Lodgepole Pine Bole Wood Density 1 and 11 Years after Felling in Central Montana

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ABSTRACT

Estimates of large dead and down woody material biomass are used for evaluating ecological processes and making ecological assessments, such as for nutrient cycling, wildlife habitat, fire effects, and climate change science. Many methods are used to assess the abundance (volume) of woody material, which ultimately require an estimate of wood density to convert volume to biomass. To assess wood density and decomposition rate, this study examined in situ wood density of lodgepole pine logs at the Tenderfoot Creek Experimental Forest, central Montana, 1 and 11 years after felling. Wood density decreased from 0.39 g cm^{-3} to 0.35 g cm^{-3} over 10 years and the single exponential decay rate was 0.0085 yr^{-1}. A common 5-category decay classification system was evaluated for estimating wood density by decay class; however, the relationship was only partially significant.

Keywords: biomass, decomposition, decay class, decay rate, down woody material

Dead and down woody material (DWM) plays a well-documented ecological role in forest ecosystems (Maser and Trappe 1984, Harmon et al. 1986, Stevens 1999, Brown et al. 2003) and can account for a substantial portion of aboveground forest carbon, sometimes exceeding 20% of the total (Grier and Logan 1977, Harmon et al. 1987, Harmon and Hua 1991). More recently, the role of carbon and associated flux between biosphere and atmosphere has come to the forefront (Currie and Nadelhoffer 2002, Weedon et al. 2009). Given the importance and relative abundance of DWM accurate assessments are necessary for use in land management programs.

While numerous methods for sampling DWM have been previously described: planar intersect (Warren and Olsen 1964, Van Wagner 1968, Brown 1971), area sampling (Bate et al. 2004), relascope sampling (Ståhl 1998, Gove et al. 1999), and photographic (Fischer 1981, Arcos et al. 1998, Keane and Dickinson 2007); the primary attribute sampled with most of these methods is DWM volume. However, biomass (mass per unit area) is the attribute most used to report the abundance of DWM, thus an accurate estimate of wood density is needed for converting wood volume estimated with the various DWM sampling methods to biomass.

Wood density varies considerably based on species, disturbance history, local conditions, and current state of decay (Harmon et al. 1986). Decay state is a function of residence time and decomposition rate, which itself is dependent on climate, substrate quality, and wood characteristics (Maser and Trappe 1984, Harmon et al. 1986). The density of DWM declines on a continuum from the initial condition when DWM reaches the forest floor to the time it is incorporated back into the soil as organic matter (Maser and Trappe 1984, Harmon et al. 1986).

Given the numerous factors affecting wood density it is preferable to calculate the loading of DWM using locally determined, species-specific wood density collected across a range of decay states to ensure accuracy of the estimates. Making wood density calculations is an expensive, time-consuming task that requires specialized equipment so, to remove the burden of making them, researchers and managers prefer to use published values. While a number of studies have examined the wood density and decay rate of lodgepole pine in the same general region of North America as the current study (Fahey 1983, Johnson and Greene 1991, Busse 1994, Wei et al. 1997, Herrmann and Prescott 2008) no studies have examined wood density on the Little Belt Mountains of central Montana.

This study was conducted to provide locally derived wood density and decay rate information to be used in research at the Tenderfoot Creek Experimental Forest (TCEF). The objectives of this research were to: (1) measure wood density of recently felled lodgepole pine boles (*Pinus contorta* Douglas ex Loudon var. *latifolia* Engelm. ex S. Watson), (2) test for significant change in wood density after 10 years, and (3) estimate the single exponential decay rate for the 10-year time period. A post hoc test examined difference in wood density between decay classes.

Methods

Study Area

This study was conducted at the TCEF in central Montana. The TCEF is located at about 46.9 degrees north latitude and situated at the head of the Tenderfoot Creek drainage. Forest cover is dominated by lodgepole pine with scattered patches of subalpine fir (*Abies lasiocarpa (Hook.) Nutt.*) and Engelmann spruce (*Picea engelmannii Parry ex Engelm.*) dominating older stands. Sample sites ranged between 2,180 and 2,350 m in elevation.

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This article uses metric units; the applicable conversion factors are: meters (m): 1 m = 3.3 ft; centimeters (cm): 1 cm = 0.39 in.; grams (g): 1 g = 0.035 oz.

