

Comparing Classification Systems for Ponderosa Pine Snags in Northern Arizona

Justin D. Waskiewicz, Peter Z. Fulé, and Paul Beier

ABSTRACT

The degree to which snag classification systems predict actual snag "age" (time since tree death) is rarely known. We used dendrochronology to determine the death dates of 79 large (more than 40 cm dbh, more than 3 m in height) ponderosa pine snags in northern Arizona and compared the snag ages to those predicted by a commonly used simulation model and to five classification systems. The methods are limited to trees for which intact tree-ring samples could be extracted, but the data provided evidence of some snags standing for long periods (to 141 years) and correlation of snag traits with age. The simulation model underestimated snag age in the first three categories. Mean ages of snags in the last category were estimated accurately but with low precision. Comparison of snag ages to their classification in five systems showed that bole breakage was unrelated to snag age, that limb loss occurs at divergent rates between individual trees, and that wood decay does not necessarily proceed sequentially. A system based on the attrition of bark from snag boles proved useful for distinguishing snags by physical traits, but different classification systems may be needed to meet specific needs for assessing past forest structure and wildlife habitat.

Keywords: wildlife habitat, dendrochronology, snag dynamics

Trees that remain standing after death are called snags. Snags have long been of interest to forest managers as fire hazards and estimators of past mortality (Pearson 1939). The important role of snags in forest ecology has been the subject of increasing study since the 1970s (Neitro et al. 1985). In the ponderosa pine forests of northern Arizona, cavity nesting species may constitute over one-third of total bird diversity in ponderosa pine forests, and their populations are significantly correlated with snag densities (Morrison et al. 1987). Individual snags in the same stand, even of the same species and size, differ in terms of wood quality, bark and limb retention, and bole integrity. Different characteristics support different ecological roles. For example, soft (rotten) snags are heavily used for nesting and foraging (Thomas et al. 1979, Cunningham et al. 1980, Raphael and White 1984), and hard (fresh) snags are used by bark gleaners and some stronger-billed primary cavity nesters (Mannan et al. 1980). The attributes of a snag population thus determine what wildlife species it is capable of supporting. Snag characteristics also can be important for diverse management issues such as fire hazard (rotten wood is more easily ignited), public safety (snags falling on roads or campgrounds), or developing guidelines for forest restoration (Holden et al. 2006). Large-diameter snags tend to persist longer than smaller snags (Keen 1929, 1955, Chambers and Mast 2005).

Many snag characteristics roughly correlate with snag age. Snags lose needles, twigs, branches, bark, and, eventually, sections of bole over time. A number of systems have been devised to classify snags by their level of decay, based on observations of bark cover, twig and limb retention, wood quality, or some combination (e.g., Keen [1955], Scott [1978], Cline et al. [1980], Raphael and White [1984], Horton and Mannan [1988],

Boucher et al. [1999]). The categories of such classification systems are designed to reflect important stages in the deterioration of a typical snag over time. To the extent that a system's category sequence correlates with snag age, it can be used to estimate past mortality events as well as predict future habitat quality (Neitro et al. 1985). A system developed by Thomas et al. (1979), described more fully later in this article, has been particularly influential in the Southwest because it was incorporated into resource management guidelines and a commonly used ecological simulation model (Ecosim; Rogers et al. [1984]).

Despite the importance of understanding how long snags have been standing, the relationship between snag characteristics and age has been quantified rarely. In the Southwest, short-term (less than 30 years) snag dynamics after bark beetle kill (Keen 1955) or wildfire (Chambers and Mast 2005, Holden et al. 2006, Passovoy and Fulé 2006) have been assessed with longitudinal studies, but longer predictions are based on unevaluated estimates because of the difficulty of tracking snags for decades to centuries. We applied dendrochronological techniques to determine exact death dates of large ponderosa pine snags. Our objectives were to (1) compare snag age predictions from a commonly used simulation model with actual ages, (2) assess the accuracy and precision of the Thomas et al. (1979) and four other systems, and (3) draw inferences about individual and stand-level snag dynamics by examining the current demographics and age distribution.

Methods

This study was conducted near Mount Trumbull, located in the Uinkaret Mountains about 80 km southwest of Fredonia, Arizona

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Table 1. Description of five classification systems used to categorize large (40 cm or more dbh, 3 m in height) snags at Mt. Trumbull, Arizona, in 1999.

