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Estimating Historical Snag Density in Dry Forests East of the Cascade Range

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Abstract

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Estimating snag densities in pre-European settlement landscapes (i.e., historical conditions) provides land managers with baseline information for comparing current snag densities. We propose a method for determining historical snag densities in the dry forests east of the Cascade Range. Basal area increase was calculated from tree ring measurements of old ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) trees. Historical stand structure was assumed to be open and parklike, with low densities favoring larger diameter trees, and it was considered relatively stable at the landscape level. Snag density (S) was calculated by holding forest stand structure relatively constant (basal area range 13.8 to 18.4 square meters per hectare [60 to 80 ft^2/acre] and diameter size class distributions with *q*-factors of 1.1 or 1.2), assuming snag recruitment could be no greater than annual basal area increase, and estimating that all snags fall by 45 years; $S = (a)*(1 + \Sigma r_i)$, where a is annual recruitment and Σr_i is a sum of the ratios of snags remaining from previous recruitment years (i). If eight representative snag sizes are selected, snag density in historical landscapes ranged from 14.5 to 34.6 snags per hectare (5.9 to 14.1 snags per acre).

Keywords: Snag density, ponderosa pine, *Pinus ponderosa,* snag recruitment, historical forest structure.

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Introduction

Snags are important structures in forest ecosystems. They provide wildlife habitat (Thomas and others 1979) and affect fire behavior (Agee 1993), fish habitat (Platts 1983), and bank stability in streams (Platts 1983). Snags eventually may become down logs and provide important ecosystem functions, such as nutrient cycling (Maser and others 1979), water storage (Maser and others 1979), soil stabilization (Graham and others 1994), and habitat for wildlife and numerous invertebrate, microbial, and fungal species. Snags that fall across streams provide links between terrestrial and aquatic ecosystems and contribute to the development of stepped stream profiles that reduce channel erosion (Harmon and others 1986). The importance of snags and logs within terrestrial and aquatic ecosystems is reviewed by Harmon and others (1986).

Land managers may choose to develop snag management strategies that ensure the recruitment of snags in a full range of sizes. Previous studies and recommendations concerning snag management levels have been carried out in present-day landscapes altered by fire suppression, logging, and grazing. As land managers attempt to restore historical ecosystem conditions, it is important that any sustainable snag management strategies that are developed be guided by the range of natural variability (see Morgan and others 1994, Swanson and others 1994, USDA 1995a, USDA and USDI 1994).

We propose a method of estimating presettlement snag recruitment in dry forests (ponderosa pine [*Pinus ponderosa* Dougl. ex Laws.], Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco] and dry plant associations within the grand fir [*Abies grandis* (Dougl. ex D. Don) Lindl.] series) on the east side of the Cascade Range. We provide estimates of presettlement snag densities in several diameter classes and demonstrate how this model is useful as a tool for ecosystem management on the east side of the Cascade Range.

Methods

The process of determining historical snag density involves first modeling historical stand structure, then measuring tree growth under historical conditions, and finally estimating snag fall rates.

Historical Stand Structure and Growth

We assumed that long-term snag recruitment potential cannot exceed the rate of tree growth on the landscape. We also assumed that snag densities and recruitment rates in historically dry forest landscapes of the east side of the Cascade Range were predictable, based on a historical disturbance regime of frequent, low-intensity fires. These fires created an uneven-aged vegetative structure at the landscape scale with small (<0.5 hectare [1.2 acre]), even-aged groups of trees primarily dominated by large ponderosa pine (Agee 1994, Avery and others 1976, Hessburg and others 1994, Johnson 1994, Weaver 1943, Wickman 1992). Tree mortality in these historical landscapes were continuous and occurred in small patches (<0.5 hectare [1.2 acre]) as a result of low intensity fire, insects (particularly western pine beetle [*Dendroctonus brevicomis*]), and diseases (Agee 1994, Hessburg and others 1994, Weaver 1943, Wickman 1992).

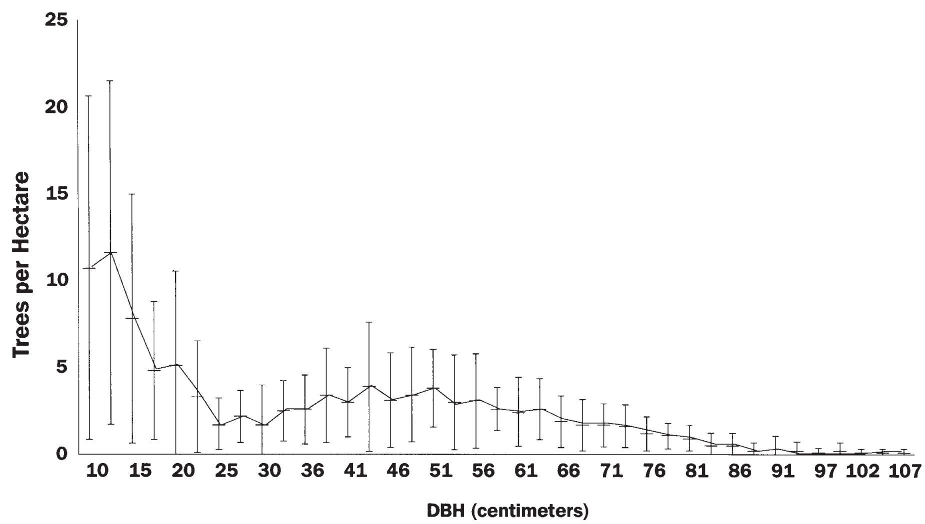

Figure 1—Mean number and standard deviation of trees per hectare by diameter size class from a ponderosa pine stand, Arizona, 1929 (from Avery and others 1976).

