FIELD NOTE

Dating Tree Mortality Using Log Decay in the White Mountains of New Hampshire

Andrew J. Fast, Mark J. Ducey, Jeffrey H. Gove, and William B. Leak

ABSTRACT

Coarse woody material (CWM) is an important component of forest ecosystems. To meet specific CWM management objectives, it is important to understand rates of decay. We present results from a silvicultural trial at the Bartlett Experimental Forest, in which time of death is known for a large sample of trees. Either a simple table or regression equations that use diameter, species group, and decay class can be used to predict time since mortality for a given log.

Keywords: coarse woody debris, downed wood, snags, dating mortality, New Hampshire

Coarse woody material (CWM; also called coarse woody debris) has gained increasing attention as a component of managed forest ecosystems (Hagan and Grove 1999). Knowledge of CWM decay rates is invaluable for projecting future CWM stocks based on current abundance and inputs and for reconstructing past disturbances based on current CWM abundance (Storaunet and Rolstad 2002). Decay of CWM is influenced by a variety of abiotic and biotic factors, including the physical and chemical characteristics of the CWM, microclimate, the decomposer community, and their interactions (Harmon et al. 1986, Yin 1999). Although several studies have examined changes in CWM stocks in response to stand age or management in northeastern North America (e.g., Fraver et al. 2003), relatively little information on CWM decay rates has been published (Yamasaki and Leak 2006).

Determining how long a bole has been decaying, dating mortality, has been a consistent challenge for researchers (Henry and Swan 1974). One approach to dating and tracking CWM decay is to use discrete, field-recognizable decay classes. More quantitative approaches exist, but decay class systems remain attractive for practical use because of their simplicity and ease of implementation (Dynesius and Jonsson 1991, Pyle and Brown 1998). Dynesius and Jonsson (1991) compared eight different methods that can be used to date the mortality of a windthrown tree: cross-dating, growth release, initial growth, tree regeneration on the fallen log, tree regeneration in the pit, fell scars, reaction wood, and stage of decay. Although stage of decay was not the most precise method, often, it is a preferred method for its rapid assessment, ease, and ability to include virtually all tallied stems as viable data (Dynesius and Jonsson 1991). Decay class systems often include subjective assessments, and a single log may be composed of multiple decay classes (Pyle and Brown 1998, 1999). Nonetheless, decay classes remain valuable for practical work (Dynesius and Jonsson 1991).

This study documents relationships between time since mortality and decay class for CWM in a long-term growth study at the Bartlett Experimental Forest (BEF) in New Hampshire. Snag longevity at this site has previously been reported by Yamasaki and Leak (2006). This study augments that work by addressing the downed wood component.

Methods

We conducted fieldwork during the summer 2004 at the BEF (BEF; 44°03′N, 71°17′W) located in the White Mountain National Forest in New Hampshire. The BEF is dominated by northern hardwood, sugar maple–American beech–yellow birch (*Acer saccharum–Fagus grandifolia–Betula alleghaniensis*) forests; detailed descriptions can be found in Filip and Little (1971) and Gamal-Eldin (1998). Our study was overlaid on a silvicultural study originally designed to evaluate growth and yield of northern hardwoods at a range of densities (Leak and Solomon 1975, Solomon 1977). The study is comprised of 48 square plots of ⅓ ac each; all trees have been individually numbered and stem-mapped, and growth and mortality have been recorded in 1967, 1969, 1972, 1974, 1980, 1985, 1989, 1991, 1995, and 2000. Recent results of the silvicultural study have been reported by Leak (2003).

We used the stem-map data to identify individual downed logs, and associated dbh just before mortality, as well as date of mortality (to within the remeasurement period when it occurred). For data summary purposes, date of mortality was taken as uniformly distributed within each measurement period; for regression analyses, date of mortality was imputed as a year selected uniformly at random within the measurement period. Where possible, tree tags were used to confirm log identity; when tags were not present, position, species, and diameter were used. Log diameters were measured with calipers (in this article, we use diameter at the basal or large end of the log), and each log was assigned a decay class based on a seven-class system (Table 1). The system, which is a refinement of the usual

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Table 1. Decay classes used and their approximate relationship to the five-class system of Pyle and Brown (1998).

Decay class	Characteristics	Pyle and Brown class
1	Fine twigs are present on branches; medium branches are present; bark is present and sapwood is hard	I
2	Fine twigs are absent; medium branches are present; bark is present and sapwood is hard	I
3	Fine twigs are absent; medium branches are absent; bark is present or sapwood is hard	I–II
4	Sapwood in a stage of decay; "punky" on the outside of the tree bole	III
5	Sapwood and heartwood in a stage of decay; "punky" throughout the bole; structurally can hold weight	III
6	Sapwood and heartwood in a stage of decay; "punky" throughout the bole; structurally can not hold weight	IV
7	Bole in an advanced stage of decay such as a "lump," or buried or hidden in forest floor	V

five-class system (Pyle and Brown 1998); Charlie Cogbill, (Hubbard Brook Long Term Ecological Research Project, pers. comm., Apr. 29, 2004), suggested additional detail within the classification system would be valuable in estimating time since mortality.