System	Class	Description
Thomas	3	Recent dead
	4	Loose bark
	5	Clean
Decay	6	Broken above breast height
	2	Still retaining leaves or twigs, bark is tight
	3	Leaves, twigs gone, bark loosening, larger branches intact
	4	Bark mostly loosened, sloughing off, most limbs broken
Bark	5	Bark gone, wood softening, limbs down to stubs
	6	Wood very soft, bole usually broken
	1	100% Intact
Limb	2	75–99% Remaining
	3	50–75% Remaining
	4	25–50% Remaining
	5	1–25% Remaining
	6	No bark remaining
Wood	1	Twigs remain (quaternary branches, or to about pencil diameter)
	2	Branchlets remain (tertiary, or to about thumb diameter)
	3	Branches remain (secondary, or to about arm diameter)
	4	Limbs remain (primary, or to about leg diameter)
	5	Limbs broken (limbs gone or reduced to stubs)
	6	Sound, fresh
Wood	1	Less than 1 in. softened
	2	1–4 in. Softened
	3	More than 4 in. softened
	4	Hard, dry, weathered
	5	Charred
	6	

(latitude 36°22'N and longitude 113°7'W). Elevations ranged from about 2,000 to 2,300 m, with volcanic soils. Two remote automated weather stations (RAWS) are in the area: precipitation averaged 430 mm annually between 1992 and 2005 (Nixon Flats RAWS) and 326 mm annually between 1985 and 2005 (Mount Logan RAWS). The area experienced frequent surface fires before about 1870, when grazing, logging, and fire suppression altered the natural structure and disturbance regime, leading to the high tree densities and fuel loads now typical of southwestern forests (Moore et al. 1999).

In 1999 we measured the diameter and height of all snags that were 40 cm or more dbh and 3 m in height on six 36-ha plots distributed across the Mount Trumbull forest. Fallen trees were not sampled. We chose trees larger than 40 cm dbh because they are of high management value for wildlife habitat (Thomas et al. 1979, Raphael and Morrison 1987, Rabe et al. 1998) and represent a minimum size for old-growth forest structure (Mast et al. 1999). A single observer assigned each snag to one category in each of five classification systems (Table 1):

1. *Thomas et al.* (1979) developed a nine-stage classification system for the Blue Mountains of Oregon. The system covers changes from live tree to stump. It has been cited frequently and was reproduced in a textbook (Hunter 1990). The National Park Service uses the Thomas system, with slight modification, to describe trees in its fire monitoring protocol (USDI National Park Service 2001, 95). These modifications designate Thomas's class 6 ("broken") as "broken above breast height," and Thomas's class 7 ("decayed") as "broken below breast height." Because no snags less than 3 m in height were measured in this study, we assigned no snags to classes greater

than 6. From here onward, when a condition class is mentioned without referring to a specific classification system, the Thomas et al. (1979) system is assumed.

2. The *decay* system is based on a number of features, described in Table 1. It is purposely flexible and subjective. We created it based on the systems of Keen (1955), Thomas et al. (1979), and Raphael and Morrison (1987) and on personal observations in southwestern ponderosa pine forests.
3. *Bark* is exposed to weathering all around a snag's bole. The percentage of bark cover remaining on a snag is commonly used as an indicator of both age and potential wildlife use (Dahms 1949, Scott 1978, Cunningham et al. 1980). Following Dahms (1949) for ponderosa pine in the Pacific Northwest, the idea is that bark loss does not begin until bark cover is first breached, possibly several years after tree death, and that the last scraps of bark may remain long after the vast majority is gone. Therefore, the bark classification system classifies 0 and 100% loss separately, because they may represent more important stages than any arbitrary divisions between them.
4. *Limbs* are an obvious indicator of decay, because their diameter and, therefore, their resistance to breakage increases toward the bole. It should take more time for increasingly larger limbs to soften and break.
5. *Wood* was expected to rot progressively from the outside of a snag inward (Cline et al. 1980) at a rate of radial penetration unaffected by snag size (Basham and Belyea 1960). We chose the divisions of wood classes 1–4 based on personal observations of ponderosa pine decay. We added class 5 to include those snags that, although obviously advanced in age, did not appear to be softening. Cunningham et al. (1980) called these "hard snags" and attributed their resistance to high pitch content. We added class 6 to include snags that have been charred by fire (Boucher et al.'s [1999] "type III" snags). Classes 4, 5, and 6 are not necessarily sequential.

