NOTES

Longevity of windthrown logs in a subalpine forest of central Colorado

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Abstract: The number of years since tree death for wind-thrown logs of lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.) and Engelmann spruce (*Picea engelmannii* Parry) was used to examine the longevity of this component of coarse woody debris in an old-growth subalpine forest in the central Rocky Mountains. Death dates of downed logs were determined by dendrochronological cross-dating methods. We were able to determine death dates for 73 logs from both species, the oldest being a lodgepole pine dead 139 years ago. Sound lodgepole pine and Engelmann spruce logs lying on the ground persisted for many decades with a majority of their volume intact. No difference was seen in decay classes of logs collected from two primary study sites on opposite (north and south) exposures. There was also no significant difference in decay classes between the two species, although lodgepole pine logs were in general older than Engelmann spruce logs within any decay class. There was little decrease in the specific gravity of wood remaining in logs with time, although there was a corresponding greater loss of wood volume.

Résumé : Les auteurs ont utilisé le nombre d'années écoulées depuis la mort des arbres renversés par le vent, dans le cas des billes de pin lodgepole (*Pinus contorta* var. *latifolia* Engelm.) et d'épinette d'Engelmann (*Picea engelmannii* Parry), pour étudier la longévité de cette composante des débris ligneux grossiers dans une vieille forêt subalpine de la région centrale des montagnes Rocheuses. Les dates auxquelles sont morts les arbres renversés ont été déterminées à l'aide de méthodes dendrochronologiques de datation croisée. Nous avons pu déterminer la date de la mort de 73 billes des deux espèces, la plus vieille étant un pin lodgepole mort il y a 139 ans. Des billes saines de pin lodgepole et d'épinette d'Engelmann reposant sur le sol ont persisté pendant plusieurs décades en conservant intacte la plus grande partie de leur volume. Il n'y avait pas de différence dans les classes de décomposition des billes prélevées sur deux sites d'étude primaires qui avaient des expositions opposées (nord et sud). Il n'y avait pas non plus de différence significative dans les classes de décomposition entre les deux espèces, même si les billes de pin lodgepole étaient généralement plus vieilles que les billes d'épinette d'Engelmann, peu importe la classe de décomposition. La masse spécifique du bois encore présent dans les billes diminuait peu avec le temps même si la perte correspondante de volume de bois était plus grande.

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Introduction

Dead tree stems may constitute a large fraction of above-ground detrital biomass in old-growth forests (e.g., Harmon et al. 1986; Means et al. 1992; Keenan et al. 1993). In old-growth coastal Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) forests of western Oregon, dead stems accounted for up to 80% of detrital biomass and 17% of total organic matter in the ecosystem (Grier and Logan 1977; Sollins et al. 1980). This coarse woody debris (CWD) consists of standing dead trees (snags), downed logs, and larger diameter branches (>2.5 cm; Harmon et al. 1986) on the forest floor. CWD provides habitat and nutrition for many species of animals and plants, influences and controls geomorphic and hydrologic processes in streams and rivers, and serves a large role in nutrient and carbon cycling and storage within old-growth forested ecosystems (see Harmon et al. 1986 for a review of the ecology of CWD).

The long-term dynamics of large dead wood biomass in most forest ecosystems are not well known, especially its residence time in these ecosystems. This information is needed to assess turnover rates of carbon and other nutrients present in CWD, to use in studies examining forest productivity over long time periods, and for management of certain wildlife populations (Thomas 1979; Harmon et al. 1986). Here we used dendrochronological cross-dating methods to determine death dates of wind thrown, downed logs in a subalpine forest in the central Rocky Mountains. The purpose of this study was to quantify empirically the time that

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Table 1. Decay classifications for logs sampled in this study.

Class	Description
1	Needles and small branches present, bark whole, log solid
2	Needles gone, small branches present, 75–100% of bark remaining, log solid
3	Small branches not present, bark loose but 50–75% present, some sapwood decay but generally log solid
4	Bark 0–50% present, log sapwood layers beginning to flake, some settling of the stem
5	Bark gone, log sapwood layers heavily flaked and easy to remove, log circumference flattened
6	Little structural integrity from outside to inside of the log but wood still present

Note: Bark percentages were for top and visible sides of log. Bark percentages and log structural integrity were estimated for entire length of extant woody stem.

wind thrown logs may persist in this ecosystem. We concentrated our study on windthrown trees in an attempt to assess decomposition under conditions in which time since tree death equaled time on the ground for the downed log. CWD that remains standing for some length of time before falling is subject to different decomposition rates and decay processes than CWD on the forest floor, principally owing to differences in habitats available for heterotrophic decomposer organisms (Harmon et al. 1986; Johnson and Greene 1991). Our assumption was that, by selecting what appeared to have been windthrown logs, the trees would have been alive when felled and time since tree death equaled time on the ground. We determined the specific gravity (mass density) and total fraction of wood in downed logs from two species of the subalpine forest, lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.) and Engelmann spruce (*Picea engelmannii* Parry) that had been decomposing under different microclimatic moisture and temperature regimes on north- and south-facing slopes.

