# Persistence of Pinyon Pine Snags and Logs in Southwestern Colorado

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**ABSTRACT:** *We examined the persistence of pinyon pine (*Pinus edulis *Engelm.) standing snags and downed logs in southwestern Colorado pinyon-juniper woodlands. The time since death of pinyon pines killed by bark beetles, black stain root disease, or unknown causes in three study areas in southwestern Colorado was determined through monitoring of permanent plots and dendrochronological crossdating methods. The structural condition and form of the trees was recorded and related to the time since death. Pinyon snags may persist for up to 25 years, with persistence of intact snags averaging 8.4 years and broken snags averaging 13.2 years. Sound logs had been dead for a mean of 9.8 years, whereas more fragmented logs had been dead for a mean of 14.4 years. Extremely fragmented trees had been dead for 16.2 years. There was no statistically significant difference in the time since death for snags versus logs in similar condition classes. A simplified rating system to determine the number of years dead for pinyon pine based on form and condition is provided. West. J. Appl. For. 20(4):247–252.*

**Key Words:** *Pinus edulis*, *Leptographium wageneri* var. *wageneri*, *Ips confusus*, decay.

Pinyon pine (*Pinus edulis*) is the dominant pine species in nearly 14.9 million hectares in the southwestern United States, primarily in Colorado, Arizona, Utah, and New Mexico (Ronco 1990). Pinyon pines are codominant with juniper species (*Juniperus* spp.) in the pinyon-juniper woodlands of the semi-desert zone that cover approximately 24.7 million hectares from Texas to California, occupying foothills, low mountains, mesas, and plateaus from 1,370 and 2,440 m (Ronco 1990). There are over 1.8 million hectares of pinyon-juniper woodlands in Colorado (Landis and Helburg 1976), making pinyon-juniper the dominant forest cover type in Colorado. Pinyon pine is a major component of southwestern ecosystems, providing food, wildlife habitat, shelter, and erosion control in the transition zones between desert and higher elevation ponderosa pine ecosystems.

Pinyon are generally long-lived trees but are susceptible to damage by drought and other climatic factors, fire, insects, and disease. Two common mortality agents in southwest Colorado are ips bark beetles (*Ips confusus*) and the black stain root disease (BSRD) pathogen (*Leptographium wageneri* var. *wageneri*). These two pests may kill trees independently or in conjunction (Kearns and Jacobi 2005).

Coarse woody debris consisting primarily of downed logs and snags (standing dead trees) provides many important functions within forested ecosystems. Some of these include provision of wildlife habitat, substrate for plants and lichens, sources of nutrients and energy, sites for microbial nitrogen fixation, sources of soil organic matter, stability of soils, and structural complexity (Harmon et al. 1986, Bull et al. 1997). Snags are particularly important components of woodland ecosystems because of their relationship to wildlife as nesting, perching, cover, and food sources (Scott 1978, Thomas et al. 1979, Mannan et al. 1980, Davis 1983, Bull et al. 1997). To ensure provision of wildlife habitat and other ecosystem functions, new snags need to be recruited into the ecosystem. The ability to predict the persistence of standing dead trees or fallen parts of dead trees as they provide wildlife habitats, influence soil retention and development, and enhance hydrologic processes is important information for management programs.

NOTE: W.R. Jacobi can be reached at Fax: (970) 491-3862; william.jacobi@colostate.edu. We recognize the contributions of two anonymous reviewers, J. Friedley, F. Johnson, J.E. Lundquist, R.M. Reich, E.L. Smith, F.W. Smith, J.R. zumBrunnen, and the cooperation of the San Juan National Forest, Southern Ute Indian Tribe, Bureau of Indian Affairs, and Mesa Verde National Park. Funding and support for this project were provided by USDA Forest Service, Region 2, Forest Health Monitoring; USDA Forest Service, Forest Health Technology Enterprise Team (RMRS-98,103-CA); Colorado State Forest Service; San Juan National Forest; Southern Ute Indian Tribe, Bureau of Indian Affairs; Colorado State University; and Colorado Agricultural Experiment Station. 