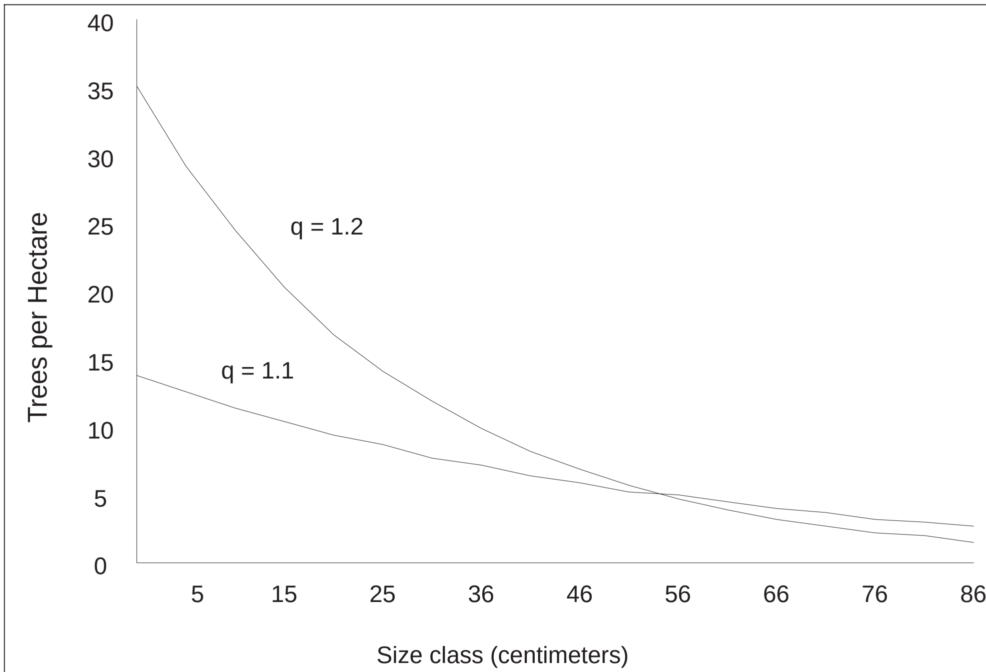

Figure 2—When basal area is 18.4 square meters per hectare (80 ft^2/acre), the diameter distribution with a *q*-factor of 1.1 produces a flat inverse J-shaped curve indicating many large and fewer small trees. A *q*-factor of 1.2 produces a slightly more pronounced inverse J-shaped curve indicating more small trees.

We also assumed that the tree-stem diameter distribution of single-species, uneven-aged stands or landscapes generally can be described by an inverse J-shaped curve, when tree diameter is plotted against the number of trees per unit area. This curve is convertible to a straight line if the logarithms of the numbers of trees per unit area are plotted against the arithmetic diameters (Smith 1986). The *q*-factor, which stands for quotient and describes the shape of the curve, defines a geometric progression of increasing number of trees with decreasing diameters (Smith 1986). Determining the shape of the inverse curve involves choosing three parameters: initial basal area, selection of a *q*-factor, and maximum tree size. Because no historical stand data apparently exist for the east side, we used ponderosa pine stand descriptions from 1920 and data sets from Arizona (Avery and others 1976) to guide our selection of parameter values. The data presented in Avery and others (1976) come from 16 subplots (total of 16 hectares [40 acres]) from the 31-hectare (76-acre) G.A. Pearson Natural Area. The area is described as a climax forest in irregular, uneven-aged stands consisting of small even-aged groups with an abundance of large ponderosa pine individuals (fig. 1). Avery and others (1976) note that the area had not been logged or subjected to stand replacement fire. Our study area was within the Douglas-fir and grand fir climax series, but these sites were dominated by ponderosa pine.

We calculated size class distributions of trees by using the equation from Alexander and Edminster (1977):

$$\mathbf{N}_d = k(e^{-D(\ln * q)1/2}),$$

where N_d is the number of trees per hectare in size class D, k is the residual density parameter, and D is the midpoint of a diameter class. We used several combinations of parameter values to derive two inverse J-shaped curves that we assume approximate historical diameter distributions. Historical basal area likely ranged from about 13.8 square meters per hectare (60 ft^2/acre) (Avery and others 1976) to less than 21 square meters per hectare (90 ft^2/acre)[1] or 23 square meters per hectare (100 ft^2/acre).[2] For the initial basal area, we chose values of 13.8 square meters per hectare (60 ft^2/acre) (from Avery and others 1976) and 18.4 square meters per hectare (80 ft^2/acre). The *q*-factors of 1.1 and 1.2 were chosen to define two possible shapes for the diameter distribution curves (fig. 2), which represent a range of historical structural conditions (Avery and others 1976; and as suggested by Agee 1993, 1994; Keen 1929, 1955). Maximum initial tree size was held constant at a 91-centimeter (36-in) diameter at breast height (DBH) for both calculations.

To determine growth rate of trees under historical stand conditions, we sampled 69 randomly selected, old ponderosa pine trees at 32 sites within 15 kilometers (9 mi) north and south of Leavenworth, Washington. All sites were in dry plant associations within the Douglas-fir and grand fir series (Lillybridge and others 1995). We measured increment cores, taken at breast height, to determine mean 10-year growth rates by

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[1] Personal communication. 1994. Jim Hadfield, forest pathologist, Wenatchee Forestry Sciences Laboratory, 1113 Western Ave., Wenatchee, WA 98801.

