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V. Decomposition of Woody Debris				

J. BRUCE WALLACE[1,2], JACKSON R. WEBSTER[3], SUE L. EGGERT[1,2], JUDY L. MEYER[2], and EDWARD R. SILER[1]

[1]Department of Entomology, and [2]Institute of Ecology, University of Georgia
Athens, Georgia USA 30602
[3]Department of Biology, Virginia Polytechnic Institute and State University
Blacksburg, Virginia USA 24061

Large Woody Debris in a Headwater Stream: Long-Term Legacies of Forest Disturbance

key words: large woody debris, chestnut blight, stream, forest, disturbance, dynamics

Abstract

We excluded litter (leaves and wood) inputs to an Appalachian headwater stream for 5 years. Leaves disappeared from the streambed very rapidly (<1 year) following litter exclusion, however, a large residual mass of woody debris remained. After excluding inputs of leaf litter and wood to the stream for 3 years we removed all small wood (<10 cm diameter) from the stream. There was close agreement (within 10%) between estimates of mass of small woody debris made using line intersect methods and that made by direct removal. Two years later, we removed all large woody debris (LWD = >10 cm diameter) from the wetted perimeter of the stream. Five annual estimates of LWD mass made with line intersect methods exceeded those of complete removal by a factor of about 2×, although total wood removed was within the 95% confidence interval of that estimated by the line intersect method. Species of wood removed from the stream displayed weak similarity (percent similarity = 45 to 49%) with recent (1993 and 1972) measures of basal area of tree species in the surrounding forest, but stronger similarity (65%) with tree species measured in 1934. About 37% of the LWD removed consisted of American chestnut, *Castanea dentata*, (~24%) and black locust, *Robinia pseudoacacia*, (~14%), which currently represent < 1.5% of the basal area of the surrounding forest. LWD in the stream reflects large inputs of chestnut following the chestnut blight in the1930s and inputs of early successional species such as black locust following extensive timber harvesting in the early 1920s. These earlier disturbances to the forest were important sources of LWD that remain in the stream today. Thus, the structure and function of present day streams are influenced by forest disturbances that occurred over six decades ago.

1. Introduction

Excluding tundra and arid land streams, allochthonous inputs exceed those of autochthonous sources for most streams that have been studied (WEBSTER and MEYER, 1997). In most headwater streams draining forested regions of eastern North America, allochthonous inputs from the surrounding forest far exceed within-stream primary production (WEBSTER *et al.*, 1995). Numerous studies have pointed to linkages between stream invertebrates and terrestrial organic matter (e.g., HYNES, 1963, 1975; ROSS, 1963; FISHER and LIKENS, 1973; CUMMINS, 1974; CUSHING *et al.*, 1995; WALLACE and WEBSTER, 1996). Experiments conducted in artificial streamside channels have shown that densities of some invertebrates are strongly related to levels of coarse particulate organic matter (CPOM) loading (RICHARDSON, 1991).

To examine the linkage between CPOM inputs and stream ecosystem processes, we have been conducting an ecosystem-level study in which we are excluding terrestrial detrital

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inputs to a headwater stream in western North Carolina for 5 years. During the first 3 years of exclusion, we found significant decreases in abundance and biomass of many invertebrates that feed on both CPOM and fine particulate organic matter (FPOM), as well as predatory invertebrates compared to populations in nearby reference streams (WALLACE *et al.*, 1997). However, despite the disappearance of leaf litter during the first year of exclusion, a large residual mass of woody debris remained in the treatment stream after the initial 3 years of litter exclusion (WALLACE *et al.*, 1997). Detritivorous invertebrates in the treatment stream also consumed a larger proportion of woody debris than those of the reference stream (HALL *et al.*, 2000). There is also evidence of enhanced nutritional quality of epixylic biofilms in the treatment stream as microbial activities such as respiration, fungal biomass, and decomposition were enhanced on woody substrates in the treatment stream (TANK, 1996; TANK and WEBSTER, 1998). At the end of the third year of litter exclusion, all small woody debris (SWD = <10 cm diameter) was removed by hand (WALLACE *et al.*, 2000) and litter exclusion was continued. Removal of SWD resulted in an additional 47 to 50% reduction in abundance, biomass, and production of benthic fauna compared to the third year of litter exclusion alone (WALLACE *et al.*, 1999).

