,949 plots was Douglas-fir (*Pseudostuga menziesii*)—(almost 41 percent of all plots). Other common forest types included spruce/fir (almost 19 percent), lodgepole pine (over 16 percent), and ponderosa pine (about 7 percent). Very few were classified as limber pine, western redcedar, grand fir, western hemlock, mountain hemlock, aspen, cottonwood, or birch, thus necessitating the lumping of some cover types (table 3).

Among the 1,158 plots classified as uncut, a similar pattern emerged: Douglas-fir types were the most common (roughly 36 percent), followed by spruce/fir (about 24 percent) and lodgepole pine (20 percent; table 3).

Ninety-five plots were not classified into a habitat type group, because no habitat type was assigned to the plot by the FIA program or because I could not confidently group the habitat type into a habitat type group (nor did Green and others 1992). Of the remaining 1,854 plots, the most common habitat type groups represented were the "moderately-warm-dry-B" (23 percent) and "cool-moist-E" (22 percent) types. Habitat type groups "wet-F," "cold-moderately-dry-I," and "cold-J" were all represented by less than 3 percent of sample plots (table 3).

Among the 1,116 plots classified as uncut for which habitat type groups could be assigned, patterns were similar, although some groups—presumably those with high productivity and accessibility and thus attractiveness for timber production—were less well represented than they were when considering all plots. In particular, the "moderately-warm-dry-B" group fell to a 16 percent representation (from 23 percent), and the "warm-moist-D" group fell to 9 percent (from 11 percent). At the other extreme, only a single plot classified as "cold-J" had experienced timber harvesting or other significant human intervention (table 3).

Roughly 44 percent of plots classified as uncut fell within the "cool, infrequent-but-stand-replacing fire regime" potential vegetation group. Similar numbers of plots were classified as "warm, moist, mixed-fire regime" (18 percent) and "warm, dry, frequent-but-low-intensity-fire regime" (17 percent). Fewer uncut plots were classified as "very moist, maritime climate, very-infrequent-fire-regime" (7 percent).

Table 3—Plot sample sizes by cover type and habitat type group.

	Habitat type groups											
	A	B	C	D	E	F	G	H	I	J		
Cover type	Warm, dry	Moderately warm, dry	Moderately cool, dry	Warm, moist	Cool, moist	Wet	Moderately cool, moist	Cool , moderately dry	Cold, moderately dry	Cold	No habitat type groups	Total
Cut plots[a]												
Ponderosa	33	42	2	2	1						9	89
Douglas-fir	28	180	55	24	20	2	38	9			21	377
Larch		4	4	14	19		3	9			5	58
Mesic conifer			1	36			3				2	42
Spruce				5	10	6		3	1		3	28
Spruce/fir		1	3	10	55	5		8	4		6	92
Lodgepole	1	14	13	5	16	1	8	19	3		5	85
Dry subalpine								2		1		3
Hardwood	1	4	1	2	3	1					5	17
No cover type												
Total	63	245	79	99	126	15	52	50	8	1	53	791
Uncut plots only												
Ponderosa	23	15	1					1			3	43
Douglas-fir	48	151	78	34	37	2	13	43	1		15	456
Larch		2	4	14	20		7	4		2	1	54
Mesic conifer			3	27	1	1					1	33
Spruce				6	18	5		3		1	2	35
Spruce/fir	1		1	2	142	14		65	27	20	4	276
Lodgepole	2	9	32	18	57	2	13	77	15	4	5	231
Dry subalpine		1	1		4			6	8	10	0	30
Hardwood		3	2	1		3					7	18
No cover type										3		3
Total	74	181	122	102	284	27	33	202	51	40	42	1,158

[a] Plots subject to cutting or other human disturbance.

To further understand differences among cover types, habitat type groups, and potential vegetation groups, I summarized each by mean elevation, slope, and aspect. These summaries are presented in appendix D. Stands with a history of timber harvest were not, however, a random sample of all stands, as characterized by mean elevation and slope. Cut stands had significantly lower elevations (F = 273.9, df = 1, 1946, $P < 0.001$) and gentler slopes (F = 224.1, df = 1, 1946, $P < 0.001$) than did uncut stands after they were controlled for the effects of cover type.

Over 72 percent of plots classified as uncut were in the sawtimber size-class, with most of the remainder (18 percent) being in the poletimber class; about 8 percent were classified as seedling/sapling and the remaining as nonstocked (table 4). Lodgepole pine cover types formed the major exception to this general trend (table 5): only 45 percent of such stands were classified as sawtimber, while almost 47 percent were poletimber. Spruce/fir stands had a substantial component (15 percent) of seedling/sapling plots.

Overall Natural Patterns of Snag Abundance

Overall Means—Assessed across the entire range of cover types, habitat type groups, potential vegetation groups, and stand-size classes, there were an average of 10.41 (standard error [SE] = 0.43) snags per acre (more than 9.0 inches d.b.h.) on all plots. Of these, a mean of some 8.12 (SE = 0.39) snags per acre were small (9 to 14.9 inches d.b.h.), 1.69 (SE = 0.09) were medium (15 to 20.9 inches d.b.h.), 0.44 (SE = 0.03) were large (21 to 26.9 inches d.b.h.), and 0.16 (SE = 0.02) were very large (27 inches d.b.h. or larger). On these same plots, total stems per acre (live trees and snags 9 inches or greater d.b.h.) averaged 74.57 (SE = 1.12). Considering uncut plots only, total snags averaged 13.98 per acre (SE = 0.63), with 11.05 (0.57), 2.21 (0.14) , 0.56 (0.04), and 0.17 (0.02) per acre in the small, medium, large, and very large categories, respectively. On these same plots, total stems per acre averaged 86.85 (SE = 1.51). On average, snags had a density roughly 14 percent of all 9 inch or greater d.b.h. stems (about 16 percent on uncut plots). This total tree/snag proportion remained relatively constant throughout the diameter distribution (fig. 1), with all size classes having from 14 to 17 percent snags. The largest proportion representation by snags was in the 9 to 14.9 inch (small) diameter class, where snags made up just over 16 percent of the total stems.

Spatial Distribution of Snags—The distribution of snag densities among uncut plots was highly variable; plots with an average snag density were rarely encountered. In fact, the modal category for snags per acre was zero (table 6). Considering all 9 inch or greater snags on uncut plots, over half the plots had densities of over 5 snags per acre, while 38 percent had

Table 4—Sample sizes of plots by stand-size class.

Category	Cut stands	Uncut stands
Nonstocked	24	14
Seedlings/saplings less than 5 inches d.b.h.	170	96
Poletimber 5 to 9 inches d.b.h.	119	213
Sawtimber greater than 9 inches d.b.h.	477	833
(Sawtimber greater than 15 inches d.b.h.)	(446)	(826)
Total	790	1,158

Table 5—Proportion of uncut plots in the four stand-size classes by cover type.