Table 1. The log decay classification characteristics used in this study were reproduced from Maser et al. (1979).

Log characteristic	Decay class I	Decay class II	Decay class III	Decay class IV	Decay class V
Bark	Intact	Intact	Trace	Absent	Absent
Twigs	Present	Absent	Absent	Absent	Absent
Texture	Intact	Intact to partially intact	Hard large pieces	Small, soft, blocky pieces	Soft and powdery
Shape	Round	Round	Round	Round to oval	Oval
Wood color	Original	Original	Original to faded	Light brown to faded brown or yellowish	Faded to light yellow or gray
Portion of log on ground	Elevated on supporting points	Elevated on pints but slightly sagging	Sagging near ground	All on ground	All on ground

Climate

Climate data recorded by the Onion Park SNOTEL site within the TCEF were accessed from the National Water and Climate Data Center[1] and summarized for the period 2002–2009. Data prior to 2002 were incomplete. Average summer (April to September) and winter temperatures (October to March) were 8° C and −4° C, respectively. High temperatures during the warmest parts of summer were typically 20° C to 25° C while during the coldest parts of the winter temperatures often fell below −20° C. Average annual precipitation was 83 cm, about evenly split between the two seasons.

Field Methods

All wood samples in this study were cut from 46 live lodgepole pine trees felled in 1998. Trees were cut in nine groups. Group locations were not selected randomly, rather they were selected in stands across a range of structural characteristics representative of the TCEF (Barrett 1993). Each cutting group consisted of 7–13 felled trees. Trees were selected within each group such that the diameter breast height (dbh) frequency distribution of the sample would be similar to the diameter distribution of the surrounding stand, thus fewer sample trees were felled in stands with more homogeneous stand structure. The boles of felled trees were partitioned into 2-m "logs." The entire bole was partitioned, thus there was no defined minimum diameter for the logs. Some logs were created by physically segmenting the tree bole with a chainsaw and the remaining boles had the 2-m logs marked using a small saw nick. Each log was given an identifier consisting of concatenated tree tag number and log number with the logs numbered sequentially starting at the base of the bole. The sample trees yielded 390 logs. After initial samples were collected in 1999, a sampling schedule of the remaining logs was created with random logs (without replacement) selected for sampling at 10-year intervals beginning in 2009.

All wood samples were collected by cutting a 5–10-cm thick disk perpendicular to the central axis of the sample log using a chainsaw. The samples were cut from the ends of the logs in 1999—less than 10 months after felling—and from the middle of logs in 2009. The decay class of the log was recorded before removing the sample and piece diameter was measured using a flexible d-tape after it had been cut from the log. The 1999 sample included 45 wood samples from 12 trees and the 2009 sample included 25 samples from 16 trees. Two additional assessments were made for logs sampled in 2009: (1) we recorded the position of the log as either in contact with the ground or suspended above the ground by branches, vegetation, etc. and (2) we recorded if one or both of the log ends had been completely cut through (segmented) in 1998. Samples were stored in sealed plastic bags until lab work began.

Log decay class was visually assessed using the classification described in Maser et al. (1979) (Table 1). The classification uses a condition criteria assessment of bark, twigs, texture, shape, color of wood, and portion of the log on the ground. An entire log rarely met all the criteria of a class but was assigned to the decay class of which it met the majority of criteria.

Lab Methods

Wood density for all samples collected in 1999 and 2009 was determined using the same procedure. All bark was removed as were pieces of dirt, debris, and any loose chips left over from cutting with the chainsaw. Piece volume was determined using water displacement by placing a tub of water on a scale and submersing the piece in the water bath using an apparatus where the submersed portion had a known volume (USDA Forest Products Laboratory 1956). Piece volume was calculated by assuming 1 g of water displacement was equal to 1 cm^3 of wood volume. By substituting volume for displacement the volume of each sample was calculated using Equation 1, which accounted for any water absorbed by pieces during the short time they were submerged:

$$V_n = V_g + (W_2 - W_1) - V_a \tag{1}$$

where

V_n = net volume (cm^3).
V_g = gross volume (cm^3).
W_1 = piece weight before submersion (g).
W_2 = piece weight after submersion (g).
V_a = volume of the submerged portion of the apparatus (cm^3).