We attempted to extract an increment core from each snag and, for successful extractions, cored a similar-sized live tree in close proximity (Scott 1978). To ensure that cores captured the last year of each snag's life, we sampled from wood still covered by bark, bearing bark beetle galleries (indicating the surface nearest the cambium), or otherwise identifiable as the outermost extent of the tree's growth (Stokes and Smiley 1968). We cross-dated cores using previously established tree-ring chronologies and by comparison to adjacent live tree cores (Stokes and Smiley 1968). We measured tree-ring widths and used the program COFECHA (Grissino-Mayer and Holmes 1993) for quality control of cross-dating. We assigned death dates to snags as the last year of growth recorded in the core and we calculated snag ages by subtracting the death date from the year of sample collection, 1999.

We produced death date estimates for Mount Trumbull snags using Ecosim equations (Rogers et al. 1984). Rogers et al. (1984) presented snag change rates to describe the movement from one snag class to the next, using the Thomas et al. (1979) system. For example, 20% of the snags in condition class 3 were projected to move to condition class 4 annually. To determine when the "average" or 50th percentile tree had moved to the next class, we solved the interest rate equation $V_n = V_0 (1 + i)^n$ where V_0 is the initial quantity (100%), V_n is the quantity at year n , and i is the rate. Setting V_n to 0.5 (50%) and i to 0.20, solving for n gives $\ln V_n - \ln V_0 / \ln(1 + 0.2) = 3.8$ years. The decay rates were diameter

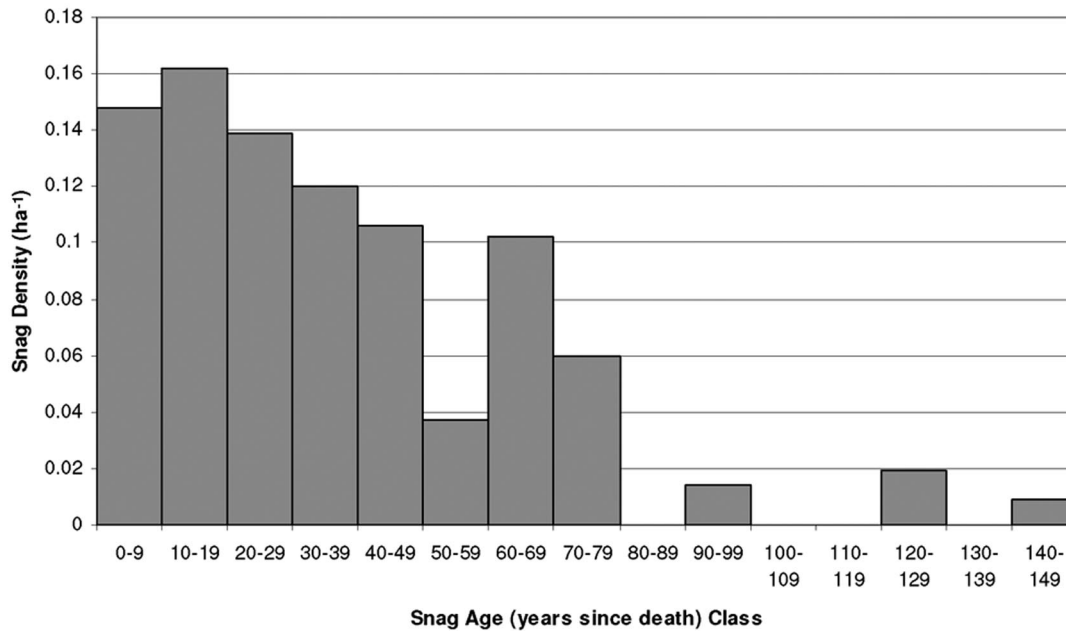


Figure 1. Decadal-scale age distribution of large (40 cm or more dbh and 3 m in height) snags at Mount Trumbull, Arizona, in 1999.

independent, except for movement into the final snag condition class. Calculations were made for the 50th percentile or “average” tree, as well as the 25th and 75th percentile, representing rapidly changing and slowly changing conditions, respectively. Predicted snag ages were compared with the quartiles (25, 50, and 75%) of the measured snag ages in each class. The percentiles and quartiles essentially are the same thing, viz., dividing a continuous population at the breakpoints of 25, 50, and 75%. For clarity, we used “percentile,” to describe the solution of the snag equations, versus “quartile,” to describe dividing the measured population of snag ages.