Despite removal of SWD and ongoing litter exclusion, a significant residual mass of FPOM and large woody debris (LWD) remained in the treatment stream (WALLACE *et al.*, 1999). The importance of woody debris to stream ecosystem structure and function has only been recognized in the last few decades (e.g. KELLER and SWANSON, 1979). In small, high-gradient streams, (slopes > 4 percent), such as those of the southern Appalachians, LWD performs many functions. These include: retention of particulate organic matter; reduced stream-channel erosion; substrate for many invertebrates; and, a food resource for xylophagous invertebrates (BILBY and LIKENS, 1980; BILBY, 1981; HARMON *et al.*, 1986; SWANSON *et al.*, 1982; PEREIRA *et al.*, 1982; MOLLES, 1982; WEBSTER *et al.*, 1994; WALLACE *et al.*, 1994, 1995a, 1995b). In 1998, we removed all LWD from the stream channel and extended litter exclusion for a sixth year.

The objectives of this paper are as follows: First, we compare annual estimates of LWD standing crop made by non-destructive line intersect methods during the first five years of litter exclusion with complete removal of all woody debris. Second, we compare the amount of various species of wood removed from the stream with that of the surrounding catchment based on long-term studies of the forest composition and basal area. Third, based on long-term changes in forest stand dynamics, we discuss the most likely scenarios contributing LWD to headwater streams within the Coweeta Basin.

2. Materials and Methods

The stream examined in this study is at the Coweeta Hydrologic Laboratory (U.S. Forest Service) in western North Carolina, U. S. A. (35°03′ N, 83°25′ W). Coweeta is a 1625-ha drainage basin in the Blue Ridge Province of the southern Appalachian Mountains. SWANK and CROSSLEY (1988) gave detailed descriptions of the Coweeta basin. The study stream is first order and drains Catchment (C) 55, which has a southern aspect. Current vegetation consists of mixed hardwoods, and is characterized as a mixed oak and hickory forest. Dense growths of understory rhododendron (*Rhododendron maximum*) result in heavy shading of the streams for most of the year. One early natural forest disturbance was the chestnut blight caused by an introduced fungus species, *Endothia parasitica*, which reached the southern Appalachians in the mid-1920s. However, death of the trees was gradual (WOODS and SHANKS, 1959), and at Coweeta large declines in American chestnut, *Castanea dentata*, basal area and stem density occurred between 1934 and 1953 (NELSON, 1955).

Elevation, area drained, thermal regime, and discharge of the study stream are provided in Table 1. The stream is fishless, and salamanders are the only vertebrates. The overall roughness of the streambed topography, including woody debris, results in high retention, with abundant accumulations of leaves and wood prior to litter exclusion and woody debris removal. CUFFNEY *et al.* (1990); MEYER *et al.*

(1998); WALLACE *et al.* (1991, 1997, 1999) report additional information about the study stream. Discharge was gauged continuously using an FW-1 stage as well as an ISCO 3230 Bubble Flow Meter (ISCO, Inc., Lincoln, Nebraska) recorder attached to an 1-ft H-flume at the base of the catchment. Since August 1993, the entire stream has been covered by a gill net canopy (1.2 cm mesh) in addition to a lateral movement fence on each bank to prevent litter from entering the stream from the surrounding forest (WALLACE *et al.*, 1997, 1999). Export of coarse particulate organic matter (CPOM), including woody debris, has been measured continuously every two weeks since 1985. Export was measured with a large CPOM trap (4-mm mesh) that filters the entire stream flow at the base of the catchment (CUFFNEY and WALLACE, 1988). All CPOM, including wood, was dried, weighed, ashed (500 °C), and re-weighed to obtain ash free dry mass (AFDM).

Table 1. Physical parameters of the stream draining catchment (C) 55 at the Coweeta Hydrologic Laboratory. Elevation was measured at the gauging flume.