[2] Sloan, J. 1994. Historical density and stand structure of an old growth forest in the Boise basin of central Idaho. Ogden, UT: Intermountain Research Station. 24 p. Unpublished report. On file with: Wenatchee National Forest, Leavenworth Ranger Station, 600 Sherbourne, Leavenworth, WA 98826.

diameter classes (inside bark). The most recent 60 years (outer 60 rings) were ignored because active fire suppression and partial-cut logging likely impacted tree growth. Our sample provided information for the period from 1700 to 1930. Fire suppression in the area studied did not become efficient until about 1930 (USDA 1995b). We assumed that the sampled trees were growing under the frequent fire regimes dominant before European settlement.

For the trees sampled, diameters inside bark (DIB) were converted to estimated diameters outside bark (DOB) by including bark thickness (BT). Outside bark diameters were estimated by using the equation, DOB = DIB/0.87, which is derived by rearranging BT = 0.065 (DOB) for Douglas-fir (Ryan and Reinhardt 1988). Peterson and Ryan (1986) observed that bark thickness of ponderosa pine, western larch (*Larix occidentalis* Nutt.), and Douglas-fir are similar for a given diameter.

We applied the 10-year growth rates by diameter class to stands described by the two inverse J-shaped curves selected. The 10-year basal area increase was used to determine snag recruitment potential by 10-centimeter (4-in) DBH size categories. The 10-year basal area increase was divided by eight diameter groups to estimate snag recruitment potential. Basal area increase of representative trees (midpoint) of each diameter class was used to calculate snag recruitment potential. Basal area increase of trees less than 10 centimeters (4 in) was ignored because it would not contribute to producing 15-centimeter (6-in) or larger snags. Basal area available for snag recruitment by diameter category was converted to number of snags per hectare (SPH, or SPA for acre).

Fall Down Rates and Snag Density

Snag fall down rates from 0 to 15 years were determined by compiling data from the literature (Bull 1983; Keen 1929, 1955; Schmid and others 1985) and estimating curves for small (30 centimeters [12 in] in diameter) and medium and large DBH ponderosa pine snags (43 centimeters [17 in] and 64 centimeters [25 in], respectively). These fall rates were similar to those that Raphael and Morrison (1987) determined for Jeffrey pine (*Pinus jefferyi* Grev. & Bals.), which is similar to ponderosa pine. Falling rates beyond 15 years were extrapolated because we could find no data on snag longevity beyond this period. We assumed that all small (30 centimeters [12 in] in diameter) snags would have fallen by 20 years and medium to large (43 centimeters [17 in] and 64 centimeters [25 in] in diameter, respectively) snags would have fallen by 45 years (fig. 3). It should be noted, however, that any fall rate can be applied to this model.

Snag density by the eight size categories was calculated from the equation $S = (a) * (1 + \Sigma r_i)$, where S is snag density, a is the annual snag recruitment rate (recruitment rate per decade divided by 10), and Σr_i is a summation of the ratios (percentage divided by 100) of snags remaining from previous recruitment years (i).

We performed a sensitivity analysis (Brown and Rothery 1993) of the extrapolated portion, beyond year 15, of our snag density estimates by varying the time, from 30 to 60 years, at which 100 percent of snags recruited during any event have fallen.

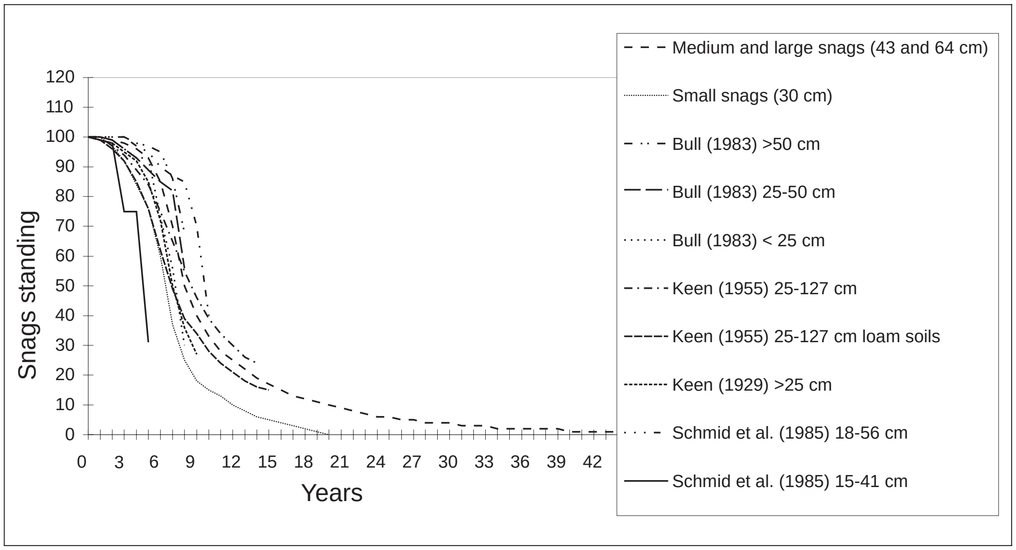

Figure 3—Fall down rates of small, and medium and large snags. Fall down rates from year 0 to year 15 were based on several studies. Rates beyond 15 years were extrapolated.