Results and Discussion

Population Characteristics

We recorded data on 198 dead trees in the six plots. Of these, we successfully extracted cores from 125 (63% of snags) and confirmed 79 death dates (40% of snags; 63% of cores). The dated subset of snags did not significantly differ in size from the larger sample as a whole (61.2 cm dbh versus 61.7 cm dbh, $P = 0.786$; 15.2 m in height versus 13.6 m in height, $P = 0.064$; independent samples t -test). There were, however, significantly fewer (29% versus 38%; $P < 0.001$; chi-square test) broken snags in the dated subset (a likely reason for the slight difference in average height).

Failure to obtain death date data for any individual snag was a function of two factors: inability to extract a core, usually because of excessive rot, and inability to successfully cross-date the core, usually because of ring complacency. Higher-category snags were less likely to be cored successfully, with cores extracted from 84, 74, 56, and 47% of snags in categories 3–6, respectively. No such trend occurred for successful cross-dating across the categories, although cross-dating did differ among the categories (59, 55, 93, and 64%). The net result was that categories 3 and 5 were overrepresented in the subsample of snag ages, whereas category 6 was underrepresented. Each dated snag in category 3 represented 2 in the full sample, each category 4 represented 2.5, each category 5 represented 2, and each category 6 represented 3.3.

Older and broken snags are more likely to be rotten (McClelland and Frissel 1975) and therefore were less likely to be cored successfully. Sample bias against snags on more moist sites is a possibility, because such snags would be more likely to be rotten (bias against successful core extraction) and also more likely to display complacent rings (bias against successful cross-dating).

Distribution

Dated snags ranged in age from 1 to 141 years old, averaging 36 years (Figure 1). The age distribution showed a gradual decline in number across decadal age class, with no outstanding peaks or valleys apparent. The extreme age reached by some snags and the relative flatness of the age distribution suggest that ponderosa pine snags decay very slowly, and, at least in the absence of fire, some may persist for up to 150 years. The distribution was influenced by both previous mortality (snag recruitment) and by the snag fall rate; it is impossible to estimate the share of influence between those two factors. Past management practices, including harvesting, which might have captured potential mortality, and snag cutting have undoubtedly affected the snag population distribution. Given also that mortality of large ponderosa pine over the last 100 years has more likely risen than fallen (Biondi 1996, Mast et al. 1999), it is possible that the degree of negative slope in the age distribution owes as much to increasing trends in recruitment and decreasing trends in removal as to natural snag attrition.

Snag Age Prediction

Comparing predicted versus actual snag ages, estimated death dates for the 25th, 50th, and 75th percentiles in each category were all later calendar dates (i.e., younger snag age dates) than the actual first, second, and third age quartiles for snags in categories 3–5 (Table 2). For category 6, we predicted a range of death dates covering the range of category 6 snag diameters. The second and third age quartiles of category 6 snags fit within the ranges predicted by the model’s corresponding percentiles.

Table 2. Death dates predicted for snags classified in Thomas et al. (1979) categories 3–6 (category numbers in parentheses) by ECOSIM's 25th, 50th, and 75th percentiles, contrasted with the first, second, and third quartiles of large snag death dates in each category at Mt. Trumbull, Arizona, in 1999.

	Ecosim percentile			Snag age quartile		
	25	50	75	1st	2nd	3rd
Recent (category 3)	1999	1999	1999	1985	1990	1994
Loose bark (category 4)	1991	1995	1997	1950	1975	1984
Clean (category 5)	1981	1990	1995	1912	1935	1950
Broken (category 6)	1879–1937	1939–1968	1974–1986	1949	1964	1977

Table 3. Average, range, and SD of difference between individual snag death dates and death dates predicted by Ecosim's 25th, 50th, and 75th percentiles for Thomas et al. (1979) categories (category numbers in parentheses).