Variable	C 55
Catchment	
Area (ha)	7.5
Elevation (m asl)	810
Channel length (m)	170
Wetted width (m)[a]	1.2-1.6
Bankful channel area (m^2)	373
Bedrock outcrop % composition	13
Mixed substrate % composition	87
Discharge (L/s)	
Average (5-yr avg.)	2.39
Maximum (5-yr)	40.2
Temperature (for 1985-1997, °C)	
Annual average	12.2
Annual degree-days	4512
Maximum	20.1
Minimum	0.7
Chemistry (1985 to 1993)	
PH	6.7
HCO_3 (mg/L as $CaCO_3$)	3.6
NO_3-N (μg/L)	4
NH_4-N (μg/L)	2
SRP (μg/L)	2

[a] Average wetted widths as measured during dry and wet periods.

Standing crop of wood in the wetted stream perimeter was assessed using two methods. First, line intersect measurements (WALLACE and BENKE, 1984) were made every 5 m (n = 33) in which wood diameters were measured (to the nearest mm) for each piece of wood. Surface area of wood and volume was converted to a per unit area of stream (m^2) by dividing mean area and volume of all transects by wetted stream area. Annual measurements of LWD (n = 5) were made during late summer of 1994, 1995, 1996, 1997, as well as in 1998 prior to removal of all LWD from the stream in late August. All LWD was removed from the stream by hand. Larger logs were cut into manageable lengths using a chain saw. All wood removed from the stream was measured (length and diameter), wet-weighed, and a subsample of known volume was removed for wet-weight to dry-weight conversion. Subsamples of wood were dried, weighed, ashed (500 °C), and re-weighed to obtain AFDM. Personnel in the Department of Wood Science and Forest Products, Virginia Polytechnic Institute and State University, Blacksburg, were provided additional samples of each piece of LWD for microscopic analyses of wood structure and species determination. Wood of several species of oaks were broadly grouped, i.e., red oaks included northern red oak, *Quercus rubra*, scarlet oak, *Quercus coccinea*, and black oak, *Quercus velutina*. Likewise, white oaks included both white oak, *Quercus alba*, and chestnut oak, *Quercus prinus*. The average specific gravity (0.439 g/cm^3) of these subsamples was applied to estimates of volume to convert line intersect volume to AFDM.

Thirteen permanent vegetation plots (each 20 m × 40 m) were established by the U.S. Forest Service on Catchment 55 in 1934 with the initial forest inventory. Plants were identified to species except for hickories, *Carya* spp., which were identified to genus. In the 1934 and 1972 survey all 13 plots were measured, however for the 1993 survey a subset of 4 plots was used for the forest inventory. Diameter at breast height (DBH) and stem densities were measured for each plot using methods described by ELLIOTT *et al.* (1997). We used only tree species from the plot data; however, evergreen understory species, *Kalmia latifolia* and *Rhododendron maximum*, are dense on C 55 and together comprised 86 to 90% of total stem densities and 54.4 to 61.5% of total basal area in the 1972 and 1993 inventories. Although these shrubs do not contribute to LWD in the stream, they are very significant sources of small woody debris (< 10 cm diameter). Proportional similarity between wood removed from the stream and stem densities and basal area inventories were conducted according to the formula of WHITTAKER (1975).

3. Results

No large woody debris was exported from the stream during either the pretreatment or 5-year litter exclusion period.

Annual estimates of LWD standing crop measured by line intersect methods varied from 6.3 kg AFDM/m^2 (+5.43) in 1997 to 9.9 (+7.04) in 1998 (mean +95% CI). However, large wood is patchily distributed in the stream channel, and this resulted in large confidence intervals for the data. For example, the 95% confidence interval for LWD ranged from 75 to 99.9% of the mean among years (Fig. 1B) and were much larger than the 37 to 47% measured previously for small wood. LWD contributed more to wood mass than SWD. However, prior to removal of SWD in late 1996 most of the surface area of wetted wood was from SWD (Fig. 1A). Surface area of SWD averaged 0.75 m^2 of wood per m^2 of stream surface during the initial 3 years of exclusion (Fig. 1A). In contrast, that of LWD averaged 0.31 m^2 wood per m^2 of stream surface prior to its removal at the end of 1998 (Fig. 1A).