Pieces collected in 1999 were dried at 100° C for 27 days. Pieces collected in 2009 were dried at 100° C for 9 days—a time period that accounted for more than 99% of weight loss seen in the 1999 drying data. Wood density was calculated using green volume and dry weight (Equation 2).

$$D = W_3/V_n \tag{2}$$

where

D = wood density (g cm^{-3}).
W_3 = dry piece weight (g).
V_n = net volume (cm^3).

The single exponential decay model has been used to estimate decay of large DWM (Fahey 1983, Busse 1994, Wei at al. 1997). The decay rate equation used in this study was based on the single exponential decay model presented by Olson (1963) in the form published by Herrmann and Prescott (2008) (Equation 3).

$$k = -\ln(D_1/D_0)/Yr \tag{3}$$

where

k = single exponential decay constant.

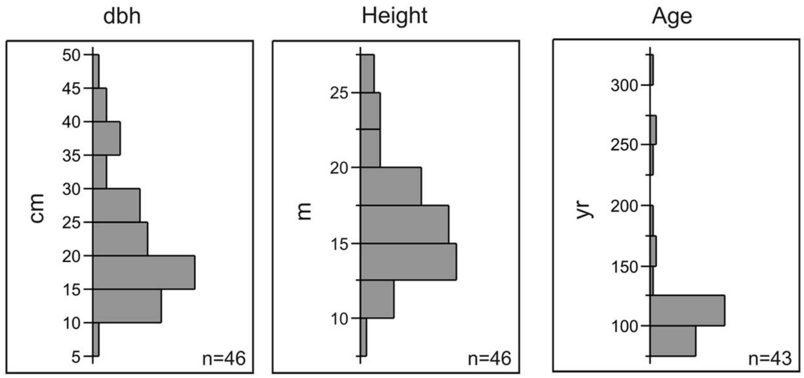

Figure 1. Diameter (dbh), height, and age distribution of the trees selected for this study. Heartrot prevented aging of three trees.

Table 2. Summary statistics for piece diameter and wood density samples collected in 1999 and 2009.

		Wood density				Sample piece diameter			
Year	n	Min.	Max.	Mean	Std. dev.	Min.	Max.	Mean	Std. Dev.
		.................(g cm^{-3}).................				...................(cm)...................			
1999	45	0.35	0.44	0.39	0.02	3.8	40.4	17.1	9.4
2009	25	0.22	0.41	0.33	0.04	6.1	40.9	18.3	8.8
2009	23[a]	0.30	0.40	0.34	0.02	6.1	31.0	16.5	6.5
2009	12[b]	0.34	0.40	0.35	0.02	6.1	23.4	16.6	6.0

[a] Two samples with heart rot excluded from the initial 25-log sample.
[b] Two samples with heartrot and 11 samples from segmented logs excluded from the initial 25-log sample.

D_1 = wood density in 2009.
D_0 = wood density in 1999.
Yr = time period, in years, between D_0 and D_1.

Mean wood density across and between decay classes was tested using analysis of variance (ANOVA) and the Tukey–honestly significant difference (HSD) test to see how well the external characteristics selected for decay classification presented in Maser et al. (1979) predicted wood density.

Results

Histograms of dbh, height, and age for the 46 sample trees are shown in Figure 1. Ages for three trees could not be sampled because of heartrot. When sampled in 1999 the logs displayed no evidence of shrinkage and the mean moisture content of the samples was 51% at the time of volume determination so it was determined the 10-month delay in sampling the logs did not bias the sample. Mean sound, bark-free wood density of the 45 samples collected at the TCEF in 1999 was 0.39 g cm^{-3}. This is greater than green lodgepole pine density presented in the USDA Forest Service, Wood Handbook (Kretschmann 2010) and lower than entire stemwood specific gravity of similar size and age lodgepole pine trees in the same latitudinal range presented in Koch (1987): 0.38 g cm^{-3} and 0.41 g cm^{-3}, respectively.