Results

Historical Stand Structure and Growth

The total number of trees per hectare (TPH) per decade, given an initial basal area of 18.4 square meters per hectare (80 ft^2/acre) and a *q*-factor of 1.1 was 110.7 (44.8 trees per acre [TPA]) (table 1). Using the same *q*-factor, but changing the initial basal area to 13.8 square meters per hectare (60 ft^2/acre), resulted in a 25-percent decrease in the number of TPH (92.7; 37.5 TPA) and a corresponding 25-percent decrease for each size class; the shape of the curve remained the same. When a *q*-factor of 1.2 was used, the total number of TPH with an initial basal area of 18.4 square meters per hectare (80 ft^2/acre) was 167.5 (67.8 TPA; table 1). The reduction of trees per unit area created by using the 1.2 *q*-factor and reducing an initial basal area to 13.8 square meters per hectare (60 ft^2/acre) was again 25 percent (125.6; 46.1 TPA).

Diameter growth per decade for 5-centimeter (2-in) inside bark size classes (fig. 4) was converted to DBH. This diameter growth was applied to the 18.4 square meters per hectare (80 ft^2/acre) and 13.8 square meters per hectare (60 ft^2/acre) diameter distribution models to determine basal area increase per decade (table 1). The 13.8 square meters per hectare (60 ft^2/acre) models are 75 percent of the basal area and trees-per-hectare descriptions (table 1). Change in basal area, which could be available for snag recruitment, was 2.04 square meters per hectare (8.86 ft^2/acre) per decade for a *q*-factor of 1.1 and an initial basal area of 18.4 square meters per hectare (80 ft^2/acre) (table 1). Change in basal area for a *q*-factor of 1.2 and an initial basal area of 18.4 square meters per hectare (80 ft^2/acre) was 2.72 square meters per hectare (11.83 square feet per acre) (table 1).

Table 1—Change in basal area per decade (as measured in our study) and total trees per hectare by diameter class[a]

DBH class		q 1.1, 18.4 square meters per hectare (80 ft^2/acre)				q 1.2, 18.4 square meters per hectare (80 ft^2/acre)			
Start	End	TPH (TPA)[b]	Starting BA[c]	Ending BA	Change in BA	TPH (TPA)	Starting BA	Ending BA	Change in BA
Centimeters (in)									
10 (4)	13.8 (5.4)	12.60 (5.10)	0.10 (0.44)	0.19 (0.82)	0.09 (0.38)	29.16 (11.8)	0.24 (1.03)	0.44 (1.90)	0.20 (0.87)
15 (6)	18.6 (7.3)	11.37 (4.60)	0.21 (0.90)	0.31 (1.35)	0.10 (0.45)	24.46 (9.90)	0.44 (1.94)	0.68 (2.91)	0.22 (0.97)
20 (8)	24.5 (9.6)	10.38 (4.20)	0.34 (1.47)	0.49 (2.13)	0.15 (0.66)	20.26 (8.20)	0.65 (2.86)	0.96 (4.16)	0.30 (1.30)
25 (10)	29.0 (11.4)	9.39 (3.80)	0.47 (2.07)	0.62 (2.69)	0.14 (0.62)	16.80 (6.80)	0.85 (3.71)	1.11 (4.82)	0.25 (1.11)
30 (12)	34.2 (13.5)	8.65 (3.50)	0.63 (2.75)	0.79 (3.46)	0.16 (0.71)	14.09 (5.70)	1.03 (4.47)	1.29 (5.63)	0.27 (1.16)
36 (14)	39.0 (15.4)	7.66 (3.10)	0.76 (3.31)	0.92 (3.99)	0.16 (0.68)	11.86 (4.80)	1.18 (5.13)	1.42 (6.18)	0.24 (1.05)
41 (16)	44.0 (17.3)	7.17 (2.90)	0.93 (4.05)	1.09 (4.74)	0.16 (0.69)	9.88 (4.00)	1.28 (5.58)	1.50 (6.54)	0.22 (0.96)
46 (18)	48.9 (19.3)	6.42 (2.60)	1.05 (4.59)	1.21 (5.26)	0.15 (0.67)	8.15 (3.30)	1.34 (5.83)	1.53 (6.68)	0.20 (0.85)
51 (20)	54.0 (21.3)	5.93 (2.40)	1.20 (5.24)	1.35 (5.92)	0.16 (0.68)	6.92 (2.80)	1.40 (6.11)	1.58 (6.90)	0.18 (0.70)
56 (22)	58.8 (23.1)	5.19 (2.10)	1.27 (5.54)	1.41 (6.13)	0.14 (0.59)	5.68 (2.30)	1.39 (6.07)	1.54 (6.72)	0.15 (0.65)
61 (24)	63.5 (25.0)	4.94 (2.00)	1.44 (6.28)	1.57 (6.82)	0.12 (0.54)	4.70 (1.90)	1.37 (5.97)	1.49 (6.48)	0.12 (0.51)
66 (26)	68.3 (26.9)	4.45 (1.80)	1.52 (6.64)	1.63 (7.10)	0.10 (0.46)	3.95 (1.60)	1.35 (5.90)	1.45 (6.31)	0.09 (0.41)
71 (28)	73.1 (28.8)	3.95 (1.60)	1.57 (6.84)	1.66 (7.23)	0.09 (0.39)	3.21 (1.30)	1.28 (5.56)	1.35 (5.87)	0.07 (0.31)
76 (30)	78.0 (30.7)	3.71 (1.50)	1.69 (7.36)	1.77 (7.72)	0.08 (0.36)	2.72 (1.10)	1.24 (5.40)	1.30 (5.66)	0.06 (0.26)
81 (32)	83.0 (32.7)	3.21 (1.30)	1.67 (7.26)	1.74 (7.58)	0.07 (0.32)	2.22 (0.90)	1.15 (5.03)	1.21 (5.25)	0.05 (0.22)
86 (34)	88.2 (34.7)	2.97 (1.20)	1.74 (7.57)	1.81 (7.90)	0.08 (0.33)	1.98 (0.80)	1.16 (5.04)	1.21 (5.27)	0.05 (0.23)
91 (36)	93.4 (36.8)	2.72 (1.10)	1.79 (7.78)	1.86 (8.11)	0.08 (0.33)	1.48 (0.60)	0.97 (4.24)	1.02 (4.42)	0.04 (0.18)
Totals		110.71 (44.80)	18.38 (80.09)	20.42 (88.95)	2.03 (8.86)	167.52 (67.80)	18.34 (79.87)	21.06 (91.70)	2.72 (11.83)