To examine the influence of species and diameter on the average relationship between time since mortality (t) and decay class, we used a linear model with the natural logarithm of t as the dependent variable, with large end diameter as a continuous independent variable, and with species group and decay class as categorical independent variables. Species groups were defined as red maple, all other hardwoods, and softwoods. In equation form,

$$\ln(t) = \beta_0 + \beta_D D + \beta_{RM} RM + \beta_{SOFT} SOFT + \beta_2 decay_2 + \beta_3 decay_3 + \cdots + \beta_7 decay_7, \quad (1)$$

where β are coefficients estimated from the data, D is large end diameter (in.), RM is a dummy variable that equals one only if the tree is a red maple, SOFT is a dummy variable that equals one only if the tree is a softwood, and $decay_2$ through $decay_7$ are dummy variables for decay classes 2–7, respectively. By definition, the coefficients for "other hardwood" and decay class 1 equal 0. This model was fitted using ordinary least squares, and the significance of terms in the model was tested using the usual F-tests. To develop additional predictive relationships, we used quantile regression (Koenker 2005) using the same model structure (including D, species group, and decay class). Models were built to predict the 0.10, 0.25, 0.5, 0.75, and 0.90 quantiles, corresponding to the 10th, 25th, 50th or median, 75th, and 90th percentiles of times since mortality, respectively.

Results and Discussion

A total of 575 downed logs (565 hardwoods and 10 softwoods) were identified, assigned a decay class, and dated. Frequency by decay class is shown in Table 2; the median decay class was 6. Large end diameters ranged from 4.5 to 19.8 in., with a mean diameter of 9.4 in. Average time since mortality was 20.6 years. Average time since mortality was significantly different between decay classes ($F = 93.41$; $P < 0.0001$; Table 2). The cumulative distribution of time since mortality for each age class is shown in Figure 1. These cumulative distributions can serve as a first cut for predicting the time since mortality of a log. For example, if we see a log that is in decay class 2, we would expect approximately one-quarter of such logs to have died within 4 years, one-half to die within 6 years or less,

Table 2. Average time since mortality by decay class.

Decay class	No. sampled	Average time (yr)	Standard error
1	14	4.1	1.1
2	5	6.5	1.4
3	54	9.0	0.7
4	136	17.7	0.6
5	64	18.9	0.8
6	69	22.0	0.8
7	230	26.6	0.4

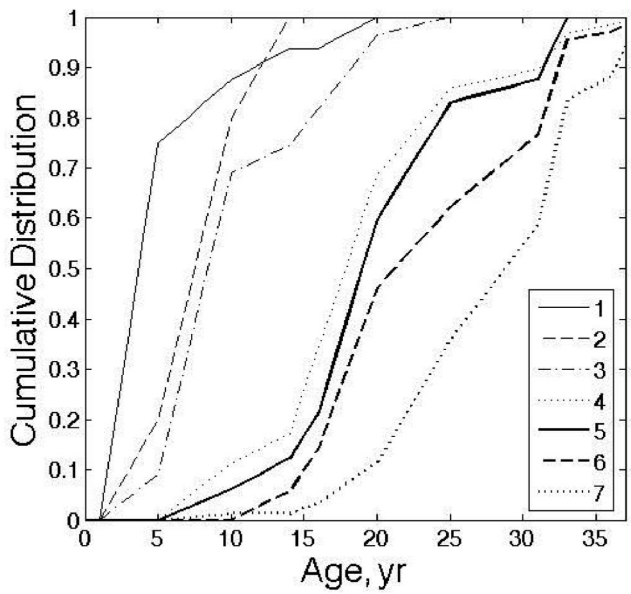

Figure 1. Cumulative age distribution of downed logs by decay class (1 through 7).

and three-quarters to die within 8 years or less. Nearly all decay class 2 logs have died within the last 13 years.

Results of the ordinary regression and quantile regression are summarized in Table 3. For the ordinary regression, diameter and decay class were highly significant ($P < 0.0001$), while the red maple and softwood species groups also were significant ($P < 0.05$). Not all variables were significant in all the quantile regressions, but we have retained all the variables to maintain a consistent set of predictive models. These models can be used to give species- and size-specific estimates of time since mortality. For example, suppose we encounter a dead red maple with $D = 10$ in. in decay class 2. Then, from Table 3, we obtain:

Average expected time since mortality (ordinary least squares [OLS]):

$$\ln(t) = \beta_0 + \beta_D D + \beta_{RM} RM + \beta_{SOFT} SOFT + \beta_2 decay_2$$
$$= 1.1004 + 0.0068 \times 10 - 0.0843 + 0.7133$$
$$= 1.7974$$

$t = 6.0$ years

10% percentile:

$$\ln(t) = -0.1035 + 0.0081 \times 10 - 0.1584 + 0.7214$$
$$= 0.8901$$

$t = 2.4$ years

Table 3. Coefficients for predictive relationships derived from ordinary least squares (OLS) (which predicts mean values) and quantile regression.