Methods

We conducted this study at the 9300-ha Fraser Experimental Forest (FEF), located in the central Rocky Mountains of Colorado west of the Continental Divide 81 air km from Denver. Forests at FEF are typical of cool, dry subalpine environments of central Colorado (Popovich et al. 1993). The majority of logs used for this study were collected from two approximately 30-ha old-growth stands (ca. 300 years old) located on opposite north- and south-facing aspects of West St. Louis Creek, a tributary of the main St. Louis drainage at FEF. Latitude and longitude of the stands is 39°53.1′N, 105°55.2′W, and elevation averages 2990 m. These two stands were chosen in an attempt to keep microsite conditions of slope degree and elevation constant while examining differences in decomposition rates that may have been related to aspect. All logs were collected in the summers of 1993 and 1994.

Logs were selected based upon four criteria:

(1) All logs had intact root masses and tip-up pits at their base indicating that windthrow had been the cause of death. We occasionally were able to collect partial cross sections from living scarred trees that appeared to have been hit by a selected log when it came down to check if the death date of the log matched the fell date recorded by the scar on the living tree.

(2) Logs had intact sapwood on at least a portion of their circumference so that we could obtain a death date for the tree.

(3) Logs had a breast height diameter >30 cm in an effort to insure we would have enough rings for cross-dating purposes.

(4) Logs were lying on the ground for a majority of their length to obtain uniform conditions for assessment of decay classes. For this study, six field classifications for the state of decay of logs were defined (Table 1).

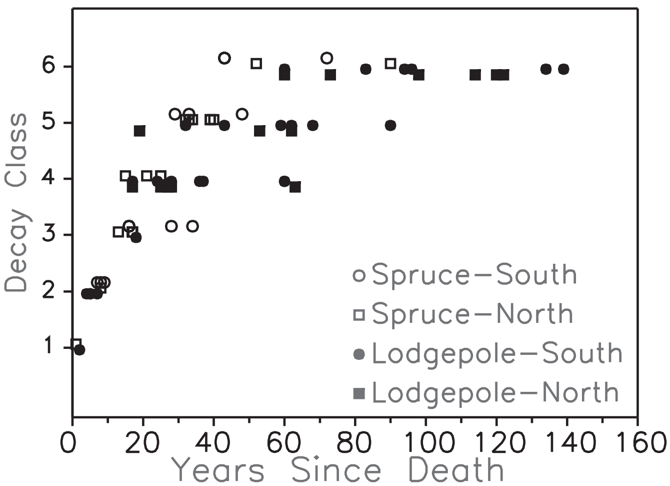
We removed at least one full circumference cross section from each log for age determination. After surfacing with hand planers and belt sanders, all cross sections were dendrochronologically cross-dated using correlation coefficients of measured ring widths. Correlation coefficients between ring series were determined using program COFECHA (Holmes 1983). Undated ring width series were compared with absolutely dated ring width chronologies developed from living trees in the FEF area (Brown et al. 1995; Brown and Shepperd 1995, and unpublished data). Any cross-dating suggested by COFECHA output was confirmed by visual examination of the ring series that replied upon cross matching of patterns of both ring width and latewood widths or darkness between logs and dated tree ring series. If there was any question in the cross-dating of a log either from COFECHA output or after visual examination of the ring series, it was not used in further analyses.

From most logs that we were able to obtain a death date, we also collected three additional cross sections equally spaced up the remaining bole. These cross sections were used to determine specific gravity (mass density) of wood remaining in the log. In contrast to green volumes usually used to determine specific gravity (e.g., US Forest Products Laboratory 1967), all cross sections were dried for a minimum of 4 days at 60°C before volume determinations owing to different decay states of the wood. A volumetric pycnometer (sensu Blake and Hartge 1986) using millet (*Panicum miliaceum* L.) seed as a measuring medium was used to determine volume displacements. We used millet seed rather than water for measuring volume displacement of samples. Millet seed did not fill up small gaps in the wood as would water and offered a more robust estimate of surface area and hence volume displacement on the occasionally heavily decayed and broken cross sections. We tested volume determinations derived by millet seed displacement using squared wood samples of known volumes and multiple replicated measurements. Specific gravity was calculated as dry mass per unit dry volume displacement of each cross section from the downed logs.