[a] Each 5-centimeter (2 in) size class is represented by the midpoint diameter (e.g., the 20-centimeter [8-in] class represents trees 17.8 to 22.6 centimeters [7.0 to 8.9 in]. English equivalents are provided in parentheses.
[b] TPH = trees per hectare; TPA = trees per acre.
[c] BA = basal area.

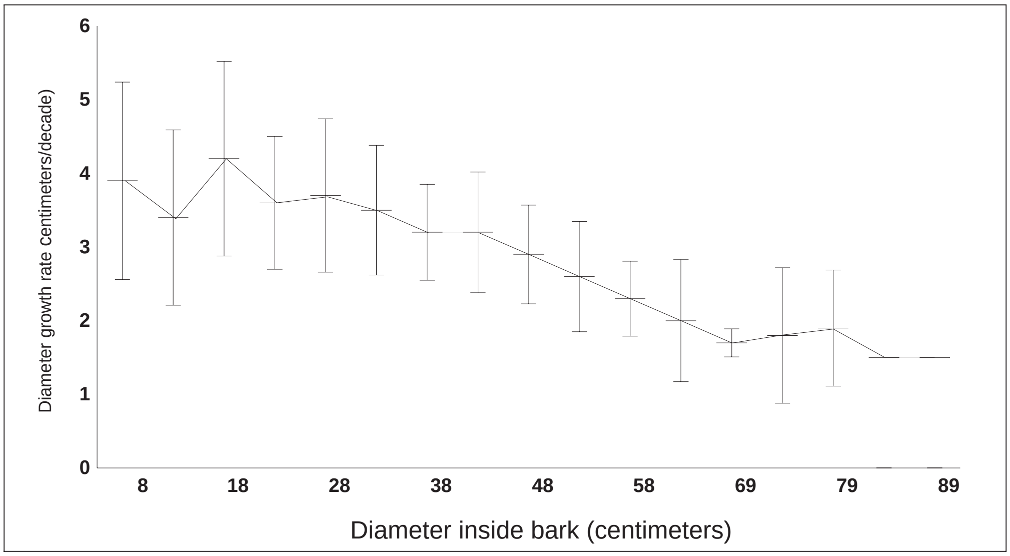

Figure 4—Mean diameter growth and standard deviation per decade decreases as diameter inside bark increases.

The basal area available for snag recruitment in each of eight size categories and actual snag recruitment rate per decade for representative trees sizes are presented for two stand types with an initial basal area of 18.4 square meters per hectare (80 ft^2/acre) and *q*-factors of 1.1 and 1.2 (table 2). The 13.8 square meters per hectare (60 ft^2/acre) models are 75 percent of the basal area and trees-per-hectare descriptions (table 2).

Fall Down Rates and Snag Density

At any given year, the number of snags remaining from any recruitment event can be calculated and is expressed as a ratio. The sum of the ratios intersected at any given year (i.e., $1 + \Sigma ri$) is conceptually presented in figure 5. The sum of the ratios was 7.6 for small snags and 11.2 for medium and large snags. Annual recruitment (*a*) was derived from table 2. A range of snag densities for *q*-factors of 1.1 and 1.2, and basal areas of 13.8 square meters per hectare (60 ft^2/acre) and 18.4 square meters per hectare (80 ft^2/acre), is presented in table 3. The total range of estimated S for all eight size categories was 14.5 SPH (5.9 SPA) to 34.6 SPH (14.1 SPA) (table 3).

Shortening longevity of medium to large snags to 30 years reduced snag density by 5 percent, and lengthening snag longevity to 60 years increased snag density by 8.5 percent.

Table 2—Potential snag recruitment rate per decade for 8 representative tree sizes given 2 stand types[a]

Stand structure and initial basal area	Snag size category	Basal area available for snag recruitment	Representative tree size	Potential snag recruitment rate/10 yrs
Square meters per hectare (ft^2/acre)	*Centimeters (in)*	*Square meters per hectare (ft^2/acre)*	*Centimeters (in)*	*TPH (TPA)*[b]
q = 1.1, 18.4 (80)	15-20 (6-8)	0.19 (0.83)	18 (7)	10.4 (4.2)
	25-30 (10-12)	0.29 (1.28)	28 (11)	4.8 (1.9)
	36-41 (14-16)	0.32 (1.39)	38 (15)	2.8 (1.1)
	46-51 (18-20)	0.31 (1.36)	48 (19)	1.7 (0.7)
	56-61 (22-24)	0.29 (1.27)	58 (23)	1.1 (0.4)
	66-71 (26-28)	0.32 (1.39)	69 (27)	0.9 (0.3)
	76-81 (30-32)	0.16 (0.68)	79 (31)	0.3 (0.1)
	86-91 (34-36)	0.15 (0.66)	89 (35)	0.2 (0.1)
q = 1.2, 18.4 (80)	15-20 (6-8)	0.42 (1.84)	18 (7)	23.2 (9.4)
	25-30 (10-12)	0.55 (2.41)	28 (11)	9.0 (3.7)
	36-41 (14-16)	0.51 (2.21)	38 (15)	4.4 (1.8)
	46-51 (18-20)	0.42 (1.81)	48 (19)	2.3 (0.9)
	56-61 (22-24)	0.33 (1.44)	58 (23)	1.2 (0.5)
	66-71 (26-28)	0.28 (1.23)	69 (27)	0.8 (0.3)
	76-81 (30-32)	0.11 (0.48)	79 (31)	0.2 (0.1)
	86-91 (34-36)	0.09 (0.41)	89 (35)	0.2 (0.1)