	Cover type[a]									
Category	PP	DF	WL	ES	SF	LP	MC	SA	HW	Total
Nonstocked	0.05	0.02	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01
Seedling/saplings (less than 5 inches d.b.h.)	0.07	0.05	0.00	0.06	0.15	0.08	0.06	0.10	0.06	0.08
Poletimber (5 to 9 inches d.b.h.)	0.02	0.08	0.22	0.06	0.14	0.47	0.03	0.17	0.44	0.19
Sawtimber (greater than 9 inches d.b.h.)	0.86	0.85	0.78	0.89	0.70	0.45	0.91	0.72	0.50	0.74
N	43	422	54	35	276	234	34	29	16	1,108

[a] PP = ponderosa pine; DF = Douglas-fir; WL = western larch; ES = Englemann spruce; SF = subalpine fir; LP = lodgepole pine; MC = mesic conifer; SA = subalpine; HW = hardwoods.

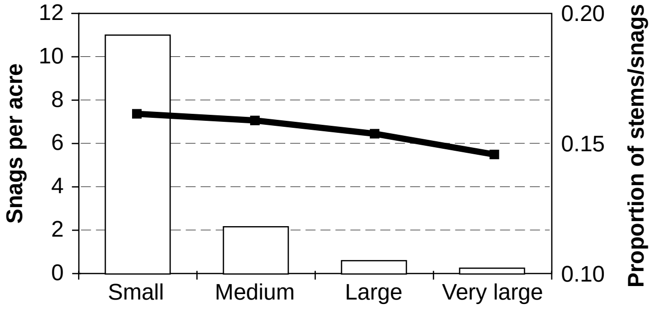

Figure 1—Snags per acre (open bars) and the proportion of all standing stems made up by snags (solid squares connected by solid line) and by d.b.h. class (small = 9 to 14.9 inches, medium = 15 to 20.9 inches, large = 21 to 26.9 inches, very large = 27 inches or greater) among all plots classified as "uncut."

Table 7—Snag abundance on cut and uncut plots by d.b.h. class. Also shown are approximate z and probability values (2-sample Mann-Whitney tests).

D.b.h. class	Uncut	Cut	z	p
inches				
9 to 14.9	11.05	3.83	–10.78	0.0000
15 to 20.9	2.21	0.92	–6.66	0.0000
21 to 26.9	0.56	0.28	–4.71	0.0000
27 or greater	0.17	0.15	–0.47	ns
All	13.98	5.18	–11.68	0.0000

none. Again considering uncut plots, over 77 percent had no snags of 21 inches or greater (while 17 percent had more than 2 per acre). As quantified by plots of approximately 1 acre, the geographic distribution of snags was highly clumped. Plots with no snags were generally more common among those classified as cut, while plots with many (10 or more) snags per acre were more common among those classified as uncut; however, the overall frequency distributions of snags per acre on cut and uncut plots did not differ significantly.

Differences Between Uncut and Cut Plots—Snags were significantly ($P < 0.0001$) more abundant on uncut than on cut plots (table 7) in all diameter classes except the largest. The pattern of snags being reduced on cut plots relative to uncut plots was general across cover types, habitat type groups, and potential vegetation groups. All pairwise comparisons (cover type X d.b.h. class) displayed the same directional trend of fewer snags on cut than uncut plots, although the magnitude differed among cover types. For example, ponderosa pine-dominated plots with no history of timber cutting averaged 1.6 times more snags than did previously cut ponderosa pine plots, whereas uncut western larch (*Larix occidentalis*) plots averaged 3.9 times more snags than larch plots with a history of timber harvest (table 8).

Table 6—Frequency distribution of snags per acre across all cover type habitat type groups and potential vegetation groups.

Density	9 inches or greater	21 inches or greater
0	442	895
0.001 to 1	6	11
1.001 to 2	31	73
2.001 to 3	40	87
3.001 to 4	32	30
4.001 to 5	26	25
5.001 to 6	25	13
6.001 to 7	17	21
7.001 to 8	27	3
8.001 to 9	26	3
9.001 to10	16	4
10 or greater	470	6

Differences Among (Successional) Stand-Size Classes—On uncut plots, snags were more abundant on plots classified as sawtimber than on plots classified as seedling/sapling or poletimber. Snag abundance on sawtimber plots was not significantly different from that on nonstocked plots, with about 86 percent as many snags on nonstocked plots as on sawtimber plots (fig. 2). Considering larger snags only (21 inches or greater), the largest number of snags occurred on nonstocked plots, although the only significant difference occurred between sawtimber and poletimber plots (fig. 3). The dynamics of snag creation and attrition differed from the analogous dynamics of live stems (fig. 2, 3). Snags constituted the majority of total stems on uncut plots classified as nonstocked, gradually declining in their proportional representation with time (fig. 2). The absolute number of snags also declined from the nonstocked to seedling/sapling stages, while the absolute number of live stems increased. Among the largest diameter-class snags, this decline continued into the poletimber stage (fig. 3); it was not until the sawtimber stage that new large-diameter snags were again recruited.

Snag Abundance by Individual Cover Types, Habitat Type Groups, and Potential Vegetation Groups

While interesting, background information summarizing snag characteristics across all types of forests found in western Montana is not terribly useful, because these characteristics differ markedly depending on site quality, elevation, time since disturbance, and

Table 8—Mean snag abundance by cover type and d.b.h. class.

Cover type	N	Total	Small (9 to 14.9 inches)	Medium (15 to 20.9 inches)	Large (21 to 26.9 inches)	Very large (more than 27 inches)
		- - - - - - - - - -	- - - - - - *Snags per acre*	- - - - - - - - - -		
Cut plots						
Ponderosa pine	89	1.57	1.13	0.17	0.20	0.08
Douglas-fir	377	3.36	2.32	0.75	0.18	0.12
Western larch	58	4.79	3.66	0.98	0.25	0.10
Englemann spruce	28	4.58	2.80	1.12	0.54	0.12
Spruce/fir	92	11.75	9.35	1.83	0.44	0.13
Lodgepole pine	85	6.80	6.08	0.50	0.12	0.11
Mesic conifer	42	12.51	8.21	2.61	0.98	0.71
Dry subalpine	3	1.59	1.59	0.00	0.00	0.00
Hardwoods	17	4.72	2.12	1.18	0.90	0.52
Uncut plots						
Ponderosa pine	43	2.51	1.51	0.61	0.24	0.15
Douglas-fir	422	8.96	6.78	1.62	0.46	0.10
Western larch	54	18.79	15.23	2.45	0.81	0.30
Englemann spruce	35	21.32	17.13	3.18	0.72	0.29
Spruce/fir	276	21.09	16.06	3.79	0.92	0.32
Lodgepole pine	234	12.18	11.13	0.85	0.17	0.03
Mesic conifer	34	21.68	12.57	7.20	1.38	0.53
Dry subalpine	30	31.44	27.62	2.78	0.98	0.06
Hardwoods	16	5.38	5.33	0.00	0.00	0.05

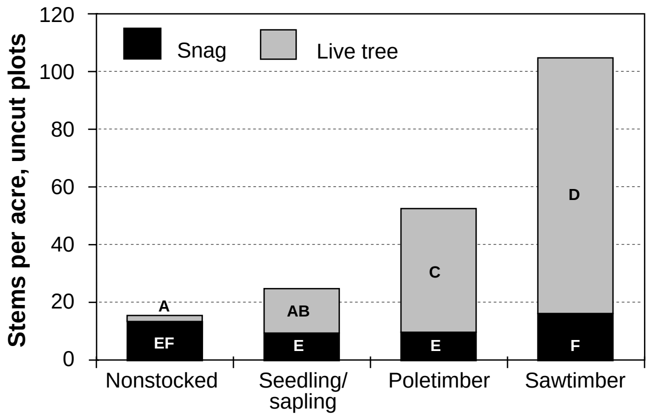

Figure 2—Standing stems per acre (9 inches or greater) in uncut plots by the four successional stages identified by the FIA program, showing both snags (dark shading) and live trees (light shading). Bars with the same letter are not significantly different at $P < 0.05$ (Tukey's Honestly Significant Difference Post-Hoc Test).