Many of the older and more decayed cross sections used to determine specific gravities were missing portions of their original circumference owing to decomposition or fragmentation of the log. To determine how much of the original wood remained in each cross section, we calculated an approximate original volume based upon the field measured diameter and a laboratory-measured average thickness (longitudinal dimension) of each cross section. The original volume of each cross section was then divided by the volume displacement determined from the millet seed pycnometer to derive an approximate fraction of the original wood remaining in the cross section. This fraction was always less than 1.0 since pycnometer-measured volumes were determined after samples had been dried, which resulted in shrinkage of cross sections.

We examined the influence of species, aspect, and time since tree death on log decay class, and the influence of time since tree death on specific gravity of log cross sections and fraction of original volume of cross sections using regression analysis. We used least absolute deviation (LAD) regression procedures (Neter et al.

Fig. 1. Years since tree death for Engelmann spruce and lodgepole pine logs on north- and south-facing slopes by decay class.



1989) to develop 50% quantile curves. LAD regression estimates regression coefficients by minimizing the sum of the absolute deviations of observations from their means. The LAD method places less emphasis on outlying observations for calculating median curves (Neter et al. 1989).

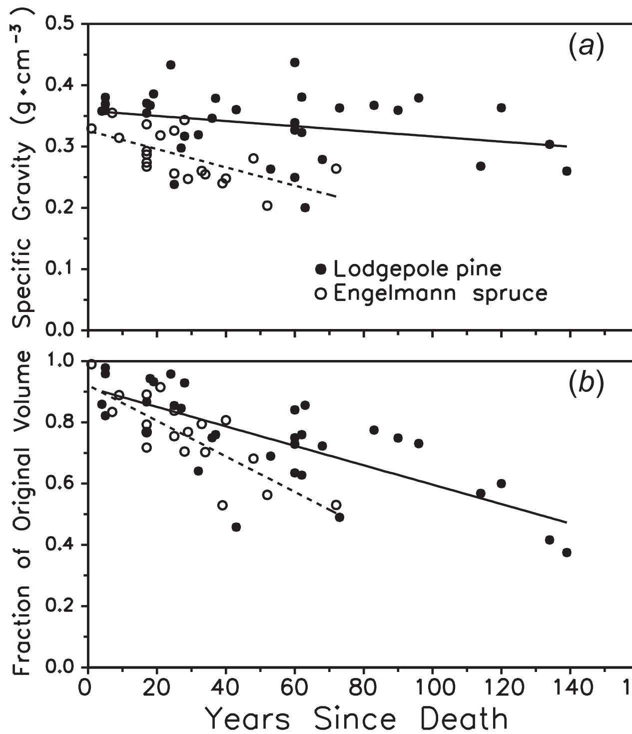
Results

We were able to determine death dates for 73 of a total of 104 logs collected. Years since tree death for cross-dated logs are plotted by decay class in Fig. 1. We found no significant differences between decay classes of logs based upon species or aspect in regression analyses of log decay classifications, although in general, lodgepole pine logs were older than Engelmann spruce logs within any decay class (Fig. 1). However, species and aspect are confounded in the regression analyses since lodgepole pine are more common on south-facing slopes than Engelmann spruce at any elevation where the two species coexist.

We collected fell scars recorded on living trees for six of the cross-dated logs. Of those six, four of the fell scar dates matched death dates of the corresponding logs; i.e., the trees were alive at the time they fell, and time since death equaled time on the ground. Two of these logs were Engelmann spruce, and two were lodgepole pine. The other two fell scar dates were recorded 10 and 16 years, respectively, after the death date of the corresponding log; i.e., the logs had been standing dead snags before falling. Both of these logs were lodgepole pine. Another eight of the cross-dated logs died in 1976, which is when a high wind event (microburst) occurred in this area (unpublished data). Five of these logs were from Engelmann spruce and three were lodgepole pine. Therefore, only 2 of 14 logs with corroborated death dates were not killed at the time of falling, indicating our assumption that tree death dates equaled time on the ground was possibly correct in the majority of our data.

Specific gravities determined by millet seed pycnometer measurements from 53 of the 73 cross-dated logs are in Fig. 2*a*. We did not collect cross sections for specific-gravity measurements from the other 20 cross-dated trees (with generally more recent death dates) because of time constraints.

Fig. 2. (*a*) Specific gravity of wood remaining in cross-dated logs by years since tree death. Each point is the mean of three cross sections from each log. The regression equation for lodgepole pine (solid line) is $y = 0.36 - 0.00040x$ ($N = 33$, $R^2 = 0.08$). The equation for Engelmann spruce (broken line) is $y = 0.33 - 0.0015x$ ($N = 20$, $R^2 = 0.38$). (*b*) Mean fraction of original wood volume in three cross sections used to determine specific gravities. The regression equation for lodgepole pine (solid line) is $y = 0.91 - 0.0032x$ ($N = 33$, $R^2 = 0.56$). The equation for Engelmann spruce (broken line) is $y = 0.92 - 0.0058x$ ($N = 20$, $R^2 = 0.64$).