How long trees remain standing after being killed by various causes is not well understood. The durability and variation of snag structure in lodgepole (*Pinus contorta* var. *latifolia*) and spruce/fir (*Picea*/*Abies*) in British Columbia was affected by stand age, characteristics of predisturbance forest, and the type of disturbance (Clark et al. 1998). In a study of snag retention in the interior ponderosa pine type of northeastern California and southern Oregon, the rate of fall was attributed to the time elapsed since death, tree size, soil conditions, and other unmeasured attributes (Keen 1955). In another California study, snag persistence was related to species, diameter, height, and mortality agent (Morrison and Raphael 1993). As snag and log retention and durability in pinyon pine is not well understood, this study was undertaken as part of a larger study of the impacts of insects and disease on pinyon pine (Kearns and Jacobi 2005).

## Methods

Thirty-six BSRD mortality centers were surveyed for a range of dead and dying trees. Twenty-two mortality centers were located near McPhee Reservoir, north of Cortez, Colorado, within the western portion of the San Juan National Forest. Eight mortality centers were located in a second study area, which straddles the boundary of the Southern Ute Reservation and the San Juan National Forest, east of Ignacio, Colorado, and is approximately 113 km east of the McPhee sites. Elevations of mortality centers ranged from 1,945 to 2,334 m, essentially covering the middle portion of the elevational range of pinyon in Colorado (Ronco 1990). Six additional monitoring plots previously established by USDA Forest Service personnel in Mesa Verde National Park were examined. Mesa Verde National Park is located between the McPhee Reservoir and Ignacio study sites, with pinyon-juniper woodlands occupying elevations from greater than 1,700 to 2,500 m (Floyd et al. 2003).

At each of the 30 plots near McPhee Reservoir and Ignacio, plot center was established at the location of the oldest estimated pinyon mortality, based on the condition of the snag or log, within the plot. Three belt transects were established within each mortality center. Transects radiated out from plot center with a minimum of 45° between the centerline of transects. Whenever possible, transects were placed so as to include declining pinyon. When only one transect included chlorotic pinyon, remaining transect centerlines were located at 120° intervals. Transects were 6.1 m wide and varied in length from 7.9 to 74.4 m with a mean transect length of 33.2 m, ending at the first green, nonsymptomatic pinyon beyond all declining and dead trees. For each tree, snag, or log with a base falling within the transect, the following were recorded: height (total standing height or total length of log segments to estimate height when standing and whole), diameter at root crown measured as the average of two caliper measurements taken at 90° from each other at 10 cm, tree status based on a nine-class system designed to describe snag/log condition (Table 1), presence of damaging agents, and symptoms and signs of BSRD and ips beetles.

**Table 1. Snag and log rating system applied to BSRD centers in pinyon-juniper woodlands.**

| Snag/log class[a] | Description |
|---|---|
| 1 | Crown with red/brown foliage remaining on twigs; tree dead |
| 2 | Few to no needles, many fine twigs, intact bark, sound heartwood |
| 3 | No needles, many twigs, bark may be missing in patches, relatively intact crown, sound heartwood |
| 4 | No needles, few twigs, 5%–33% branches broken, bark loose or missing in places |
| 5 | Very few twigs remaining, >33% branches broken, bark loose or missing |
| 6 | Downed, few twigs, 5%–33% branches broken, bark loose or missing in places, like no. 4 |
| 7 | Downed, very few twigs remaining, >33% branches broken, bark loose or missing, like no. 5 |
| 8 | Downed, stem broken into pieces, few branches |
| 9 | Well deteriorated, extensive loss of original mass, original shape apparent to undistinguishable, becoming incorporated into soil |

[a] Modified from Sharon 1985, D. Omdal, personal communication.

Tree increment cores and/or stem cross-sections were obtained from sound pinyons in all tree classes present within individual mortality centers to determine persistence of pinyon snags and coarse woody debris. Increment cores were taken as close to ground level as possible and perpendicular to the slope to minimize tension and compression wood effects on ring size. Stem cross-sections were obtained, when possible, from older tree classes. Increment cores and stem cross-sections were mounted on wooden blocks, sanded, and examined using a binocular microscope. Crossdating was conducted using the skeleton plot technique (Stokes and Smiley 1968) based on chronologies developed from live trees on each site. The master chronologies developed for the McPhee and Ignacio study sites were based on increment cores obtained from a minimum of 20 live, healthy trees. This process of crossdating was used to determine the date of mortality, which was assumed to be the last year in which a growth ring was added. A total of 277 cores and stem cross sections from the 30 mortality centers at McPhee Reservoir and Ignacio were crossdated to determine the year in which the last growth ring had been added.