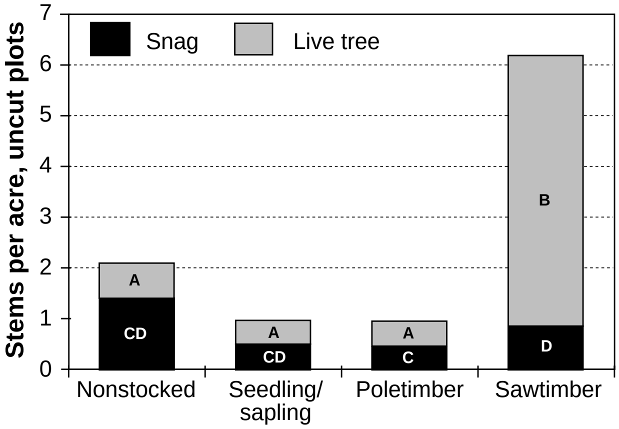

Figure 3—Standing stems per acre (21 inches or greater) in uncut plots, by the four successional stages identified by the FIA program, showing both snags (dark shading) and live trees (light shading). Bars with the same letter are not significantly different at $P < 0.05$ (Tukey's Honestly Significant Difference Post-Hoc Test).

other factors. The overall mean reflects the weight given to each of these factors by the underlying sampling regime.

Table 8 summarizes mean snag abundance by cover type. As already discussed, snags were more abundant on uncut (table 8) than cut (table 8) plots. Table 9 summarizes mean snag abundance by habitat type group. Table 10 summarizes mean snag abundance by potential vegetation group.

Viewed simply, the abundance of sawtimber-size snags on any given cover type, habitat type group or potential vegetation group, will be determined by (1) the abundance of sawtimber-size live trees from which snags can be recruited, (2) the recruitment rate of snags (mortality rate of trees), and (3) the rate at which snags fall to the ground. Forest Inventory Assessment data were ill equipped to add insight into the second and third factors, but they did allow inference regarding the first, as well as the product of the second and third (that is, the proportion of total stems that are snags at any given time). Figures 4 and 5 summarize these relationships by plotting the mean density of live trees per acre by cover type as well as the mean density of snags.

Considering all diameter classes, live trees were most dense on mixed conifer types, and somewhat less so on Englemann spruce (*Picea englemannii*) and subalpine types (fig. 4). Live tree density was least on ponderosa pine and hardwood cover types. The proportion of total stems consisting of snags was highest on subalpine, spruce/fir, and western larch cover types, and least on ponderosa pine and hardwood cover types. For example, although overall stem density was similar among Douglas-fir, western larch, and lodgepole pine cover types, snags were relatively more abundant on western larch types (fig. 4; table 8) because proportionally more of those stems were snags.

The pattern was modified somewhat when consideration was given only to the largest diameter classes of stems (21 inches and over, in this case). Large stems were most dense in mesic conifer types, followed by Englemann spruce, ponderosa pine, and western larch types (fig. 5). Ponderosa pine types ranked much higher when viewing only these large stems than when viewing all stems, and lodgepole pine and subalpine types had by far the lowest density of large-diameter stems. However, a high proportion of these few large-diameter stems in the subalpine type were

Table 9—Mean snag abundance by habitat type groups and d.b.h. class.

Habitat type group	N	Total	Small (9 to 14.9 inches)	Medium (15 to 20.9 inches)	Large (21 to 26.9 inches)	Very large (more than 27 inches)
				Snags per acre		
Cut plots						
A = Warm, dry	63	1.70	1.28	0.20	0.16	0.06
B = Moderate, warm, dry	245	2.90	2.08	0.51	0.17	0.13
C = Moderate, cool, dry	79	3.10	2.09	0.76	0.17	0.08
D = Warm, moist	99	9.80	6.69	2.01	0.64	0.46
E = Cool, moist	126	5.62	4.13	1.06	0.30	0.12
F = Wet	15	15.33	10.60	3.36	0.89	0.49
G = Moderate, cool, moist	52	4.62	3.52	0.97	0.12	0.02
H = Cool, moderate,.dry	50	9.24	8.66	0.37	0.13	0.08
I = Cold, moderate, dry	8	8.23	7.94	0.00	0.29	0.00
J = Dry	1	0.00	0.00	0.00	0.00	0.00
Uncut plots						
A = Warm, dry	74	2.92	1.71	0.87	0.24	0.10
B = Moderate, warm, dry	181	6.66	3.95	1.42	0.39	0.09
C = Moderate, cool, dry	122	9.45	7.56	1.42	0.39	0.08
D = Warm, moist	102	18.32	13.24	3.86	0.90	0.32
E = Cool, moist	284	17.47	14.10	2.43	0.70	0.24
F = Wet	27	14.58	10.80	2.33	0.94	0.51
G = Moderate, cool, moist	33	12.97	10.61	1.39	0.90	0.07
H = Cool, moderate, dry	202	17.39	14.53	2.35	0.43	0.08
I = Cold, moderate, dry	41	28.72	23.38	4.56	0.61	0.17
J = Dry	40	16.58	13.27	2.34	0.64	0.33

Table 10—Mean snag abundance by potential vegetation groups and d.b.h. class.

Potential vegetation group	N	Total	Small (9 to 14.9 inches)	Medium (15 to 20.9 inches)	Large (21 to 26.9 inches)	Very Large (more than 27 inches)
		Snags per acre				
Cut plots						
Warm, dry, frequent fire	222	2.39	1.59	0.56	0.16	0.08
Warm, moist, mixed fire	195	3.09	2.24	0.54	0.19	0.12
Cool, stand-replacing fire	221	7.26	5.71	1.12	0.30	0.12
Very moist, maritime	66	11.41	7.44	2.60	0.73	0.63
Lodgepole types	83	6.25	4.90	0.85	0.37	0.13
Whitebark pine types	4	21.44	19.48	1.33	0.64	0.00
Uncut plots						
Warm, dry, frequent fire	194	4.53	2.94	1.07	0.40	0.12
Warm, moist, mixed fire	212	8.17	6.14	1.53	0.44	0.06
Cool, stand-replacing fire	510	17.42	14.14	2.46	0.63	0.19
Very moist, maritime	78	18.36	13.68	3.52	0.81	0.34
Lodgepole types	57	15.49	13.92	1.42	0.12	0.03
Whitebark pine types	106	22.13	17.28	3.86	0.75	0.25