[a] Ending DBH, for each 5-centimeter (2-in) DBH class, is used to distribute basal area among snag size classes. Each 10-centimeter (4-in) snag size class is represented by the midpoint diameter of two 5-centimeter (2-in) size classes (e.g., the 25-to 30-centimeter [10-12 in] class represents snags 22.8 to 32.8 centimeters [9 to 12.9 in) DBH). English equivalents are provided in parentheses.

[b] TPH = trees per hectare; TPA = trees per acre.

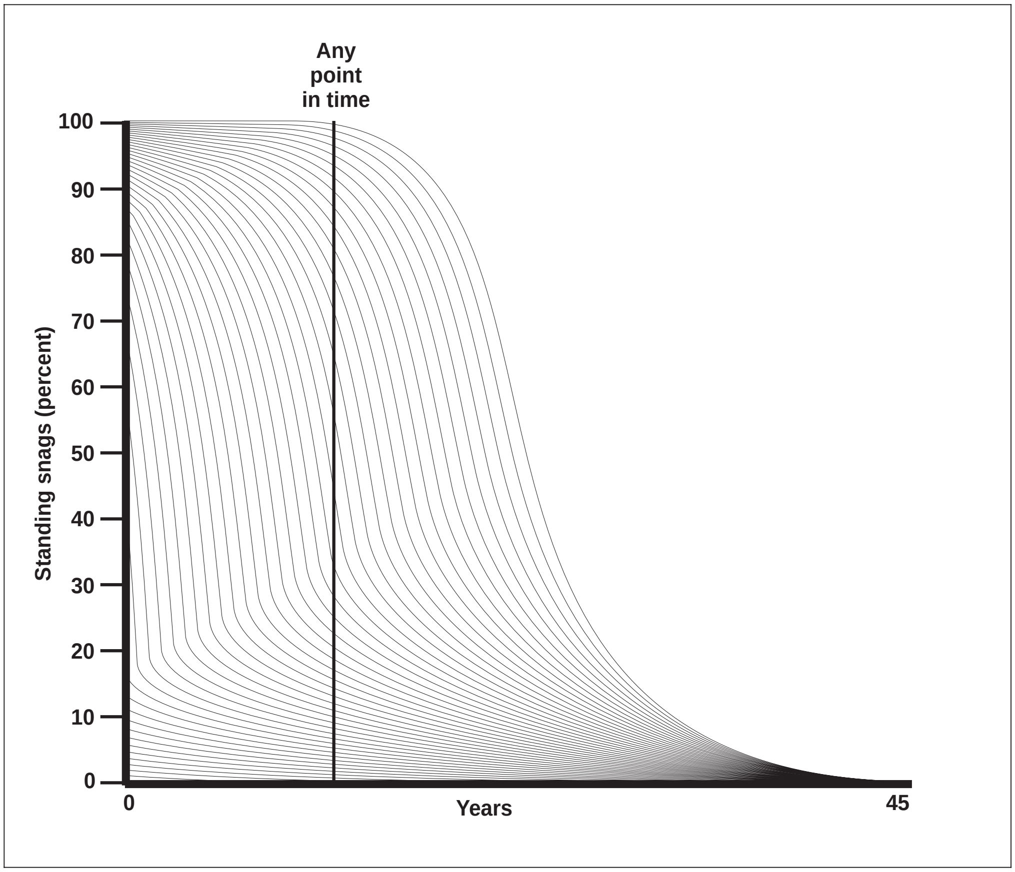

Figure 5—Conceptual diagram of the summation of the ratios of medium and large snags remaining from previous recruitment years ($1 + \Sigma r_i$). Each curve represents a recruitment year.

Table 3—A range of snag densities is presented for 8 representative tree sizes

Stand structure and initial basal area	Snag density by representative snag size SPH (SPA)[a]								
	18 (7)	28 (11)	38 (15)	48 (19)	58 (23)	69 (27)	79 (31)	89 (35)	Total
Square meters per hectare (ft^2/acre)									
q = 1.1, 18.4 (80)	7.9 (3.2)	3.6 (1.5)	3.1 (1.5)	1.9 (0.8)	1.2 (0.5)	1.0 (0.4)	0.4 (0.2)	0.3 (0.1)	19.4 (8.0)
q = 1.2, 18.4 (80)	17.6 (7.1)	6.8 (2.8)	5.0 (2.0)	2.5 (1.0)	1.4 (0.6)	0.9 (0.4)	0.2 (0.1)	0.2 (0.1)	34.6 (14.1)
q = 1.1, 13.8 (60)	5.9 (2.4)	2.7 (1.1)	2.3 (0.9)	1.4 (0.6)	0.9 (0.4)	0.8 (0.3)	0.3 (0.1)	0.2 (0.1)	14.5 (5.9)
q = 1.2, 13.8 (60)	13.2 (5.3)	5.1 (2.1)	3.8 (1.5)	1.8 (0.8)	1.0 (0.4)	0.7 (0.3)	0.2 (0.1)	0.2 (0.1)	26.0 (10.6)

[a] SPH = snags per hectare; SPA = snags per acre.