We removed 735 kg AFDM of large woody debris from the wetted perimeter of the stream in late August 1998. Based on an average wetted area of 228 m^2, this is equivalent to an average standing crop of LWD of 3.22 kg AFDM/m^2. This estimate is 44% that of the average obtained by the line intersect method during the five annual measurements. However, due to the high variability of the patchily distributed wood the 95% CI of each annual measurement of the line intersect method always overlapped that of the actual wood removed (Fig. 2).

Several species of red oaks dominated the wood removed from the stream, followed by American chestnut, white oaks, black locust (*Robinia pseudoacacia*), yellow poplar (*Liriodendron tulipifera*), and hickories (Table 2). AFDM as a proportion of wet weight varied from a high of 63.5% for beech to 32.7% for hickory (Table 2). Species of red and white oaks comprised almost 50% of the LWD removed from the stream.

As typical of aggrading forests, inventories from 1934, 1972, and 1993 showed a continuous decline in tree abundance in stem densities, i.e., 1934 = 804, 1972 = 498, and 1993 = 319 stems/ha (Fig. 3). The shift in forest basal area was less dramatic, i.e., 1934 = 5.8, 1972 = 4.7, and 1993 = 5.0 m^2/ha. The decrease in forest basal area between 1934 and 1972 was primarily attributable to three tree species. American chestnut declined from 25% of total basal area in 1934 to 0.5% in 1972, and <0.1% in 1993. Yellow poplar declined from 6.1% of total basal area in 1934 to 1.7% in 1972, and 0.8% in 1993 (Fig. 4).

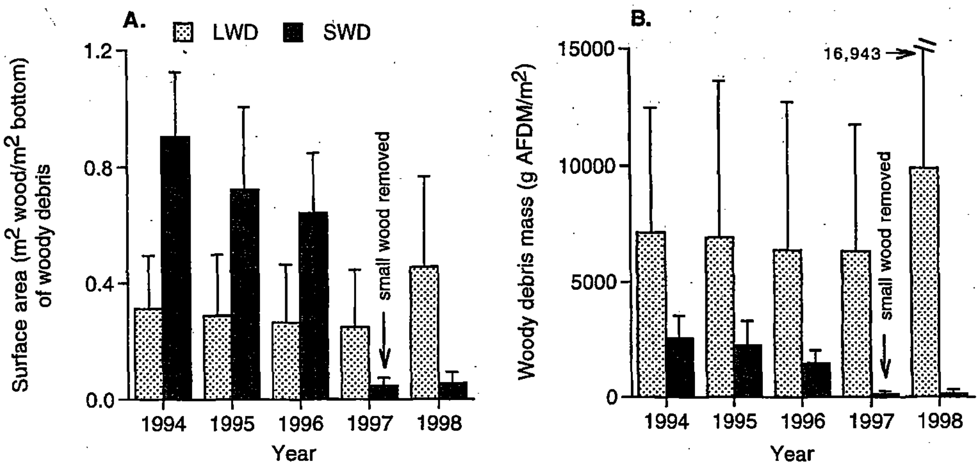

Figure 1. A, estimates of surface area per m^2 of LWD (>10 cm diameter) +95% confidence limits (CL) and SWD (<10 cm diameter) from annual line intersect measurements for the stream draining C 55. Note most SWD was removed from the stream in August 1996. B, same, for mass (g $AFDM/m^2$). Note 1998 measurements were taken just prior to removal of all LWD from the wetted perimeter of the stream.

Likewise, black locust declined from 3.5% of total basal area in 1934 to 1.4% in 1972, and 1.2% in 1993. Those species with the greatest absolute decline in forest basal area from 1934 to 1993, were American chestnut > American beech (*Fagus grandifolia)* > yellow poplar > black oak > southern red oak (*Quercus falcate)*, and black locust. During the same 59-year period, those tree species with the greatest increase in basal area were chestnut oak > scarlet oak > pitch pine > red maple followed by northern red oak (Drs. W. T. Swank and Katherine Elliott, and Jim Vose, U. S. Forest Service, Coweeta Hydrologic Laboratory).