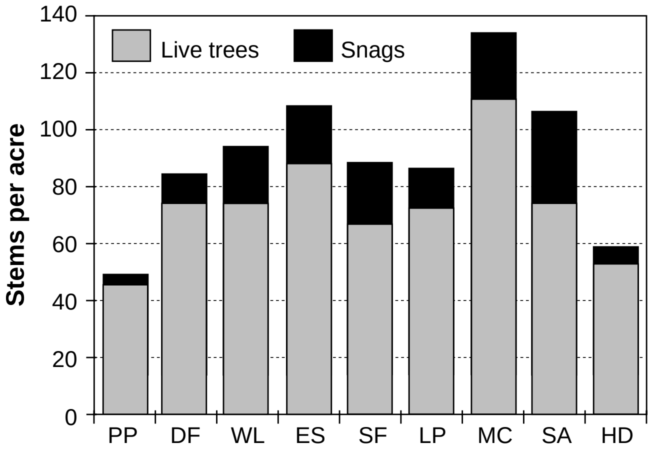

Figure 4—Density of standing live trees (light shading) and standing snags (dark shading) in d.b.h. classes 9 inches or greater, within uncut plots on classified FIA-designated cover types. Cover type abbreviations are: PP = ponderosa pine; DF = Douglas-fir; WL = western larch; ES = Englemann spruce; SF = spruce/fir; LP = lodgepole pine ; MC = mesic conifer (grand fir, western redcedar, western hemlock, western white pine); SA = subalpine (whitebark pine, limber pine, alpine larch [*L. lyallii*]); HD = hardwood (cottonwood, aspen, paper birch).

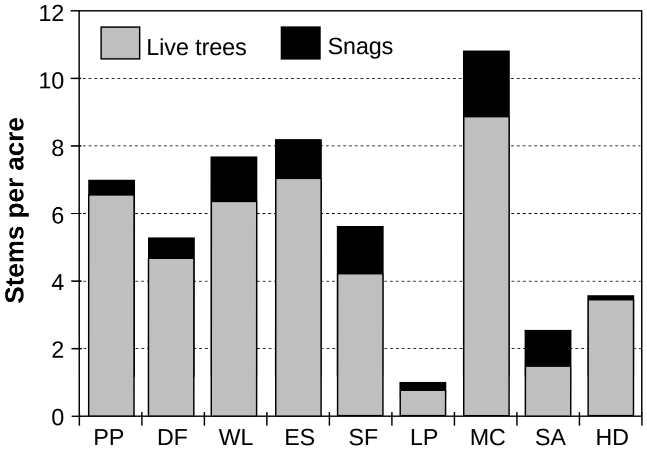

Figure 5—Density of standing live trees (light shading) and standing snags (dark shading) in d.b.h. classes 21 inches or greater, within uncut plots on classified FIA-designated cover types. Cover type abbreviations are: PP = ponderosa pine; DF = Douglas-fir; WL = western larch; ES = Englemann spruce; SF = spruce/fir; LP = lodgepole pine; MC = mesic conifer (grand fir, western redcedar, western hemlock, western white pine); SA = subalpine (whitebark pine, limber pine, alpine larch); HD = hardwood (cottonwood, aspen, paper birch).

snags, whereas snags remained a relatively low proportion of all stems in the ponderosa pine cover type.

Snag Characteristics by Cover Types

Next, I summarized snag characteristics by cover type and provided data on the predominant species of snags, particularly those that tend to be fire-resistant (western larch, ponderosa pine, Douglas-fir) (Fischer and Bradley 1987), and that frequently persisted on historical landscapes. These cover-type descriptions are limited to uncut stands.

Density of snags on ponderosa pine cover types was relatively low (fig. 6), but density of all trees was also the lowest of any cover type. Most (23 of 43 plots assigned to habitat type groups) uncut ponderosa pine cover type plots were in group ‘A’ (warm, dry), which are typically quite open, with relatively low tree density. Sample size was also small in this cover type, so inferences should be made with some caution.

Total snags were much more common on Douglas-fir types than on ponderosa pine types, averaging 8.96 per acre (SE = 0.74) (table 8) but very large (27 inches or greater d.b.h.) snags were relatively uncommon (0.10 per acre). However, Douglas-fir cover types occur on a wide variety of habitat types and potential vegetation groups, with a correspondingly wide variation in snag characteristics. Figure 7 displays the variation in snag abundance (21 inches or greater) and representation of four characteristic species within the Douglas-fir cover type. Ponderosa pine was well represented in the “warm, dry, frequent-fire regime” potential vegetation group, but essentially absent elsewhere. Western larch was well represented in the “warm, moist, mixed-fire regime” group, but less so elsewhere. Unsurprisingly, Douglas-fir was well represented in all potential vegetation groups.

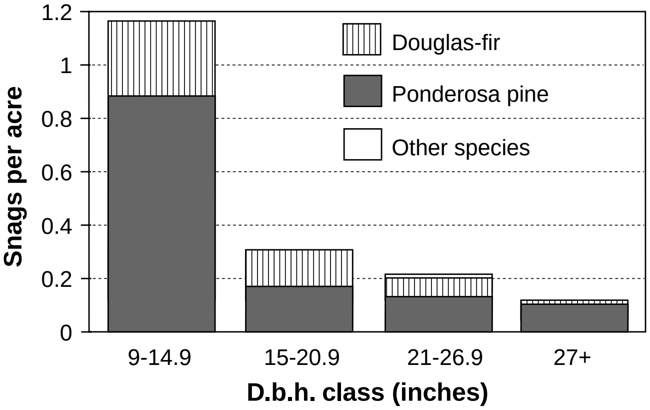

Figure 6—Snag (d.b.h. 9 inches or greater) density on uncut plots within FIA-designated ponderosa pine cover types by d.b.h. class, showing the proportion made up by ponderosa pine, Douglas-fir, and all other species.

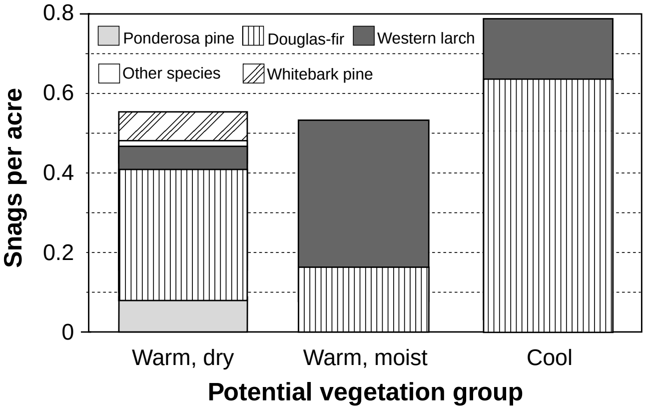

Figure 7—Snag (d.b.h. 21 inches or greater) density on uncut plots within FIA-designated Douglas-fir cover types by the three most common potential vegetation groups, showing the proportion made up by ponderosa pine, Douglas-fir, western larch, whitebark pine, and all other species.

Snag abundance was considerably greater among stands classified as western larch than either ponderosa pine or Douglas-fir (table 8; fig. 8). Total snags per acre averaged 18.79 (SE = 3.09), of which 3.56 per acre were 15 inches or larger. Most of the large snags were larch, with a smaller number of Douglas-fir. Most of the small snags were other species, notably lodgepole pine.

Snags were abundant in Englemann spruce cover types, averaging 21.32 per acre, with 4.19 per acre of these 15 inches or greater d.b.h. (table 8). Relatively few of these snags were fire-resistant species (western larch, ponderosa pine, Douglas-fir). Most of the small snags were lodgepole pine, and most of the large snags were Englemann spruce.