The 25 samples collected in 2009 were assessed for physical characteristics not consistent with study goals. Wood density of samples collected from logs in contact with the ground (n = 14) and the density of samples collected from suspended logs (n = 9) were not significantly different (t = 0.637, p(t) = 0.5308). Two logs selected for sampling in 2009 had substantial heartrot. Mean wood density for the two samples collected from these logs was significantly lower than for 23 samples from logs without heartrot (0.24 g cm^{-3} versus 0.34 g cm^{-3}; t = 6.29; p(t) = <0.0001). No samples collected in 1999 showed evidence of heartrot so, for consistency, the two samples collected in 2009 with heartrot were removed from the following four comparisons. The mean density of 11 samples from segmented logs was significantly lower than the mean density of 12 unsegmented logs (0.33 g cm^{-3} versus 0.35 g cm^{-3}; t = 2.877, p(t) = 0.009). Wood density and decay rate are a function of DWM diameter (Harmon 1986, Johnson and Greene 1991) so, to test for the influence of piece size, the mean diameter of samples collected from segmented and unsegmented logs were compared but found to be not significantly different (t = 0.096, p(t) = 0.925). The increased decomposition rate of cut logs was assumed to be artificially introduced into the study by the sampling procedure so the 11 samples from segmented logs were removed from the 10-year wood density comparison. The mean diameter of the 12-piece sample collected in 2009 was not significantly different than the 45-piece sample collected in 1999 (t = 0.167, p(t) = 0.868). The mean wood density of 12 samples collected in 2009 was significantly lower than the 45 samples collected in 1999 (t = 4.42, p(t) = <0.0001). Wood density and piece diameter summary statistics are presented in Table 2. Using the mean wood density of samples collected in 1999 and 2009 (0.39 g cm^3 and 0.35 g cm^3, respectively) the single exponential decay rate was k = 0.0085 yr^{-1}.

All 45 samples collected in 1999 were included in the post hoc test examining wood density and decay class relationships. Eleven samples cut from segmented logs in 2009 were removed to eliminate potential bias due to accelerated decomposition. Two samples with heartrot were not removed because the decay classification used in this study was based on external characteristics that would not have identified the sample logs with heartrot in the field. There was a significant difference in mean woody density of the three decay classes (F = 7.0, p(F) = 0.002). Mean wood density of samples cut from decay class I and decay class II logs were not significantly different (α = 0.05). Mean wood density of samples cut from decay class III logs was significantly lower than the mean

Table 3. Summary statistics for data used to examine the wood density and decay class relationship. Values with the same superscript were not significantly different.

Decay class	n	Density (g cm^{-3})	Std dev
I	22	0.39*	0.02
II	25	0.38*	0.02
III	12	0.34	0.05

* Values were not significantly different.

wood density of samples cut from decay class I and II logs (α = 0.05) (Table 3).

Discussion

It was of special interest that after just 11 years samples taken approximately 1 m from the end of a segmented log were significantly less dense than samples taken from unsegmented logs. Whether the density reduction was due to the increased decomposition caused by segmenting the logs or some other random factor is unknown. Herrmann and Prescott (2008) studied 20-cm log sections and reported lodgepole end and center pieces did not have significantly different mass loss after 10 years in the Kananaskis Valley of Alberta, though two other species they studied, white spruce and subalpine fir, did have greater mass loss of center pieces.

It was also interesting that logs in contact with the ground in 2009 did *not* have reduced wood density when compared to suspended pieces. Busse (1994) noted lodgepole pine boles in central Oregon decayed more rapidly once in contact with the soil surface and Wei et al. (1997) proposed a similar relationship in central British Columbia. It is possible the logs found in contact with the ground at the TCEF in 2009 had not actually been in contact for the entire 11 years since being felled but had slowly settled to the ground as branches, vegetation, and other supporting structures gave way and, thus, had not yet been significantly influenced by decomposition vectors that increase decay rate.

It is difficult to make study-to-study comparison of decay rates because of the variety of methods used to determine the age of wood samples and because of assumptions made about initial wood density. Simply for context, we compared decay rate from this study to several studies in the same general region of North America that reported lodgepole pine decay rate for a similar time period. In central Oregon, Busse (1994) used scars on adjacent trees to determine the residence time of sample boles and calculated decay rates of $k = 0.014$ yr^{-1} for decay class I logs aged 0–7 years and 0.022 yr^{-1} for decay class II logs aged 10–19 years. Fahey (1983) sampled trees in Wyoming 10 years post felling and calculated mean decay rate of $k = 0.0198$ yr^{-1}. In their southern Alberta study, Herrmann and Prescott (2008) sampled standing dead or recently fallen trees and reported decay rate of $k = 0.073$ yr^{-1} after 10 years. Wei et al. (1997) determined the age of samples by estimating time since known disturbance on sites in central British Columbia. Using samples with 5–10 years of decay they calculated decay rates of 0.021 yr^{-1} on harvested sites and 0.004 yr^{-1} on burned sites and postulated logs on harvested sites had greater contact with the ground, which increased their decay rate. Johnson and Greene (1991) approximated the age of downed boles by cross-dating growth rings with adjacent living trees and noted how variable decay rate can be, ranging from $k = 0.0035$ yr^{-1} to $k = 0.0299$ yr^{-1} in five stands in southern Alberta (mean rate $k = 0.014$ yr^{-1}).