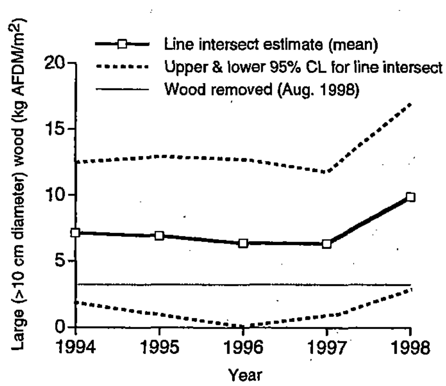

Figure 2. Mean and 95% CL for annual line intersect measurements for LWD compared to LWD actually removed from the stream in late August 1998. Note: 1998 measurements were taken prior to removal of LWD from stream.

Table 2. Taxonomic composition, mass (kg AFDM), percent of total wood removed, and AFDM as a proportion of wet mass of large woody debris removed from the stream draining Catchment 55 at the Coweeta Hydrologic Laboratory on 31 August, 1998.

Taxonomic composition	kg AFDM removed	Percent of total	AFDM/wet wt.
Red oaks	257.4	35.0	0.486
American chestnut	173.8	23.6	0.334
White oaks	109.3	14.9	0.504
Black locust	97.3	13.2	0.526
Yellow poplar	56.6	7.7	0.368
Hickory	26.6	3.6	0.327
Unknowns	7.7	1.0	0.350
Dogwood	2.5	0.3	0.437
Maple	1.9	0.3	0.384
Beech	1.8	0.2	0.635
Cherry	0.5	0.1	0.381

American chestnut and black locust combined represented nearly 37% of the wood removed from the stream; yet, these trees are extremely sparse in the extant forest. In the 1934 forest inventory American chestnut and black locust composed 30% of forest basal area. By 1972 these two species dropped to only 1.9% of basal area, declining to less than 1.3% by 1993 (Fig. 3). Overall, the forest displayed large differences in proportional similarities with respect to both basal area and stem densities based on comparison of species in the 1934 inventory with those of 1993 (Table 3, Fig. 3). Furthermore, wood species removed from the stream displayed greater similarity with the forest inventory of 1934 than with either the 1972 or 1993 inventory (Table 4, Fig. 4) (Drs. W. T. SWANK and KATHERINE ELLIOTT, and JIM VOSE, U.S. Forest Service, Coweeta Hydrologic Laboratory).

4. Discussion

The line intersect method consistently gave estimates of LWD that were approximately twice that found by hand removal. These results are in sharp contrast to those obtained with line intersect methods and SWD in this stream, where line intersect methods slightly underestimated actual wood removed by <10% (WALLACE *et al.*, 2000). The performance of the line intersect method was much poorer for large wood (Fig. 2) although the actual wood removed was always within the 95% CL of line intersect methods. Besides accuracy, there are other considerations when comparing removal and line intersect methods. For example, large wood removal was costly from the standpoint of labor. Even for the 170-m reach of our small study stream, some 200–210 person hours were required for field measurements and laboratory processing of LWD during its removal. In contrast, the line intersect method only required about 12 to 16 hours for field and laboratory processing of data. Hence, complete removal required at least 12 to 17 times more labor than the line intersect method. Furthermore, line intersect sampling is non-destructive, whereas complete removal is destructive sampling which leads to further erosion and loss of structure in stream ecosystems.