Snags in spruce/fir cover types were only slightly less abundant than in Englemann spruce cover types, with a mean of 21.09 snags per acre, of which 5.03 per acre were 15 inches d.b.h. or greater (table 8).

Snags were moderately common (10.73 per acre) in lodgepole pine cover types, but large (0.15 per acre) and very large (0.05 per acre) snags were rare. This result was unsurprising, considering the generally small diameter that typifies the species. Most of the largest diameter snags in this cover type were Douglas-fir and western larch.

Mesic cover types (grand fir, western redcedar, western hemlock, and western white pine) displayed similar overall snag abundance to that of western larch, Englemann spruce, and spruce/fir cover types (21.68 per acre). However, considering the larger diameter

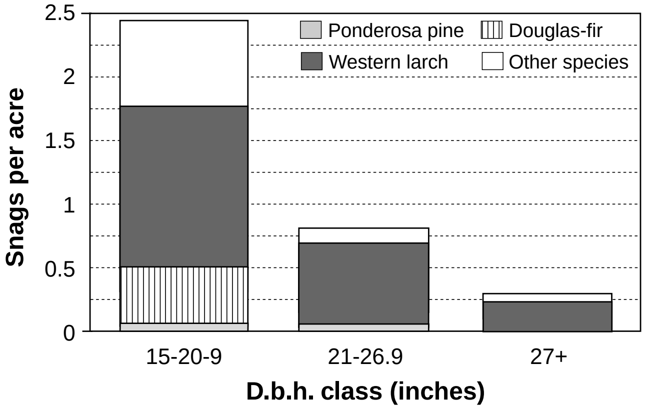

Figure 8—Snag density on uncut plots within FIA-designated western larch cover types by d.b.h. class, showing the proportion made up by ponderosa pine, Douglas-fir, western larch, and all other species.

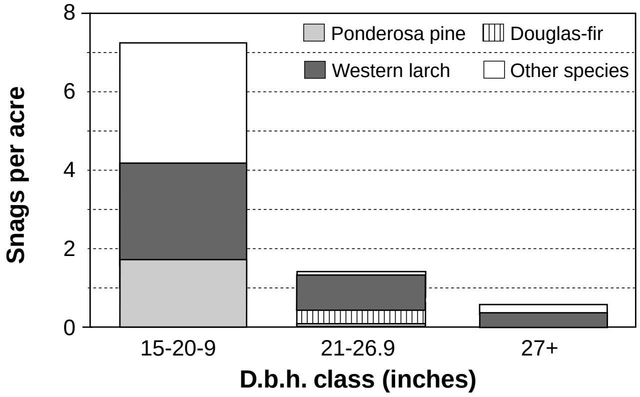

Figure 9—Snag density in mesic conifer cover types (see text for definition) by d.b.h. class, showing the proportion made up by ponderosa pine, Douglas-fir, western larch, and all other species.

snags, this cover type had the highest snag density of any defined cover type. A mean of 9.11 snags per acre were 15 inches d.b.h. or greater, and of these, a mean of 1.91 per acre were over 21 inches d.b.h. (table 8). Over half of these large-size snags were western larch (fig. 9).

Snag abundance in whitebark pine and limber pine cover types was the highest of any defined type; however, relatively few of these were in the larger diameter classes (table 8). As suggested below, current snag abundance in this type may be higher than was historically the case, due to high mortality in whitebark pine from blister rust (*Cronartium ribicola*) (Keane and Arno 1993).

Snags were less common in aspen, cottonwood, and birch cover types than in most other cover types, and large snags were particularly uncommon (table 8).

Snag Characteristics by Habitat Type Group

Total stem density was substantially higher on the warm/moist 'D' habitat type group than all others, and it was by far the lowest on the warm/dry 'A' and cold 'J' habitat type groups (table 9; fig. 10). The proportion of all stems consisting of snags generally increased from the warm/dry 'A' habitat type group on through the cold 'J' habitat type group (fig. 10). The cold/moderately dry habitat type group 'I' had the highest snag density because both total stems and proportion snags were high. As with the parallel analysis by cover types, this pattern changed somewhat when considering only the largest (21 inches and larger) stems (fig. 11). Stem density was substantially greater on the wet 'F' habitat type group. Surprisingly, the proportion of all stems constituted by snags in the wet habitat type group was the lowest of any habitat type group, resulting in a moderate total density of snags. Large snags were most common on the warm/moist 'D' habitat type group because both total stem density and proportion snags were relatively high.

Mean snag abundances on uncut plots, classified by habitat type group, varied from as few as 2.92 per acre on warm, dry 'A' habitat type groups to as many as 28.72 on cold, moderately dry 'I' habitat type groups.

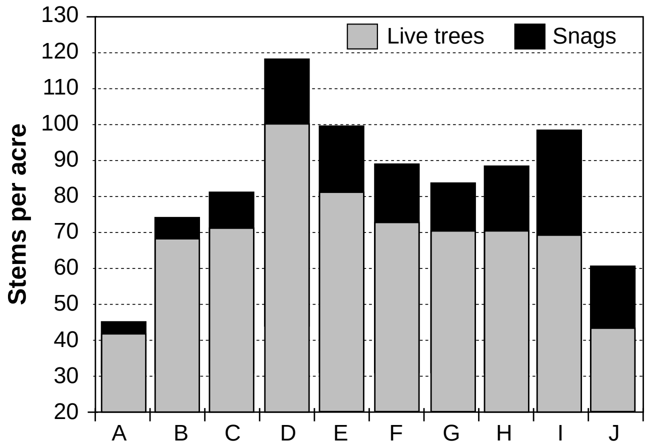

Figure 10—Density of standing live trees (light shading) and standing snags (dark shading) in d.b.h. classes 9 inches or greater, classified by habitat type groups. A = warm, dry; B = moderately warm, dry; C = moderately cool, dry; D = warm, moist; E = cool, moist; F = wet; G = moderately cool, moist; H = cool, moderately dry; I = cool, moderately dry, J = cold.

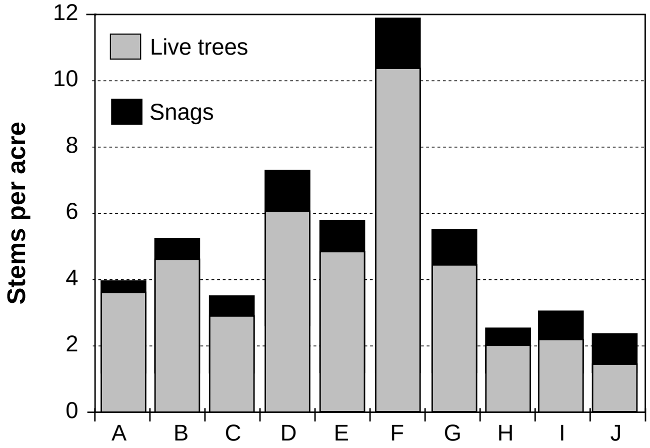

Figure 11—Density of standing live trees (light shading) and standing snags (dark shading) in d.b.h. classes 21 inches or greater, classified by habitat type groups. A = warm, dry; B = moderately warm, dry; C = moderately cool, dry; D = warm, moist; E = cool, moist; F = wet; G = moderately cool, moist; H = cool, moderately dry; I = cool, moderately dry, J = cold.