Discussion

Historical Landscape Structure

Ponderosa pine dominated the stands within the Douglas-fir series and the drier plant associations within the grand fir series because of the low-intensity fire regime (Agee 1996, Cooper 1960, Covington and Moore 1994). Low fire intensity and high fire frequency would be required to maintain a steady recruitment of ponderosa pine snags at the landscape level. Crown fires occurring infrequently would tend to create “pulses” of high-density snag recruitment followed locally by periods of no recruitment. Agee (1993, 1994) and others (Hall 1976, 1980, 1984; Hessburg and others 1994; Johnson 1994) note that dry forest landscapes east of the Cascade Range maintained rather stable structure prior to European settlement because of frequent fires and the resultant forest structure (open and parklike at the landscape level). High-intensity fires occasionally occurred within small groups of trees (stand level) and accounted for as much as 10 percent, per fire event, of the dry forest landscape.[3] The stand structures described in our study did not provide the opportunity for large, landscape-level stand replacement crown fires.

Additional evidence for maintaining steady snag recruitment can be found by examining critical stand characteristics that promote or maintain crown fire activity. These conditions include critical surface fire intensity (which incorporates crown base height and foliar moisture content) and critical crown bulk density, which is 0.1 kilogram •meter^{-3} •hectare (0.002 lb • ft^{-3} •acre^{-1}) if high potential rates of spread as measured elsewhere are assumed (see footnote 3). Crown bulk densities for forest landscapes with 18.4 square meters per hectare (80 ft^2/acre) basal area and tree size class distribution curves favoring the larger sizes (*q*-factors of 1.1 and 1.2) were 0.03 kilogram •meter^{-3}•hectare^{-1} D (0.0006 lb •ft^{-3}•acre $^{-1}$) and 0.04 kilogram •meter^{-3}•hectare^{-1D} (0.0008 lb •ft^{-3}•acre^{-1}), respectively. Surface fire intensity also was likely quite low (because of fire frequency), so again, snag recruitment and density would have been relatively stable within the forest landscape described, as compared to fluctuations associated with stand replacing fires.

Avery and others (1976) measured 14.24 square meters per hectare (62.04 ft^2/acre) of basal area on 16 plots in Arizona in 1920. Agee (1993) provides a discussion of studies that have investigated stand structures in Arizona and the Pacific Northwest and describes their similarities. Furthermore, Avery and others (1976) is the only published document providing specific data before the onset of fire suppression. Sloan (see footnote 2) suggests that basal area was likely less than 23 square meters per hectare (100 ft^2/acre) in dry forests in the Boise basin, central Idaho. An unpublished report[4] suggests that historical basal area in dry forests on the east slope of the Cascades was 21 square meters per hectare (90 ft^2/acre) or less. Our selection of a basal area range between 13.8 and 18.4 square meters per hectare (60 and 80 ft^2/acre) to determine historical snag recruitment and density is representative of the available information.

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[3] Agee, James K. Report to the fire restoration team. Wenatchee, WA: Wenatchee Forestry Sciences Laboratory. 25 p. Unpublished report. On file with: Wenatchee National Forest, Leavenworth Ranger Station, 600 Sherbourne, Leavenworth, WA 98826.

[4] Hadfield, Jim. Report to the fire restoration team. Wenatchee, WA: Wenatchee Forestry Sciences Laboratory. 15 p. Unpublished report. On file with: Wenatchee National Forest, Leavenworth Ranger Station, 600 Sherbourne, Leavenworth, WA 98826.

Snag Recruitment

Efficient fire suppression over the past 60 years has changed the structure and composition of dry forest landscapes (Agee 1994; Franklin and Dyrness 1973; Hall 1976, 1980, 1984; Johnson 1994; Marsden 1983; Mutch and others 1993; Wickman 1992). As a result, a system that historically operated under a low-severity fire regime has been converted to a moderate-to-high fire regime (Agee 1994). Snag recruitment in the landscape we have modeled was relatively stable because of the disturbance regime. Current dry forest conditions are conducive, however, to large-scale wildfires. The Tyee and Rat Creek fires of 1994 in Chelan County, Washington, provide examples of altered fire behavior and resultant landscape patterns. High-severity crown fires burned thousands of hectares thereby creating an abundance of snags. If postfire snags fall at the rates we have described, all snags will be down by the end of the fourth decade postfire. The time required for a postfire ponderosa pine tree seedling (starting with a 9-centimeter [3.5 in] tree at time zero) to reach 50 centimeters (20 in), based on the growth rates we measured, is estimated at 80 to 110 years if tree densities are regulated. During that period, only small snags have the potential to be recruited. Present-day dry forest ecosystems are recruiting snags episodically at a broad scale as compared to the systems we have described.