The decay rate calculated at the TCEF was generally slower than reported in the comparison studies but within the range published by Johnson and Greene (1991). Harmon et al. (1986) and Grier (1978) suggest a period of fungal colonization occurs in CWD before the decomposition process results in reduced wood density. Trees felled at the TCEF were living when felled in 1998 and would experience this lag period before the effects of decomposition were seen, which may explain the slower decomposition reported in this study. None of the comparison studies definitively described using initially living boles. Climate may be another potential cause of the slower decay rate noted in this study. As described in Harmon et al. (1986), within the temperature and moisture ranges of the study sites discussed in this paper, increased temperature and moisture lead to increased decomposition rate of woody material. With the exception of the study site used by Wei et al. (1997), which had colder average summer and winter temperatures, all the comparison study sites had warmer seasonal temperatures. Average annual precipitation at the TCEF was at least 25% higher than reported for the comparison study sites. Given this dichotomy of generally colder temperature but wetter climate at the TCEF, it was difficult to assess the magnitude (if any) the effect of climate had on calculated decomposition rate at the TCEF. Finally, Graham and Cromack (1982) report that decay rate may be underestimated when only changes in wood density are taken into account because bole fragmentation is not included; however, all logs sampled at the TCEF were sound so it was unlikely fragmentation influenced the decay rate calculated in this study.

The precision afforded by estimating wood density using decay classification was unsuitable for determining decay rate due to the high variability in each class. Likewise, the variability and short duration of the study did not provide statistically unique wood density values for all five decay classes. Previous studies have shown decay class to be a poor predictor of wood density with substantial overlap in wood density between classes—especially in later stages of decay and when not accounting for species (Busse 1994, Pyle and Brown 1999, Creed et al. 2004, Harmon et al. 2008, Larjavaara and Muller-Landau 2010). The problem was demonstrated in this study where samples with heartrot had wood density significantly lower than wood density samples collected from other decay class III logs. Log decay had not progressed very far after just 10 years so only decay classes I, II, and III logs were available for comparison.

The small sample size of this study precluded additional useful tests such as comparing wood density across stands. While a larger sample was preferable, the resources required for collection and analysis of additional samples, as well as the confounding characteristics of segmented logs, limited the sample size of this study. Johnson and Greene (1991) collected over 100 samples for their study but the other regional comparison studies referenced in this paper collected 8–21 samples at any one time period—similar to the sample size collected at the TCEF.

Future Study

This study will continue in 2019 and will further investigate the relationship of wood density, log position, and segmentation of logs. If the increased decay of segmented logs seen in 2009 is not due to some random effect it will pose a dilemma because those tree boles that are currently unsegmented will become segmented when sampled in future sample visits, thus increasing the decay rate of adjacent logs. Also, after just 11 years since felling care was needed to collect the entire log sample because some pieces were easily torn apart by the chainsaw. This problem will be exacerbated as logs become further decayed and more difficult to collect a complete sample from. The results of the comparison studies indicated that decay rate is highly variable, even when examined in the same study but for multiple time periods. The data collected in 2019 may help refine decay rate at the TCEF and possibly verify the lag effect suggested by Harmon et al. (1986) and Grier (1978), although the influence of log fragmentation (Graham and Cromack 1982) may be more prevalent and need to be accounted for. As decomposition progresses to create class IV and class V logs we will reexamine the wood density-decay class relationship to see if better class differentiation emerges. Finally, we will consider collecting more samples at each 10-year sample visit at the cost of reduced overall study duration.

Endnote

1. National Water and Climate Data Center information available online at www.wcc.nrcs.usda.gov.

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