Generally, dry habitat type groups had low snag abundances, and moist or wet habitat type groups had high snag abundances (table 9).

Subtle differences may be obscured by the means displayed in table 9. For example, large (greater than 21 inches) live tree and snag abundances on habitat type groups 'B' and 'E' were similar (fig. 11). However, habitat type group 'B' was characterized by the presence of ponderosa pine and Douglas-fir snags (fig. 12), whereas ponderosa pine was virtually lacking in habitat type group 'E,' and western larch was more common. The largest number of snags occurred in habitat type group 'I,' a cold and dry habitat type group, and the highest proportion of large stems consisting of snags occurred in habitat type group 'J,' a cold, dry habitat type group (fig. 10). This seeming anomaly is most likely explained by the presence of numerous dead whitebark pines (fig. 13), resulting from the current outbreak of white-pine blister rust (Keane and Arno 1993). Presumably, the historical pattern would have resulted in fewer of these whitebark pine stems becoming snags than was evident in these recent plots.

Snag Characteristics by Potential Vegetation Group

Mean snag abundances on uncut plots, classified by potential vegetation group, varied from as few as 4.53 per acre on warm, dry, nonlethal burn regimes, to as many as 22.13 on cold, whitebark pine sites (table 10).

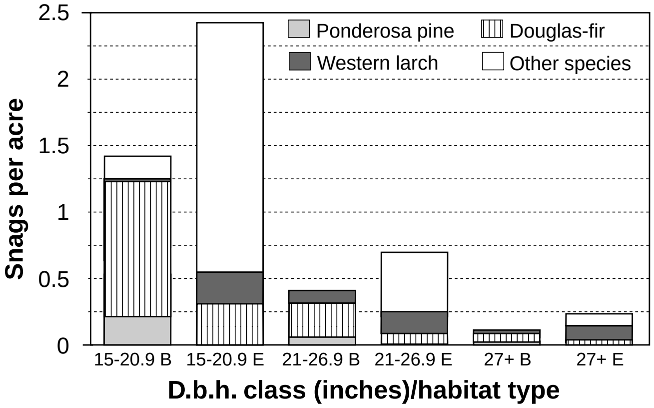

Figure 12—Snag density in two habitat type groups with a similar number of standing live trees per acre (B = moderately warm, dry; E = cool, moist) by d.b.h. class, showing the species proportion of ponderosa pine, Douglas-fir, western larch, and all other species.

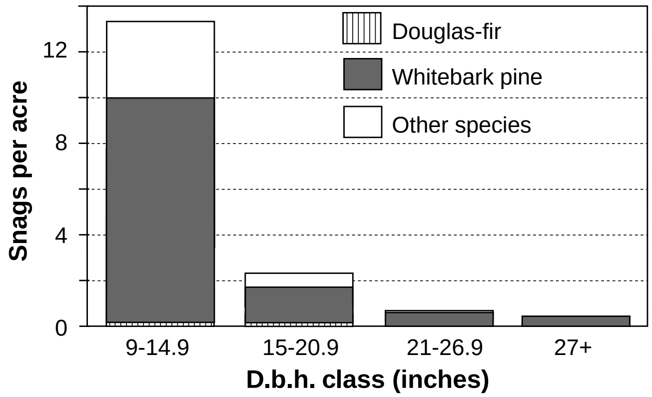

Figure 13—Snag density in the cold habitat type group by d.b.h. class, showing the predominance of whitebark pine snags.

Generally, snag abundance increased with fire intensity and fire-free intervals. Plots in the very moist/maritime potential vegetation group (usually dominated by grand fir, western redcedar, or western hemlock) had similar snag numbers as those in the cool, stand-replacing burn potential vegetation group (18.36 versus 17.42), but 15 inch or greater and 21 inch or greater snags were more abundant on the former than the latter (4.67 versus 3.28 and 1.15 versus 0.82, respectively). Species representation also differed among potential vegetation groups, with Douglas-fir and ponderosa pine dominating the "warm, dry, frequent-fire regime," western larch dominating the "warm, moist, mixed-fire regime," potential vegetation group, and the "cool, stand-replacing fire regime" having a variety of species (fig. 14).

Discussion

The use of these data are largely dependent on the degree to which the uncut plots can be reasonably interpreted as representing conditions prior to industrialized human intervention, or to which approximate corrections can be developed if this is impossible. Clearly, all plots, uncut or cut, have experienced some human influence for at least the past 60 years. Thus, some interpretation is called for before equating uncut plots, documented in the late 1980's and 1990's, with "historical conditions."

Quantifiable factors other than timber harvest that may have been important in altering snag abundance were fire frequency, insect and disease damage, wind damage, and their associated attributes of stand-size class. Although fires initially create snags, when of high intensity they also move stands out of the sawtimber class and into smaller size-classes (for example, seedling or poletimber) where snag density is generally lower (fig. 2, 3). Snags created by fire may persist for shorter times than snags created by other mortality agents (Morrison and Raphael 1993). Fires may also weaken existing snags to the point that they are more susceptible to windfall. Winds generally reduce snag abundance by blowing down trees. I would expect insect and disease damage to increase snag abundance.

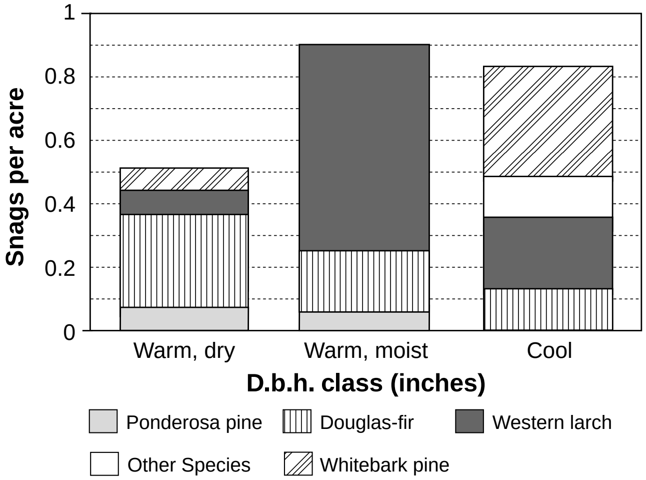

Figure 14—Density of snags 21inches or greater in the three most common potential vegetation groups, showing the species proportion of ponderosa pine, Douglas-fir, western larch, whitebark pine, and all other species.

Although uncut stands were influenced by fire suppression, fire was not entirely excluded from these plots. Fire was recorded as the "most important man-caused or natural action...evident on the sample acre" (USDA 1988 p. 37) on 13.3 percent of uncut plots compared with less than 6 percent on cut plots (table 2). Wind damage was recorded on over 4 percent of additional uncut plots compared with less than 1 percent of cut plots. Insect and disease damage was recorded for over twice as many (27.7 percent) uncut plots as with fire. Therefore, about 17 percent of uncut plots were documented as having attributes tending to reduce snag abundance, while almost 28 percent had attributes tending to increase snag abundance. However, in assessing the how "natural" these uncut stands were, the more important question is how these percentages would differ from those in stands sampled 100 years ago. Unfortunately, such comparative data are not available.