To supplement snag and coarse woody debris data collected from the McPhee Reservoir and Ignacio study sites, BSRD monitoring plots established within Mesa Verde National Park by US Forest Service personnel were relocated and visited. In 1978, Forest Service personnel established seven variable radius plots to examine mortality rates. Trees were tagged, referenced to plot center, and the condition and cause of death, if applicable, were recorded (Sharon 1985). The plots were all revisited in 1980, 1982, 1984, and 1986. Three of the seven plots were remeasured in 1992. We visited five of the plots in 1999, one in 2000, and were unable to relocate the seventh plot. The six Mesa Verde plots contained between 17 and 113 tagged pinyon, and a total of 293 pinyon were reexamined and classified according to snag/log status based on the nine-class system.

The number of years dead was then determined for each tree based on Forest Service records as the midpoint between the last year recorded live and the first year recorded as dead. These data on the number of years dead by snag/log class were then compared with the data assembled from tree ring analyses at the two study sites and were used to determine mean years dead by class.

## Data Analysis

Statistical analyses were performed with the SAS (Cary, NC) Mixed and GLM statistical procedures. The mean number of years dead was determined for each pinyon class based on data from tree ring analyses and Mesa Verde BSRD plots. Paired *t* tests were applied to determine significant differences in the number of years dead between pinyon classes. Analysis of variance was performed to determine the effect of site (McPhee, Ignacio, and Mesa Verde) on the mean number of years dead of pinyon snags and logs.

## Results and Discussion

Within BSRD mortality centers, 46.3% of all pinyon were standing dead and 21.0% were downed dead (Kearns and Jacobi 2005). Analyses of tree rings indicate that mortality occurred fairly recently within the surveyed BSRD mortality centers, with the oldest dated dead pinyon material being 26 years old. The means for number of years dead for each of tree classes one through eight were determined from tree ring analyses and observations at Mesa Verde National Park. An analysis of variance on the number of years dead of snags and logs did not show site (McPhee, Ignacio, or Mesa Verde) or site by class interactions to be significant effects. To demonstrate the lack of site differences, the sites were compared at each class (Table 2). No trees in classes one and two were recorded at the Mesa Verde sites. The noticeable difference in the number of years dead of class three snags at the different study sites is at least partly attributable to the length of time between remeasurements on plots at Mesa Verde.

Tree class and the number of years dead were highly significantly related ($P < 0.0001$). Because of the lack of a significant site effect, the data from the three study sites were combined, except for the Mesa Verde data on class three snags, which did show significant differences in the number of years dead from the McPhee site. The mean number of years dead for each of tree classes one through eight is shown in Table 3. Recently killed pinyon snags with intact crowns and bark but few needles (class two) had been dead a mean of 2.1 years, whereas those with no remaining needles, many twigs, and relatively intact crowns had been dead an average of 4.7 years (Figure 1A). Snags may persist for up to 25 years, with intact snags (class four, Figure 1B) dead an average of 8.4 years and broken snags (class five, Figure 1C) dead a mean of 13.2 years. Sound logs (class six, Figure 1D) had been dead a mean of 9.8 years, whereas more fragmented logs (class seven, Figure 1E) had been dead for a mean of 14.4 years. Trees that are extremely broken up (class eight, Figure 1F) had been dead for a mean of 16.2 years. Class nine (Figure 1G) pinyon were too decayed to permit tree ring analysis, and the age of mortality associated with them could not be determined. The class effect was significant, therefore pairwise comparisons were made between classes. There were no statistically significant differences in the ages of tree classes five and seven ($P = 0.0813$) or between classes four and six ($P = 0.0966$). This indicates that downed logs are not significantly older than snags in the same condition, and the percentage of intact branches may be a better indicator of the age of dead material than whether it is standing or fallen.