Ecosim percentile	Snag category (Thomas et al. 1979)	Average difference	Range of difference		SD of difference
			Minimum	Maximum	
25	All	-4	-123.5	118.9	46.8
	Recent (category 3)	-11	-39	-1	9
	Loose bark (category 4)	-25	-62	0	19.8
	Clean (category 5)	-56	-124	-24	32.6
	Broken (category 6)	54	-5	119	31
50	All	-19.9	-132.2	59	33.8
	Recent (category 3)	-11	-39	-1	9
	Loose bark (category 4)	-28.4	-66.2	-4.2	19.8
	Clean (category 5)	-64.7	-132.2	-33.2	32.6
	Broken (category 6)	8.4	-49.6	59	26.5
75	All	-29.2	-137.4	23.9	29.9
	Recent (category 3)	-11	-39	-1	9
	Loose bark (category 4)	-31	-68	-6	19.8
	Clean (category 5)	-70	-137	-38	32.6
	Broken (category 6)	-18	-76	24	24.7

On a snag-by-snag basis, the disparity between model-predicted death dates and actual death dates was large and negative for categories 3–5 in all percentiles (Table 3). The model consistently overestimated snag death dates (underestimated snag age) in these categories—not one estimated death date was earlier than an actual death date. In category 6, estimated death dates fell on both sides of actual dates, and the average disparity between the two for the 50th percentile estimates was relatively near zero (8.4 years). However, the SD of the disparities is large (26.5 years)—the model's 50th percentile death date estimation may be accurate over a large number but is very imprecise. Using the 25th percentile, the model tended to underestimate category 6 death dates and to overestimate them using the 75th percentile. Although the estimates of category 6 death dates using the 50th percentile *averaged* similar to the actual death date average, there was no correlation between actual death dates per tree and the estimates ($R^2 = 0.02$). The net quality of our predictions of death date based on the Thomas classification system ranged from accurate (-4-year average difference) but very imprecise (46.8-year SD) when using the 25th percentile (where underestimation of category 6 death dates compensated for overestimation of other death dates) to inaccurate (-29-year average difference) and imprecise (29.9-year SD) when using the 75th percentile.

Given high imprecision, the model would be of little use to estimate the death date of individual trees. At least at Mount Trumbull, large unbroken ponderosa pine snags change more slowly than the model predicts, and large broken ones are less likely to be as old as the model presupposes. The model is more suitable for estimating mortality patterns over large study areas, using many snags, at least if the ratio of broken and unbroken snags is similar to that at Mount Trumbull. A number of forest reconstruction studies in northern

Arizona have used the Rogers et al. (1984) model in this way (e.g., Covington and Moore [1994] and Moore et al. [2004]).

Comparing Classification Systems

The average age of snags in each category of all of the systems typically increased with advancing categories, except for several “reversals” in the last category (Table 4). This result conforms to expectations because the classification systems were designed to mirror typical decay patterns. The increasing ranges associated with consecutive categories were an inevitable result from the difference between fast- and slow-deteriorating snags. This is bound to happen in any system, but an ideal system would be based on characteristics that change at a similar and low rate in all trees, thus minimizing the overlap of age ranges between categories. Median within-category ages typically were lower than means and range centers, implying skewed distributions, with snags tending to be clustered toward the younger end of category ranges. The number of snags classified into each category varied between categories with no consistent pattern across systems.

We compared snag classification based on the following criteria. A good classification system should be (1) applicable and appropriate, with categories that represent sequential and typical conditions; (2) precise, with minimal age variability within categories; and (3) objective, with minimal overlap and quantifiable bounds between categories. No perfect system exists, but some are better than others.

Snags classified by Thomas et al.'s (1979) system generally conformed to the expected pattern. Mean and median ages both increased from category 3 to 4 to 5, but the average age for category 6 snags was lower than for category 5 and not significantly different from that of the whole sample ($P = 0.86$, two-sample *t*-test). Each

Table 4. Comparison of classification systems used to categorize large snags at Mt. Trumbull, showing total number of snags, number of dated snags, snag age range, median, mean, and SD for each category of each system.