In general, it seems reasonable to assume that the number of small-diameter snags would increase with unnaturally reduced fire frequency because stocking levels would increase, leading to many early deaths during the "stem-exclusion" stage (Oliver and Larsen 1990), particularly given the likely association with fire suppression of increased insects and disease. It seems equally logical to hypothesize that the abundance of large snags (over 21 inches d.b.h.) would generally be much less influenced by unnaturally reduced fire frequency. Current density of these large-diameter snags may be similar to the prefire suppression era, especially in cover types, habitat type groups, or potential vegetation groups in which stand-replacement fires occur but at long intervals, or in which fires occur frequently but with an intensity that is incapable of killing substantial numbers of large-diameter trees. If nothing else, most large-diameter snags must have lived a substantial portion (and in some cases, the predominance) of their lives prior to effective fire suppression. If stocking densities have increased due to fire suppression, one would expect tree growth rates to decline. An additional possible complication is that fewer trees would have grown large to begin with, reducing the potential for recruitment of large-size snags.

One additional factor that would tend to produce a downward bias in snag abundance observed on uncut stands is that such stands were biased samples of all possible stands within their respective cover types and habitat types. Uncut stands were generally at higher elevations and on steeper slopes within corresponding cover types than were cut stands. While not specifically indicated by these data, I would deduce that timber harvesting has historically occurred where stands are both easily accessible and relatively productive. Because snag abundance is partly a function of overall stem abundance (fig. 4-5, 10-11) and uncut plots are located disproportionally in areas with lower stem abundance, snag abundance may likewise be biased downwards.

Given these data, deducing the likely effects of changes in the natural disturbance regimes on snag abundance is complex and uncertain. We do, however, have access to estimates of the proportion of western Montana forest cover types in various stand-size classes around 1900 (Losensky 1993, 1997), which may be useful as an approximation to more specific questions regarding disturbance history (compare with table 4). Because snags are more abundant on sawtimber-size plots than in earlier successional stages (fig. 2, 3), it is useful to know if mean snag abundances from stands classified as uncut are biased because the sawtimber-size class is "unnaturally" common. Table 11 compares the proportion of stands in the combined nonstocked plus seedling/sapling, poletimber, and sawtimber stages from uncut plots with those estimated to characterize western Montana forests around 1900 (Losensky 1993, 1997). I combined the two early stages because sample sizes were small and because snag abundances on these plots were similar in those two classes (fig. 2, 3). I also adjusted the number of FIA plots in poletimber and sawtimber categories to more nearly reflect the classification procedures used during the 1930's and adopted by Losensky (1993, 1997). This comparison must be viewed as approximate, not only because both data sets contained uncertainty, but because cover types were not necessarily defined in the same way. Bearing this caveat in mind, it appears that nonstocked and seedling/sapling plots were less abundant in the present data than was historically the case, while sawtimber stands were more abundant than around 1900. Differences in proportions varied from almost none to over 40 percent (table 11).

Considering the various, sometimes conflicting sources of bias in using recent uncut stands as a substitute for prefire-suppression averages, I estimate that the average snag densities in tables 8 through 10 may be higher than historic levels by about 10 percent.

Management Implications

In asking how many snags a forestry operation should leave behind, there are at least two considerations that must be added to the tables presented. The first question to be asked is that of the desired landscape, for example, how many snags are desirable to maintain through time? The second question is one of implementation, for example, how does one assure that the desired number are actually present at any given time? Treating the second question first, snag abundances treated in these analyses are "standing snags." In actuality, snags have recruitment and mortality rates (snags are recruited when living trees die, and die themselves when they fall over) that vary depending on species and site characteristics (Bull 1983; Lyon 1984; Morrison and Raphael 1993). In these published studies, most snags standing at the

Table 11—Comparisons (where they could be made) between proportions of uncut plots in various stand-size classes and those estimated to characterize western Montana forests around 1900 (Losensky 1993, 1997). The "nonstocked" and "seedling/sapling" classes were combined for both data sets. Losensky's "larch/Douglas-fir" category was used to compare with the FIA "larch" category, and Losensky's "spruce/fir" category to compare with FIA's "Englemann spruce" category because the latter did not include subalpine ("noncommercial") forests, which are probably more nearly comparable with the FIA "spruce/fir" type. For PP, DF, and WL types, FIA plots were classified as "poletimber" if they were initially classed as "sawtimber" but lacked trees 14.9 inches d.b.h. or larger.[a] For ES, LP, and MC types, FIA plots were classified as "poletimber" if they were initially classed as "sawtimber" but lacked trees 12.9 inches d.b.h. or larger.[a]

	PP	DF	WL	ES	LP	MC
Uncut plots						
Nonstocked/seedlings/saplings	0.12	0.07	0.00	0.06	0.08	0.06
Poletimber	0.05	0.11	0.30	0.09	0.65	0.12
Sawtimber	0.84	0.82	0.70	0.85	0.27	0.82
Total	1.01	1.00	1.00	1.00	1.00	1.00
About 1900						
Nonstocked/seedlings/saplings	0.18	0.28	0.37	0.06	0.57	0.25
Poletimber	0.11	0.33	0.13	0.07	0.31	0.22
Sawtimber	0.71	0.41	0.50	0.87	0.12	0.53
Total	1.00	1.02	1.00	1.02	1.00	1.00

[a] PP = ponderosa pine; DF = Douglas-fir; WL = western larch; ES = Englemann spruce; LP = lodgepole pine; MC = mesic conifer.

beginning of the study had fallen by 10 to 20 years later, although larger snags (more valuable for vertebrates) lasted longer, and few studies followed the fate of extremely large, persistent species (such as ponderosa pine, western larch, western redcedar) for long time periods. Allowance must be made for the fact that snags standing following a particular management activity will not necessarily last until the subsequent management activity. Snag recruits must be figured into the snag management picture, and snag retention in practice may fall short of the targeted abundance due to logging, skidding and cable practices, and firewood cutting (legal or otherwise) subsequent to logging (Hillis 1993). Adjustments to targeted snag retention amounts, therefore, may be necessary to ensure that realized snag maintenance regimes approximate desired regimes.

The answer to the question of what desired snag abundances ought to be depends crucially on overall management objectives. If biodiversity and long-term forest health are highly valued, it seems clear that, at least on a landscape scale, characteristics of standing snags (abundances, species, distribution of size classes) should approximate those occurring historically. Results presented here show that historical cutting practices have reduced snag densities on western Montana forests, most likely to levels below those that prevailed prior to fire suppression. Attention must be paid to snag retention and recruitment in existing and future silvicultural plans to ensure that snag density does not continue to decline. There are several ways the results presented here can be used to that end:

1. Targets for standing snag density can be developed for individual timber cutting units (that is, anywhere timber is cut, snags should be left on the unit in numbers sufficient to approximate the target amounts). In this case, snag retention and recruitment targets would probably best approximate those for uncut stands in nonstocked or seedling/sapling stages, because these snags would emulate "legacies" (Franklin and others 1997) remaining some time after a natural disturbance;

2. Targets for standing snag density can be developed on a landscape scale, considering that fewer snags may be left following a given timber harvest, but this may be acceptable if sufficient snags are present on nearby stands to compensate. This is consistent with the "clumpy" distribution of snags suggested by these data. However, it should be kept in mind, if adopting such a strategy, that sufficient snags should include not merely the total number, but the number in various size classes and species. While it is true that two snags per acre does not mean that every acre must have two snags, the spatial scale of these underlying data must be kept firmly in mind. (Although a substantial number of plots used here had 0 snags per acre, this might not have been the case had sampling been conducted with larger plots.) The "clumpiness" of snags observed is highly dependent on the scale used for sampling. In other words, managing for forests in which many individual acres have no snags (or large snags) is perfectly consistent with these data; managing for forests in which entire stands have no snags (or large snags) is not. In this case, standing snag abundance can be determined empirically for proposed sale areas during timber cruising, and can be estimated by extrapolation from tables 8 through 10 for a specified landscape analysis area that is not cruised.