The line intersect method resulted in very wide confidence intervals for LWD, with 95% CL ranging from 75 to 99.9% of the mean and averaging 83.8% of the mean over the 5 annual measurements. SWD was much more evenly distributed and we found 95% CLs for volume ranging from 37 to 47% of the mean for SWD prior to its removal from the stream in 1996. However, following removal, SWD was very rare and patchily distributed and

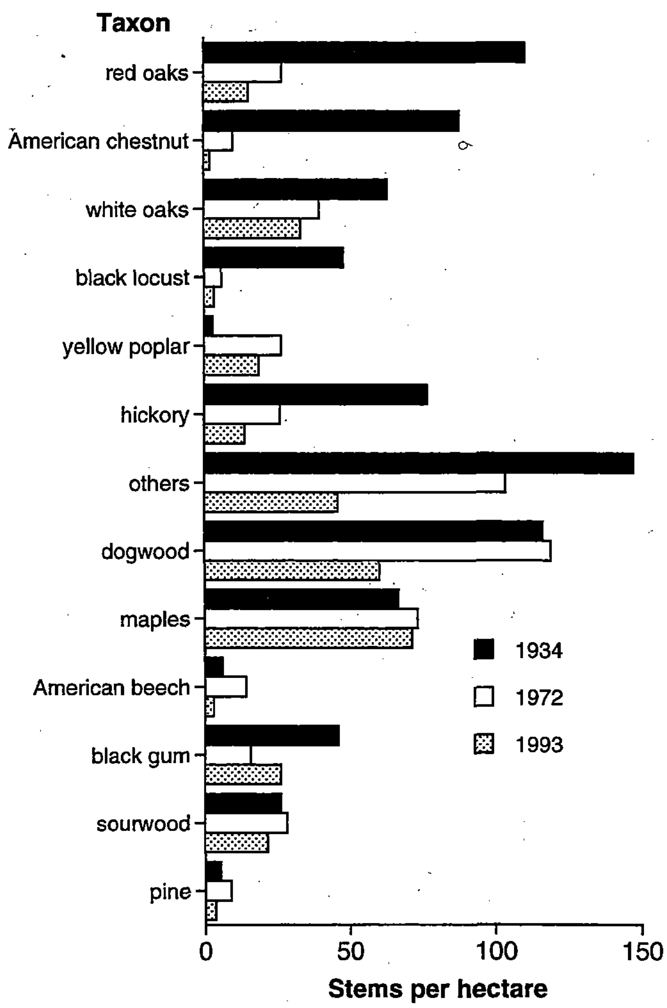

Figure 3. Stems per ha of various trees based on forest inventories of C 55 for the years 1934, 1972, and 1993. Note the general decline in stems per ha for most trees in the aggrading forest between 1934 and 1993.

Table 3. Proportional similarity between forest basal area (top) and stem densities (bottom) for tree inventories during the years 1934, 1972, and 1993.

Basal Area	1972	1993
1934	0.515	0.442
1972		0.468
Stem densities		
1934	0.557	0.374
1972		0.738