Classification system	Category	Total number	Number dated	Youngest snag (yr)	Oldest snag (yr)	Median age (yr)	Mean age (yr)	SD
All snags	All	198	79	1	141	29	36	29.6
Thomas	3	38	19	1	39	9	11	9
	4	57	23	8	70	24	32	19.8
	5	27	14	42	141	64	74	32.6
Decay	6	76	23	1	94	35	37	24
	2	31	17	1	18	5	6	5
	3	28	13	8	39	21	20	8.3
	4	32	17	10	70	31	38	19.7
	5	57	22	18	141	50	54	24.6
Bark	6	44	8	30	126	70	75	37.4
	1	38	21	1	22	7	8	6.6
	2	25	12	8	70	22	26	16.5
	3	10	4	10	24	20	19	6.2
	4	33	10	17	70	43	43	17.3
	5	48	22	15	94	44	48	19.5
Limb	6	42	8	49	141	70	89	35.6
	1	46	26	1	39	9	11	9.6
	2	24	12	10	31	22	20	6.4
	3	45	20	12	141	50	54	26.8
	4	40	12	23	126	61	65	31.6
Wood	5	43	9	24	94	44	50	23.2
	1	62	35	1	70	13	16	15.6
	2	2	1	10	10	10	10	—
	3	1	0	—	—	—	—	—
	4	60	14	18	124	43	49	27.3
	5	52	26	15	141	56	57	29.7
	6	19	2	36	43	40	40	5

category of the Thomas system included a large range of snag ages, with considerable overlap among the ranges of nearby categories. The oldest snags in category 3, for example, were much older than the youngest snags in category 4 and 6. The range of ages for category 6 snags covered almost the whole range of all snag ages, and the category included the largest number of snags. Category 4 also included a wide range of snag ages, and contained more snags than either adjacent category.

The most variable category, based on tree breakage (category 6), may not be related to age at all. Some snags are broken even before death, others are not broken until much later. Once a snag enters category 6, no matter what its condition besides breakage, it remains in that category until destroyed. Therefore, a large number of snags accumulate in category 6 because it represents a common characteristic, although not necessarily a sequential step in snag development. Broken snags were more likely to be decayed: among broken snags, 8% were recent, 39% had loose bark, and 53% were clean. It can not be determined whether this is because older snags are more likely to break or because broken snags are less likely to fall (Neitro et al. 1985) and, therefore, more likely to get older. Breakage is an important characteristic in describing the snag resource, because it is so common and is related to bird use (McClelland and Frissel 1975, Cunningham et al. 1980), but it is not helpful in estimating snag age. Thomas et al.'s (1979) system was the least precise of those examined in this study, with the highest average SD and some of the broadest age ranges in its categories. The system is relatively objective, however, with little overlap between the characteristics of adjacent categories and little room for differences in observer interpretation.

Other classification systems showed advantages and disadvantages relative to the Thomas system. The decay system was more consistent in conforming to the pattern of increasing snag age with increasing category and the larger number of categories with lower

SDs (except for category 6) made the system a more precise estimator of snag age. The decay system was more subject to the individual observer's interpretation of terms such as "larger" branches, "mostly" loosened, or "very" soft—it may not be consistently applied among multiple observers. Furthermore, because classification is based on more than one characteristic, it may be of limited use in predicting future snag properties (each category represents a number of possible combinations of characteristics).

The bark system was the most precise and had the lowest average SD of all the systems examined in this study. In the bark classification system, snags in category 3 (50–75% bark remaining) were of younger average age than snags in the previous category, and the age range was a nested subset of the previous category range. Likewise, the range of snag ages in category 4 is a nested subset of the range of category 5, while the age averages of the two categories barely differ. Therefore, bark class 3 essentially was redundant to class 2, and class 4 was redundant to class 5. This may be because the 25% divisions between categories were chosen for convenience, rather than biological meaning. The low number of snags classified in categories 2 and 3 probably indicate that snags pass through these relatively quickly—i.e., they lose the first half of their bark faster than the last half.

Limb category 5 snags averaged younger than the previous category and had a median age younger than the previous two categories. All Limb category 5 snags were broken—it is possible that breakage rather than age caused the loss of the largest limbs, explaining the category's younger mean age. Otherwise, increasing Limb categories represented generally older snags, but the Limb system had the most age range overlap between categories; the youngest snags in the highest Limb categories were not much older than the youngest in the lowest categories. The oldest of all snags still retained secondary branches, whereas snags a fifth as old had already lost all their limbs. This indicates a very wide disparity between the fastest-decaying and

Table 5. Total number of snags, number of dated snags, snag age range, median, mean, and SD for each category of a relatively accurate and precise classification system, combining features from Thomas et al. (1979) and a bark-based system.