Keen (1929, 1955) followed ponderosa pine trees killed by bark beetles for over 25 years in southern Oregon and northeastern California. Snags survived well for the first 5 years after death followed by a rapid decay and falling of snags for up to 15 years. The snags fell at a slower rate after 15 years, and after 25 years, only 10% of the original snags were still standing. Our study found that pinyon logs had been dead for 5 to 26 years, with an average of 13.5 years dead. We had expected pinyon to survive longer, as the climate consists of cold winters and dry summers.

Several studies indicate that large diameter trees remain standing longer than small diameter trees. Keen (1929) reported that 78% of ponderosa pine snags in the largest (102–122 cm) diameter class were standing 7 years after death compared with 42% of snags in the 25- to 46-cm diameter class. In a study of ponderosa and lodgepole pine

**Table 2. Mean number of years dead and SE of pinyon snags and logs by class and site in BSRD mortality centers.**

| Snag/log class | McPhee | | Ignacio | | Mesa Verde class | |
|---|---|---|---|---|---|---|
| | Years | SE | Years | SE | Years | SE |
| 1[a] | 1.5[b] | 0.8 | 1.3[b] | 2.0 | – | – |
| 2 | 2.3[b] | 0.8 | 1.6[b] | 1.4 | – | – |
| 3 | 4.8[b] | 0.7 | 4.9[bc] | 1.1 | 7.5[c] | 0.9 |
| 4 | 7.3[b] | 1.0 | 8.7[b] | 1.7 | 9.6[b] | 1.1 |
| 5 | 13.3[b] | 1.0 | 13.3[b] | 1.7 | 13.3[b] | 0.7 |
| 6 | 10.4[b] | 0.9 | 8.6[b] | 1.5 | 9.7[b] | 0.7 |
| 7 | 16.7[b] | 1.3 | 14.3[b] | 1.7 | 14.2[b] | 0.5 |
| 8 | – | – | – | – | 16.2 | 0.6 |

[a-c] Means within rows followed by different letters are statistically different at $P = 0.05$ level.

**Table 3. Mean number of years dead and SE by snag/log class for pinyon in BSRD mortality centers.**

| | Snag/log class | N | Mean years dead[a] | SE |
|---|---|---|---|---|
| 1 | Dead, red needles | 31 | 1.3[b] | 0.8 |
| 2 | Intact bark, many fine twigs, few needles | 35 | 2.1[b] | 0.7 |
| 3 | Bark partially missing, no needles, many twigs | 67 | 4.7[c] | 0.6 |
| 4 | Snag, 5%–33% branches broken, few twigs | 37 | 8.4[d] | 0.7 |
| 5 | Snag, >33% branches broken, very few twigs | 57 | 13.2[e] | 0.6 |
| 6 | Downed, 5%–33% branches broken, few twigs | 62 | 9.8[d] | 0.5 |
| 7 | Downed, >33% branches broken, very few twigs | 93 | 14.4[e,f] | 0.5 |
| 8 | Downed, stem broken, few branches | 39 | 16.2[f] | 0.8 |

[a-f] Means followed by different letters are statistically different at $P < 0.001$.