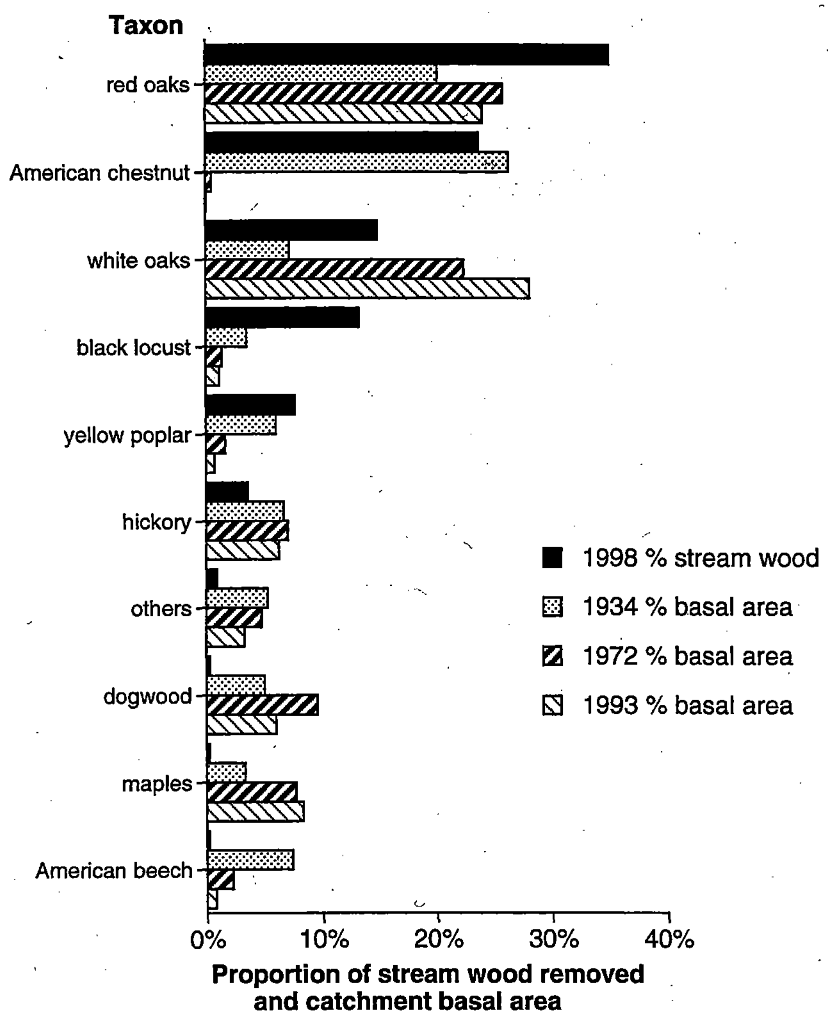

Figure 4. Proportion of LWD removed from the stream draining C 55 in August, 1998, and proportion of total catchment basal area based on forest inventories for the years 1934, 1972, and 1993.

Table 4. Percent similarity between wood removed from the stream draining Catchment 55 in August 1998 and previous inventories of forest basal area and stem densities as measured in 1934, 1972, and 1993.

Comparison	Year of forest inventory		
	1934	1972	1993
Removed wood with basal area	65.3	48.9	45.6
Removed wood with stem density	43.6	26.6	27.6

during the two post-removal line-intersect inventories (Fig. 1) the 95% CLs for SWD increased to 110–113% of the mean. These before-after comparisons underscore the importance of patchy distribution to reliability of the line intersect method. BAILLIE *et al.* (1999) pointed out two problems with applying the line intersect method to estimate LWD in small streams. First, as we have previously noted, LWD was patchily distributed in our study stream. Second, transect lengths are very short in our study stream. Where wood is patchily distributed and transect lengths are short, many more transects are required to obtain adequate characterization of LWD (BAILLIE *et al.*, 1999). ELOSEGI *et al.* (1999) note similar problems in assessing LWD in Basque streams of the Iberian Peninsula. A more viable option may be measuring lengths and diameters of each piece of LWD, which reduces variances of measurements compared with the line intersect method (BAILLIE *et al.*, 1999; ELOSEGI *et al.*, 1999). However, this latter option increases the sampling effort.

HEDMAN *et al.* (1996) used this approach to assess LWD in southern Appalachian streams. Levels of LWD measured by HEDMAN and colleagues for mid-seral forests (40–70 year old) were higher (6.3 kg/m^2) than the 3.22 kg/m^2 removed from C 55 in this study. Wood removed from C 55 also displayed some distinct taxonomic differences from that reported for nearby, larger Appalachian streams (HEDMAN *et al.*, 1996). In streams draining mid-seral stage, HEDMAN *et al.* (1996) found chestnut represented 37.3% of wood mass in the stream, followed by eastern hemlock (27%), yellow poplar and maples (19.5%), oaks (10.4%), and black locust (4.3%). Oaks were much more important contributors to woody debris in C 55, as they comprised almost 50% of the wood removed from the stream. However, streams studied by HEDMAN *et al.* were larger than that studied by us. Overall, woody debris removed in this study had only a 45.5% similarity with that of HEDMAN *et al.* (1996). Over half of the similarity between wood in our study and HEDMAN *et al.* (1996) was attributable to American chestnut. This underscores the past importance of chestnut in the Appalachian forest as well as its current importance as a contributor to LWD in Appalachian streams. Nearly 38% of the total wood removed from the C 55 stream was American chestnut (>23%) and black locust (>13%), however, these two species represent <1.5% of the basal area of the extant forest of the catchment. Our results indicate that earlier disturbances to the forest were important sources of LWD and that the structure and function of present day streams are strongly influenced by past forest disturbances.