Category	Total number	Number dated	Youngest snag (yr)	Oldest snag (yr)	Median age (yr)	Mean age (yr)	SD
100% Bark remaining	38	21	1	22	7	8	6.6
Bark loose, more than 50% remaining	34	16	8	70*	22	24	14.8
Bark loose, less than 50% remaining	57	20	15	70	40	41	16.6
Clean of bark	67	20	30	141	64	69	30.3

*The oldest snag in this category is much older than the next oldest (39 yr).

slowest-decaying snags with respect to limb loss. Some snags may lose all of their limbs in as little as 25 years, while branches may never be lost in other snags. Limb characteristics, unlike bark, may be too individualized to the tree—dependent on wood strength, crown characteristics, and exposure more than time since death—to make a good surrogate for age.

Wood categories were of relatively little value in determining snag age. Ponderosa pine snags do not seem to follow an incremental progression from sound wood to rotten, as shown by the near absence of snags in categories 2 and 3. Wood category 1 snags were clearly younger than those in categories 4 and 5 and the age ranges of categories 4 and 5 were very similar. Categories 4, 5, and 6 were not designed to represent sequential stages in snag development. They probably represent alternative fates for snags that depend more on the individual wood properties and microsite history of the tree than on time and exposure. Data from the Gila Wilderness in New Mexico suggest that charred trees might persist longer than uncharred trees (Holden et al. 2006).

Improving Snag Age Estimation

Because there are diverse reasons for classifying snags, it is not possible to recommend a single classification system. However, the results of this study can be applied to suggest ways to improve estimation methods at least in terms of the age structure of snag populations.

Bark appears to be the best single characteristic for predicting snag age. All trees have relatively uniform bark coverage while alive, in contrast to considerable variation in the amount and sizes of limbs. Bark retention also lends itself more readily to quantification by percent, although appropriate percent thresholds for different categories may be hard to determine.

The Thomas et al. (1979) classification system commonly used in the Southwestern ponderosa pine can be improved with some modifications: (1) category “broken above breast height” (category 6) is poorly linked to age, and breakage can be recorded separately if it is of interest; (2) the category “recent” (category 3) is too subjective and broad, as evidenced by the extreme age of 39 years—a snag that still retained fine twigs—and this category should include only those snags that retain 100% of their bark; (3) “loose bark” (category 4) is too broad and it should be divided into two parts corresponding to the progression of bark loss. A modified four-category system would include: (1) 100% bark, (2) bark loose and more than 50% remaining, (3) bark loose and less than 50% remaining, and (4) “clean.” This system has steadily rising mean and median ages for its categories, with relatively low SDs (Table 5). One anomalous snag in category 2 had an age of 70 years, 31 years (79%) more than the next oldest in that category. If this outlier is excluded, the modified system is the most precise of those examined here and has the most consistent increases in age in succeeding categories.

Finally, snag age data can be applied to infer the dynamics of movement between categories. An estimate of snag dynamics can be made from the demographic cross-section of the snag population at Mount Trumbull. Using a “snapshot” age distribution to estimate dynamics depends on the stability of the age distribution over time. Fire and insects can create large cohorts of snags episodically, so the ratios among current age classes are a result of past recruitment pulses interacting with deterioration patterns in complex ways (Johnson et al. 1994). However, the snag population at Mount Trumbull has some advantages for modeling. The very wide range of the snag age distribution covers over a century of potential recruitment years; therefore, it should include evidence of recruitment pulses that would have affected demographics. However, there does not appear to be evidence of such pulses, because the distribution is quite smooth. Thus, the category ratios in any given age class should fairly represent how the corresponding snag cohort stratified out over time.