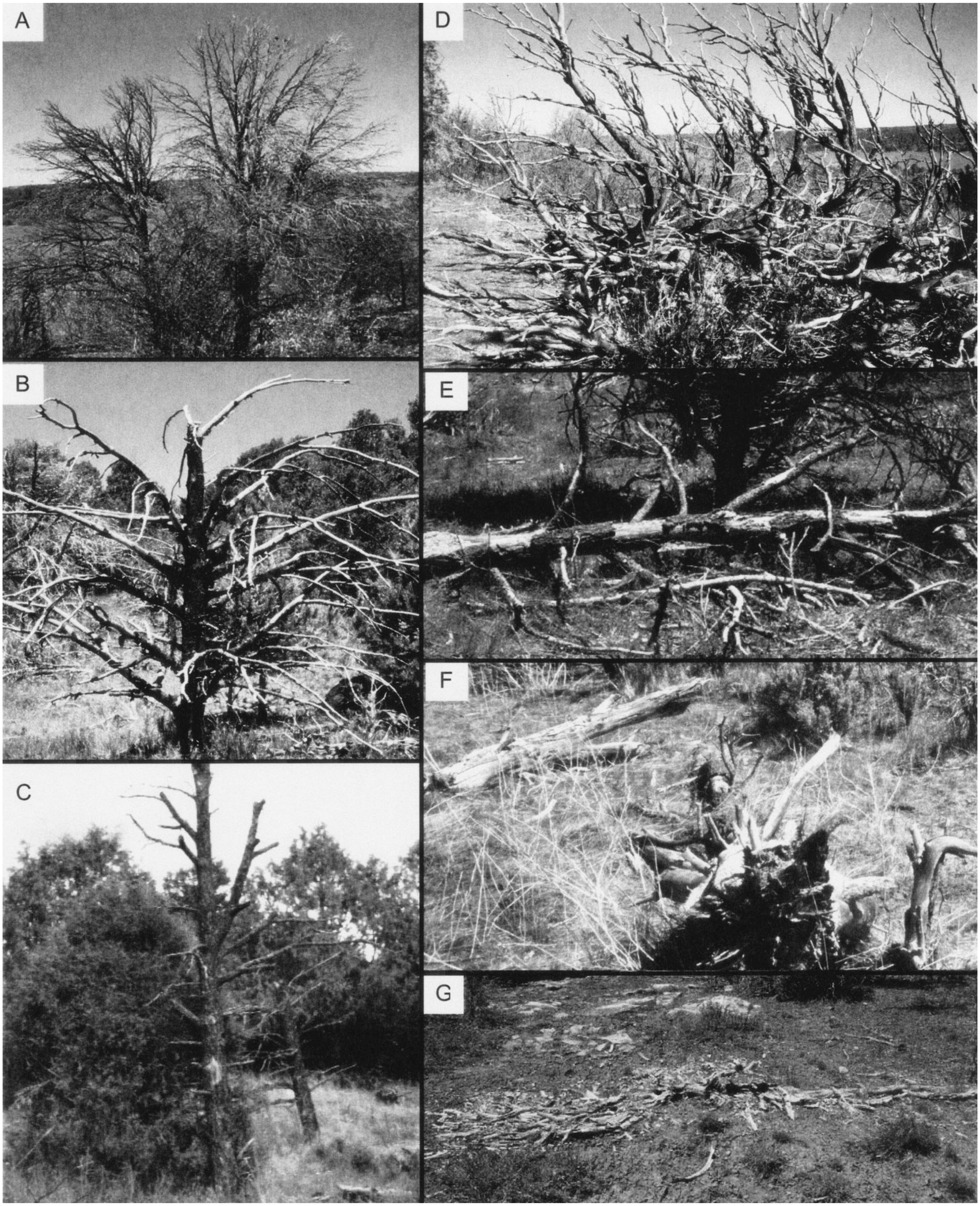



**Figure 1.** **(A) Class three pinyon, dead approximately 5 years; (B) class four pinyon, dead approximately 8 years; (C) class five pinyon, dead approximately 13 years; (D) class six pinyon, dead approximately 10 years; (E) class seven pinyon, dead approximately 14 years; (F) class eight pinyon, dead approximately 16 years; (G) class nine pinyon, cannot be dated.**

trees killed by bark beetles near La Grande, Oregon, Bull (1983) found that approximately 30% of the small diameter (<25 cm) ponderosa pine were standing 8 years after death versus 70% of the large diameter (>50 cm) trees, and 25% of lodgepole pine trees <25 cm in diameter remained standing 8 years after death versus 55% for trees >25 cm. In a California study, dead Jeffrey pine (*Pinus jeffreyi*) and lodgepole pine decayed and fell at a faster rate than white fir (*Abies concolor*) and red fir (*A. magnifica*), which had larger average diameters (Morrison and Raphael 1993). However, in our study, there were no significant differences in mean number of years dead or diameter at root crown (DRC) between standing and downed stems. Intact snags (class four) had a mean DRC of 18.6 cm and intact logs (class six) had a mean DRC of 19.5 cm; the difference was not significant ($P = 0.5821$). Fragmented snags and logs (classes five and seven, respectively) had mean DRCs of 18.0 and 16.0 cm, the difference between which was not significant ($P = 0.1306$). The lack of an effect from diameter may be related to the relatively small range of DRC in the pinyon sampled in this study.