The average fractions of original stem volumes remaining in the cross sections are in Fig. 2*b*. There was only a slight decrease in the specific gravity of wood with time since tree death, especially in the lodgepole samples (Fig. 2*a*), although there was a corresponding greater decline of total wood remaining in each cross section and the overall tree stem (Fig. 2*b*). LAD regression slopes fit through the separate species emphasize graphical differences in rates of decomposition in the two species; however, there were no significant differences between species when regression was performed on the full data set.

Discussion

Sound lodgepole pine and Engelmann spruce logs lying on the ground can persist for many decades in high-elevation environments with a majority of their volume intact. Downed tree stems may require over 150 years to completely disappear from the subalpine ecosystem of this study (Fig. 2). A linear pattern of wood loss for both species is evident as logs age, although specific gravity of remaining wood did not change appreciably (Fig. 2). Our data also clearly shows that an arbitrary classification of log condition based on easily observed features (Table 1) can be helpful in estimating the time since tree death (Fig. 1). However, accuracy of log aging using a classification scheme can decrease with time since tree death.

Decomposition of CWD is a complex process, and heterogeneity in decomposition of logs (Figs. 1 and 2) may arise from a number of factors. These factors include the amount of time a dead tree may have stood before falling, state of the tree before death, nutrient and substrate variability in different species, bole size, and both environmental and log structural conditions once the tree was on the ground. We have assumed that all logs collected for this study were alive when felled and did not stand as snags after tree death. Scatter in data points in Figs. 1 and 2 may be at least partially the result of logs that stood as snags for some length of time after death. Standing dead trees would have been subjected to different pathways and rates of decomposition, since they tend to dry out and inhibit decay organisms from invading the majority of the bole (Gore et al. 1985; Harmon et al. 1986; Johnson and Greene 1991). The presence of death dates corresponding to a known high wind event in 1976 and fell scar dates on living trees in at least four instances of our data suggest that we were able to find trees that met our assumption in a majority of sampled logs.

A second major factor in decomposition of CWD is the state of the tree before it died (Schowalter et al. 1992). Trees in the subalpine zone often exhibit heartrot at death, which would tend to increase the degree and probably the rate of decomposition once the tree was on the ground. We avoided trees that appeared to have been rotten at the time of falling by only selecting logs with intact root masses and tip-up pits at the base. Trees that have heartrot tend to break off at the base of the stem, leaving the roots in the soil (unpublished data).

Although we did not see any statistically significant differences in our data, microsite or species differences undoubtedly play a role in variability of CWD decomposition. We expected to see differences in the patterns of decomposition between north- and south-facing aspects owing primarily to differences in moisture regimes. Decomposition processes in fine-scale detritus, such as needle or leaf litter, has been determined to be related to actual evapotransporation (e.g., Olsen 1963). North-facing aspects in the FEF area retain snow much longer into the summer and often have dense understory layers of *Vaccinium* sp., which shade soils from desiccation. However, increases in moisture regimes on north-facing aspects may be at least partially offset by lower mean temperatures and consequently much shorter growing seasons for heterotrophic populations in these high, cold environments. Higher effective moisture regimes but shorter growing seasons for decomposers on north-facing slopes may equate to longer growing seasons on warmer, drier south-facing slopes and, hence, result in little differences in overall decomposition between aspects.

We also expected to see greater differences in patterns of decomposition between species. Lodgepole pine has a slightly higher specific gravity than Engelmann spruce and a more pronounced heartwood zone with greater polyphenolic deposition (USDA Forest Products Laboratory 1967). Also, there are more resin ducts in pines than spruces, which may further contribute to having a generally lower quality substrate and more hydrophobic moisture regime for establishment and growth of decomposer populations. However, in our data there are no significant statistical differences between lodgepole pine and Engelmann spruce, although lodgepole pine logs tended to be longer lasting in the environment than Engelmann spruce (Figs. 1 and 2).

Knowledge of the longevity of logs in forest ecosystems is necessary for both management of certain wildlife populations and for understanding the long-term dynamics of nutrient and carbon cycling in old-growth forests (Thomas 1979; Harmon et al. 1986). While we did not intend to model the decomposition of logs under all conditions in the subalpine ecosystem of this study, our results have shown that dendrochronological methods can be useful to quantify the rates and patterns of decomposition of CWD. Further work to quantify both nutrient and wood loss in logs of known age since death will refine patterns of decomposition in logs from the subalpine zone.

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