We used the proportion of snags occurring in each of the four high-accuracy categories (Table 5) in six age classes to model stand-level snag dynamics. The age classes were 1–5 years, 6–15 years, 16–30 years, 31–50 years, 51–80 years, and 81+ years. The increasing span of each age class maintained a high number of snags per class, permitting a smoother curve. For each category, we calculated the proportion of snags in each age class and then corrected density to account for biases in the dated subset. The estimated number of snags in each category-age combination were used to calculate the proportion of each category per age class, connecting the midpoints with a smooth curve (Figure 2) that shows the approximate percentage of remaining snags expected in each category at a given time. For example, of the snags that died in 1999 and are still standing in 2029, 1% still would be in category 1, 35% would be in category 2, 50% would be in category 3, and 14% would be in category 4. It is also possible to estimate the range and average age of transition between categories. The category 1 and 2 curves cross at about 15 years, category 2 and 3 curves cross at about 27 years, and category 3 and 4 curves cross at about 47 years. These points represent the ages at which successive categories become dominant during a cohort’s development and the average point at which snags move from one category to the next.

Bearing in mind the variability already discussed, Figure 2 provides a scenario for snag change at Mount Trumbull: snags typically retain all their bark for about 10–20 years. It takes 5–20 additional years for the first half of bark to fall off and 15–30 additional years for the remainder to fall off. After 30–70 years, snags are clean of bark.

Large ponderosa pine snags at Mount Trumbull can last for a longtime—perhaps up to 150 years in the absence of fire. This may well be typical across the Southwest, where dry climate and fire suppression have likely enabled snag populations to reach large and

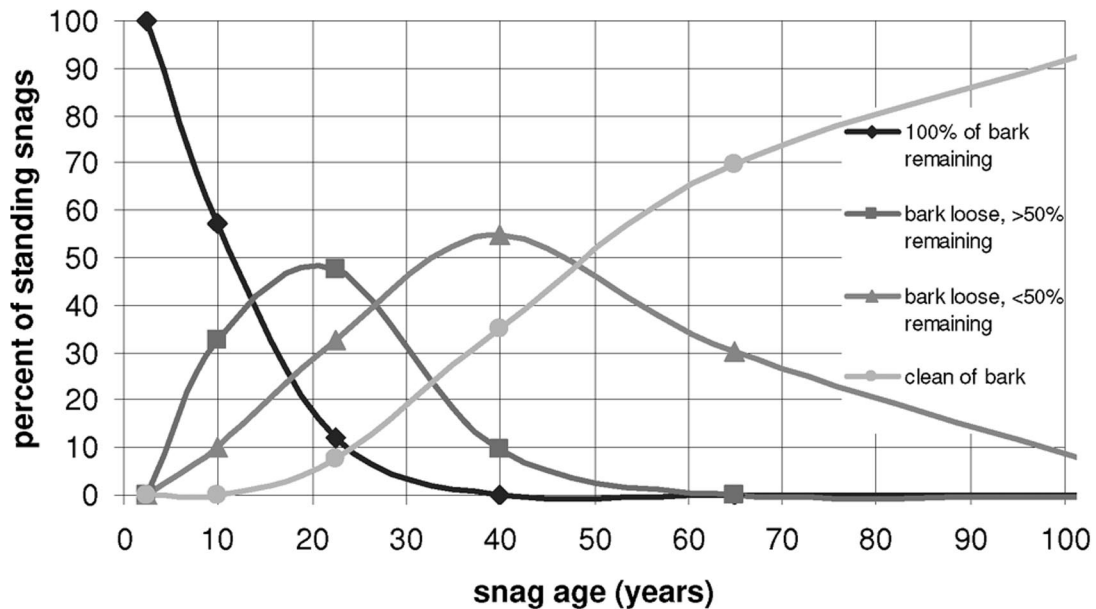


Figure 2. Expected stratification of a snag cohort into bark-based categories over time, given current large snag population demographics at Mount Trumbull, Arizona, in 1999, yielding percentage of standing snags expected in each category at given X-axis years from cohort establishment. A 70-year-old snag in the “bark loose, more than 50% remaining” category was not included in data used to make this graph.

historically unprecedented levels (Boucher et al. 1999, Ganey 1999). The bark-based modification to the Thomas et al. (1979) classification system developed here and its application to snag dynamics modeling provides a quick and relatively objective means to assess current snag age, estimate future stand snag demographics, and predict the development of individual ponderosa pine snags at sites similar to Mount Trumbull. It is important to be able to do this, because fuel reduction treatments across the Southwest would be improved by reliable information on historical reference conditions (Moore et al. 1999) and estimation of potential treatment impacts on wildlife habitat (Tiedemann et al. 2000, Wagner et al. 2000, Block et al. 2001).

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