Morrison and Raphael (1993) reported that shorter trees remain standing longer than taller trees. Our study found that there was no significant difference ($P = 0.1746$) in the height between intact snags (class four), mean height 4.2 m, and intact logs (class six), mean height 4.5 m. Fragmented snags (class five) had mean height of 2.7 m and fragmented logs (class seven) had a mean height of 3.1 m, a difference that was significant at $P = 0.0524$. The relatively small stature of pinyon pines in southwestern Colorado may negate the effects of height found in other studies.

The effect of mortality agent on snag longevity is unclear, snags created by fire may stand longer if bark is removed and decay rate reduced or they may fall to the ground faster because there are few trees standing around them to protect them from wind. Morrison and Raphael (1993) found that snags produced by fire fell to the ground sooner than those produced by factors other than fire. Dahms (1949) reported that snags created by fire remained upright longer than those created by insects; however, the difference in longevity was later attributed to soil type (Keen 1955). The mean percentage of insect-killed ponderosa pine remaining standing 9 years after tree death was 36% on loam soils, 53% on pumice soils, and for fire-killed ponderosa pine was 53% on pumice soils (Keen 1955). Keen speculated that pumice soils allowed snags to remain standing longer than loam soils because the pumice based soils quickly dry out at the surface, which may act to retard decay at the tree base. The key mortality agents in our study were BSRD and ips bark beetles; no pinyon had been killed by fire. BSRD infection was confirmed or suspected in 75.9% of all pinyon in mortality centers; ips bark beetles were present in 69.9% (Kearns and Jacobi 2005). Neither the presence of BSRD nor ips bark beetles was related to standing/downed status.

The most commonly occurring damaging agents aside from BSRD and ips beetles were nonips bark beetles, wood borers, and fungi-causing brown cubical rot, which were found in 38.6%, 41.2%, and 5.3% of all trees, respectively. Ants and termites were also actively breaking down snags and coarse woody debris. Of all dead pinyon, 43.2% had decay in the heartwood, sapwood, or both. Fruiting bodies of decay fungi occurred on less than 5% of pinyon stems. These fruiting bodies were identified by Dr. J.P. Lindsey (Department of Biology, Fort Lewis College, Durango, CO) and included *Pycnoporus cinnabarinus*, *Gloeophyllum sepiarium*, *Trichaptum abietinum*, and *Stereum* sp.

**Table 4. Simplified rating system to determine the number of years dead for pinyon pine.**

| Snag/log description | Mean years Dead[a] | SE |
|---|---|---|
| Many to few red/brown needles, intact bark, many fine twigs | 1.8[b] | 0.54 |
| Bark partially missing, no needles, many twigs | 4.8[c] | 0.64 |
| Standing or down tree, 5%–33% branches broken, few twigs | 9.8[d] | 0.55 |
| Standing or down tree >33% branches broken, very few twigs | 14.0[e] | 0.35 |
| Down tree, stem broken, few branches | 16.2[f] | 0.69 |

[a-f] Least squares means, adjusted for site differences, means followed by different letters are statistically different at $P < 0.001$ level.

## Conclusions

Keen (1955) attempted to develop a visual rating for longevity of snags based on needle color and condition of snags. He found a great range in snag ages within each of his four visual snag classes and concluded that visual condition classes were not very useful in determining snag age. Our data indicate a good relationship between pinyon snag/log age and our tree condition classes. The rating system (Table 4) was compressed into five classes for easy use in the field. This rating system, when applied to pinyon in southwestern Colorado, can act as a reasonable predictor of snag/coarse woody debris age. We do not know if these snag degradation rates or visual degradation classes will have the same values in other regions of the Southwestern United States. However, because the degradation rates we found in pinyon in southwestern Colorado were similar to the degradation rates of ponderosa and lodgepole pine trees (Keen 1929, 1955, Bull 1983), it seems logical that pinyon pine will decay at relatively the same rate elsewhere in the West.

Tree ring analyses indicate that although some pinyon snags may persist for up to 25 years, the breakdown of pinyon snags and logs is relatively rapid. Pinyon that are extremely fragmented, representing the oldest datable pinyon class, had been dead for 16.2 years, indicating that mortality within these discrete disease centers has been relatively recent. The tree class rating system developed by this study can act as a reasonable measure of snag/log persistence when applied to pinyon.

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