3. Targets for standing snag density can reflect a mix of the two scales. One possibility is to consider that previously treated stands are likely to have lower than uncut snag densities, and that stands targeted for treatment should have a higher than uncut snag abundance to compensate. Another possibility is to consider that management objectives may not sufficiently prioritize biodiversity to mandate maintaining 100 percent of historically occurring abundance.

Any of these strategies should be seen as useful interim approaches, because crucial data on snag recruitment and survival (such as length of time standing) are, with the exception of Lyon (1984), lacking for western Montana forests. Such data will ultimately be useful in developing a more holistic approach toward snag management (particularly in guiding snag recruitment strategies) that attempts to retain biodiversity while simultaneously producing wood products for human use.

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Appendix A: dBASE Filter Used to Distinguish Cut and Uncut Stands

```
* Program STNDHIST

* This program assigns a four-character name for each STAND identified in the USFS FIA Plot data

* Based on the location history

* Coded “HIST” only if all other variables indicate a ‘pristine’ stand

* Coded “HUMN” only if timber cutting is not primary human use, but others are

* Coded “CUT” if any timber cutting evident

* For codes, see ‘variable LHIS’ in Woudenberg and Farrenkopf (1988)
replace all STATUS with ‘HIST’ for STNDORG = 1 .and. CUTHISTORY = 0

* OK to use for historical pattern if no human disturbance (code 1) or code is

* 610 (animal damage), 620 (insect damage), 640 (disease), 680 (weather damage), 681 (wind damage)

* 690 (fire damage) AND Cuthistory = 0 (no cutting history)
replace all STATUS with ‘HUMN’ for STNDORG <> 1 .or. LHIS > 699

* Stand has artificial regen (stand or not 1), or is road, cleared, converted, and so forth.

* but not predominately affected by timber harvesting
replace all STATUS with ‘CUT’ for LHIS = 13 .or. LHIS = 14 .or. LHIS = 15 .or. LHIS = 16 .or. LHIS = 154 .or.
LHIS = 153 .or. LHIS = 10 .or. CUTHISTORY > 0

* Stand has been cut, either clearcut (13), selective (14), other (15), salvage (16), xmas tree (153), or post/pole (154),
or (10) This designation takes precedence (for example, can overwrite either of the previous two)
```

Appendix B: Habitat Type Groups

(Green and others 1992) Codes are habitat types (Pfister and others 1977).

Habitat type group A: warm, dry
104, 105, 130, 140, 141, 142, 160, 161, 162, 170, 171, 172, 180, 181, 210, 220, 230, 350, 320, 321, 311

Habitat type group B: moderately warm, dry
324, 340, 010, 250, 260, 261, 262, 282, 310, 312, 131, 322, 324, 340, 330, 313, 320, 430

Habitat type group C: moderately cool, dry
360, 370, 356, 351, 311, 390, 380, 280, 281, 283, 292, 323, 360, 370, 510, 750

Habitat type group D: warm, moist
520, 521, 522, 523, 530, 531, 533, 570, 571, 572, 532

Habitat type group E: cool, moist
421, 422, 420, 620, 621, 622, 623, 624, 625, 660, 661, 662, 670, 680, 832, 740

Habitat type group F: wet
410, 440, 480, 550, 610, 630, 631, 632, 650, 651, 653, 654

Habitat type group G: moderately cool, moist
290, 291, 591, 293, 590, 592, 470

Habitat type group H: cool, moderately dry
450, 640, 641, 663, 690, 691, 692, 710, 720, 731, 920, 930, 940, 792, 910, 920, 930, 940, 950, 960

Habitat type group I: cold, moderately dry
733, 780, 791, 730, 732, 820, 830, 831, 791

Habitat type group J: dry
840, 850, 870, 860, 810

Appendix C: Potential Vegetation Groups

Codes are habitat types (Pfister and others 1977)

Warm, dry, frequency low intensity fire potential vegetation group
All habitat types < 260, plus 311, 321, 323, 324, 262, and 340

Warm, moist mixed fire regime potential vegetation group
260, 261, 262, 281, 282, 283, 290, 291, 292, 312, 313, 330, 350, 505, 506, 507, 508, 510, 512, 515, 592

Cool, moist-to-dry, infrequent, stand-replacing fire potential vegetation group
511, 590, 591, 517, 518, 519, 520, 521, 522, 524, 526, 529, 420, 421, 470, 620, 621, 622, 623, 624, 625, 635, 636, 637, 660, 661, 662, 670, 671, 672, 673, 674, 675, 676, 677, 680, 681, 682, 685, 686, 687, 691, 692

Maritime, very moist cedar/hemlock potential vegetation group
530, 531, 532, 533, 534, 535, 541, 542, 545, 546, 547, 548, 550, 555, 560, 570, 571, 572, 573, 574, 576, 577, 578

Lodgepole pine sites (climax or long-term disclimax) potential vegetation group
450, 640, 663, 693, 713, 732, all over 900

Very cold whitebark pine, infrequent, low intensity fires
800-899

Appendix D: Attributes in Different Cover Types, Habitat Type Groups, and Potential Vegetation Groups

Cover type	PP	DF	WL	ES	SF	LP	MC	SA	HW
Mean elevation (x100)	43	49	43	52	60	56	39	71	44
Mean slope	30	40	28	27	36	31	34	38	8
Percent cool aspects (E, NE, N)	17	36	43	43	46	28	51	18	9
Percent warm aspects (S, SW, W)	54	34	25	19	29	39	25	55	15
n	132	799	112	63	365	319	76	33	33

Habitat type group	A	B	C	D	E	F	G	H	I	J
	Warm, dry	Moderate warm, dry	Moderate cool, dry	Warm, moist	Cool, moist	Wet	Moderate cool, moist	Cool, moderate dry	Cold, moderate dry	Cold
Mean elevation (x100)	50	46	55	39	54	50	45	60	73	72
Mean slope	36	38	38	35	34	22	31	37	30	45
Percent cool aspects (E, NE, N)	23	32	30	50	43	33	49	28	36	41
Percent warm aspects (S, SW, W)	50	40	38	22	27	12	20	44	31	39
n	137	426	201	201	410	42	85	252	59	41

Potential vegetation groups	Warm, dry, frequent fire	Warm, moist, mixed fire	Cool, stand-replacing fire	Very moist maritime	Lodgepole pine	Cold White-bark pine
Mean elevation (x100)	48	49	54	39	52	70
Mean slope	37	38	34	36	27	39
Percent cool aspects (E, NE, N)	28	33	38	51	36	42
Percent warm aspects (S, SW, W)	43	37	31	21	27	32
n	416	407	731	144	140	110

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