Fall down rates are a critical aspect of determining snag densities. Raphael and Morrison (1987) and Morrison and Raphael (1993) suggest that models of snag dynamics include species and condition of trees becoming snags, as well as causal agents of mortality. Measuring snag fall down rates requires observations made for a variety of diameter size classes over a long period. Studies concerning ponderosa pine have extended only up to 15 years (see Bull 1983, Keen 1929, Schmid and others 1985). Keen (1955) provides data over 30 years but all diameter size classes were lumped together after 17 years. Dahms (1949) provides fall down rates for 22 years after a fire, but estimated the first 10 years. His estimates assume that the fire was the causal agent of death, although actual time of death during that 10 years is unknown. Dahms' data, therefore, are likely biased toward longer retention rates because of time of death rather than because of fire increasing snag longevity. In addition, Keen (1955) points out that Dahms' measurements of fire-killed snags were made on pumice soils and were similar to his measurements of beetle-killed trees on pumice soils, thereby suggesting that soil conditions are more important than cause of death. There seems, however, to be disagreement in the literature regarding longevity of dead trees created by various killing agents. We were purposely "generous" in choosing 45 years as the point when all snags have fallen, recognizing that a few individuals within a population of snags may last longer. Some recent data collected in the Leavenworth Ranger District, Wenatchee National Forest, suggest that some snags may last up to about 80 years.[5] The rate of snag fall down at the tail end of the curve, as measured by Keen (1955), was about 3 percent per year. At this rate, 100 percent fall down likely would be realized by year 22. Keen (1929) states that it is unlikely that many snags pass the 25-year mark, but some of the largest snags

[5] Personal communication. 1994. Dick Schellhaas, research forester, Wenatchee Forestry Sciences Laboratory, 1133 Western Ave., Wenatchee, WA 98801

might last as long as 50 years (Keen 1955). Bull also points out that most large snags do not last beyond 20 years.[6] Our sensitivity analysis suggests that increasing or decreasing the point in time when 100 percent of snags fall has little effect on the overall outcome of snag density estimates. In addition, site-specific data could be substituted for our fall down rates to provide snag density estimates for any given dry, east-side area.

Applications to Ecosystem Management

The Northwest Forest Plan (USDA and USDI 1994) provides a strategy for restoring and maintaining the ecological health of watersheds through management activities. This document states that "the baseline from which to assess maintaining or restoring the [ecosystem] condition is developed through a watershed analysis," and that "improvement relates to restoring biological and physical processes within their ranges of natural variability" (USDA and USDI 1994: B-10). Natural variability refers to the composition, structure, and dynamics of ecosystems prior to European settlement (Morgan and others 1994, Swanson and others 1994) and serves as a historical baseline for comparison of existing ecosystem conditions at the watershed scale. This baseline condition can be used to establish management plan goals and objectives where sustainability of ecosystem structures and processes is desired (USDA 1995a). The maintenance of some structures, such as snags, is a key component of many management plans currently being developed by Federal agencies. The range of historical snag densities we have described for dry, east-side forests can be used to develop sustainable management approaches for down log densities for long-term site productivity, fuel levels, and the number of legacies to be retained in harvest units and to manage snags for primary cavity excavators and other wildlife species.

Our model can be modified easily to accommodate site-specific snag fall rates. We feel our method provides the best estimate currently available of the historical variability for snags on the east side of the Cascade Range. We recognize, however, that these estimates will be refined as better data become available. Our results provide a starting point for estimating historical snag structures, a reference important to implementing ecosystem management.

As described elsewhere (Agee 1994; Franklin and Dyrness 1973; Hall 1976, 1980, 1984; Johnson and others 1994; Marsden 1983; Mutch and others 1993; Wickman 1992), the disturbance regime within dry forests has been altered as a result of fire exclusion and other management activities. This has dramatic implications for availability of snags across the landscape. Currently, projects are being implemented to restore the structure of dry forests to conditions allowing for inherent disturbance regimes. There is, however, a paucity of information on historical snag levels to guide these restoration efforts. Thus, the importance and timeliness of our method. As stated by Swanson and others (1994), many of today's contentious issues in natural resource management of Federal lands arise, in part, from actions causing deviation from "natural" ecological conditions. In this paper, we have attempted to describe a method for determining the range of ecological conditions for snags in dry forests that will help guide restoration actions and, possibly, avoid some pitfalls of the past.

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[6] Personal communication. 1994. Evelyn Bull, research wildlife biologist, La Grande Forest and Range Research Station, 1401 Gekeler Lane, La Grande, OR 97850.

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Harrod, Richy J.; Gaines, William L.; Hartl, William E.; Camp, Ann. 1998.
Estimating historical snag density in dry forests east of the the Cascade Range. Gen. Tech. Rep. PNW-GTR-428. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacfic Northwest Research Station. 16 p.

Estimating snag densities in pre-European settlement landscapes (i.e., historical conditions) provides land managers with baseline information for comparing current snag densities. We propose a method for determining historical snag densities in the dry forests east of the Cascade Range. Basal area increase was calculated from tree ring measurements of old ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) trees. Historical stand structure was assumed to be open and parklike, with low densities favoring larger diameter trees, and it was considered relatively stable at the landscape level. Snag density (S) was calculated by holding forest stand structure relatively constant (basal area range 13.8 to 18.4 square meters per hectare [60 to 80 ft^2/acre] and diameter size class distributions with *q*-factors of 1.1 or 1.2), assuming snag recruitment could be no greater than annual basal area increase, and estimating that all snags fall by 45 years; $S = (a)*(1 + \Sigma r_i)$, where a is annual recruitment and Σr_i is a sum of the ratios of snags remaining from previous recruitment years (i). If eight representative snag sizes are selected, snag density in historical landscapes ranged from 14.5 to 34.6 snags per hectare (5.9 to 14.1 snags per acre).

Keywords: Snag density, ponderosa pine, *Pinus ponderosa*, snag recruitment, historical forest structure.

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