		Quantile regression				
Variable	OLS (mean)	0.10	0.25	0.50	0.75	0.90
Intercept	1.1004***	−0.1035	0.6672	1.0221***	1.2740**	2.4849***
D	0.0068***	0.0081	0.0090*	0.0126	0.0113***	0.0000
Species group						
Red maple	−0.0843*	−0.1584*	−0.1200***	−0.0730	0.0159	0.0000
Softwood	0.2962*	−0.2562*	0.0105	0.4654	0.2989**	0.1112
Decay class						
Class 2	0.7133***	0.7214***	1.1892***	0.7981***	0.6523***	0.0800***
Class 3	0.9120	1.6014	0.9987	0.8688	1.1934	0.3483
Class 4	1.6665	2.2619	1.9271	1.6874	1.6515	0.9491
Class 5	1.7407	2.4416	2.0275	1.7751	1.6889	0.9491
Class 6	1.9095	2.7896	2.0965	1.9131	1.9888	0.9808
Class 7	2.1248	3.0417	2.3814	2.2209	2.0987	1.0986

Note: Statistical significance (based on an *F*-test for OLS regression, and asymptotic variances in quantile regression) is shown as $*P < 0.05$, $**P < 0.01$, and $***P < 0.001$. Overall significance of decay class is shown next to the coefficient for Class 2.

25% percentile:

$$\ln(t) = 0.6672 + 0.0092 \times 10 - 0.1200 + 1.1892 = 1.8264$$

$$t = 6.2 \text{ years}$$

50% percentile (median):

$$\ln(t) = 1.0021 + 0.0126 \times 10 - 0.0730 + 0.7981 = 3.0042$$

$$t = 6.5 \text{ years}$$

75% percentile

$$\ln(t) = 1.2740 + 0.0113 \times 10 + 0.0159 + 0.6523 = 2.0552$$

$$t = 7.8 \text{ years}$$

90% percentile:

$$\ln(t) = 2.4849 + 0.0000 \times 10 + 0.0000 + 0.0800 = 2.5649$$

$$t = 13.0 \text{ years}$$

For example, one-half of all logs with these characteristics would fall between the 25 and 75% percentiles, or between 6.2 and 7.8 years since mortality. Eighty percent of such logs would fall between the 10 and 90% percentiles or between 2.4 and 13.0 years since mortality. However, a small fraction (10%) of such logs would have reached decay class 2 in less than 2.4 years, and a similarly small fraction (10%) would remain in decay class 2 despite having died over 13 years ago.

The coefficients of the models can be interpreted, bearing in mind the logarithmic transformation of time since mortality. For example, a little algebra applied to the OLS regression results indicates that a softwood log of a particular size, species, and decay class is likely to be, on average, about 35% older than a typical hardwood log of the same size and decay class and about 46% older than a red maple log of the same size and decay class. These figures should be regarded as approximate, especially in light of the small sample size for softwood logs. However, the results seem realistic in light of other research (Tritton 1980, Macmillan 1981, Yin 1999). A more extensive study, with a much larger sample of softwood logs, would be valuable for regional work. Likewise, increasing diameter is associated with increasing age at a given decay class. This may be caused by in part slower overall decomposition of larger logs once on the ground; however, it also may be caused by the tendency for larger logs to remain standing longer (Yamasaki and Leak 2006). Separating these two effects is beyond the capability of the data available for this study.

Some caution should be used in using Table 2 to provide rough estimates of time since mortality or the coefficients in Table 3 to provide species- and size-specific estimates. The data from this study are from a managed forest with closed-canopy conditions. Some differences might be expected between the microclimate, and hence decay rates, of unmanaged and managed forests, as found by Storaunet and Rolstad (2002) in a study in Scandinavia. Similarly, decay rates should be quite different for downed wood in a postclearcut environment.

Storaunet and Rolstad (2002) indicate that decay class is more closely tied to time since fall than to time since mortality. In this study, it was not possible to date the time of fall of individual logs. More comprehensive longitudinal studies that track the mortality, fall, and decomposition of individual trees through time would be a welcome contribution to the literature on CWM in northeastern forests.

Conclusions

Time since mortality of downed logs in this northern hardwood forest can be predicted reasonably well by their decay status. Larger diameter logs tend to be older than smaller diameter logs of the same species and decay class. Likewise, softwood logs tend to be older than, and red maple logs younger than, typical hardwood logs of the same size and decay class. The ordinary and quantile regression equations presented in this study can capture these effects and may be useful in retrospective analyses of mortality in managed, closed-canopy northern hardwood forests.

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