The Coweeta Basin was part of the Cherokee Indian Nation until the Cherokees were removed from the area in 1837. In 1842 the first European settlers colonized the basin (DOUGLASS and HOOVER, 1987). The majority of the basin is steep and rugged terrain and by 1902, when lumber companies purchased the land, less than 100 acres of the basin was under cultivation. The majority of the cultivated areas were along the larger streams in the lower portion of the basin; however, woodland grazing of livestock was rather extensive (DOUGLASS and HOOVER, 1987). In the early 1900s the Coweeta Basin was sold to lumber companies, and the forest on C 55 was harvested around 1915. In 1923 the U.S. Forest Service purchased the Coweeta Basin, which was described as a "desolate, recently logged, uninhabited tract of land" that became the Coweeta Experimental Forest in 1934 (DOUGLASS and HOOVER, 1987). The early logging focused primarily on the largest and highest quality trees such as cherry, ash, walnut, oak, and yellow poplar (U.S.D.A. 1983), whereas many chestnuts were apparently left uncut since they had many limbs, were gnarled, and difficult to handle by loggers (W. T. SWANK, U.S. Forest Service, personal communication). By the early 1930s the chestnut blight reached the Coweeta Basin and by the early 1940s virtually all chestnuts in the Coweeta Basin >10 cm DBH were dead (DOUGLASS and HOOVER, 1987). This is undoubtedly one of the worst disasters to influence Appalachian forests, as American Chestnut comprised up to 40 percent of the basal area of the Coweeta forest (NELSON, 1955) and represented over 27 percent of the basal area of our study catchment in 1934 (Fig. 3). The chronology of chestnut blight and forest inventories suggest most of the inputs of chestnut to the stream occurred between 1934 and the 1950s (Fig. 5).

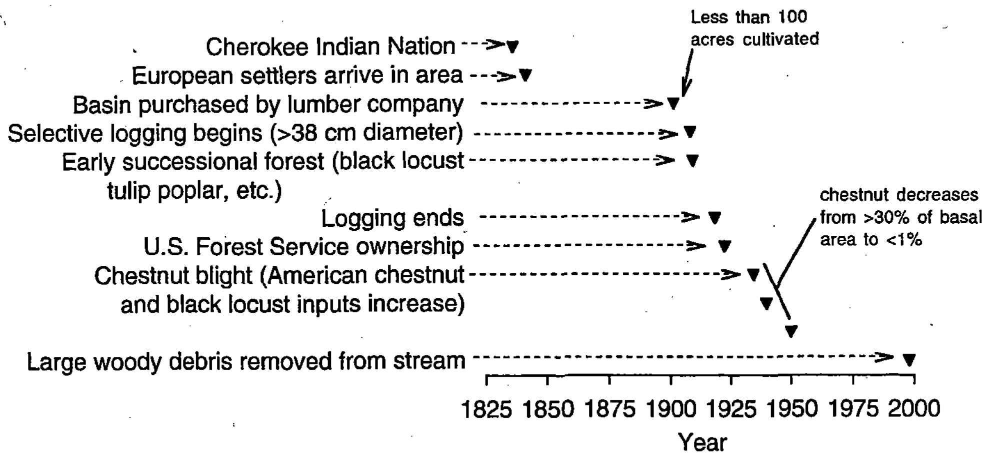

Figure 5. Suggested chronology and disturbance history contributing to disproportionate contribution of American chestnut and black locust to LWD in the stream draining C 55.

In contrast, black locust is an early successional species during forest regeneration or grassland to forest succession (BORING *et al.*, 1981; BORING and SWANK, 1984; ELLIOTT *et al.*, 1998). Based on our knowledge of forest succession following logging or other vegetation disturbances at Coweeta, extensive forest cutting in the early 1900s (1916–1921) would lead to an increase in black locust. Black locust is a woody legume, which is capable of early vegetative reproduction following disturbance and reaches heights of up to 8 m in 3 years (BORING *et al.*, 1981; ELLIOTT *et al.*, 1997, 1998; HANNAH, 1993). However, black locust is primarily an early successional species and after two decades often displays high mortality. For example, ELLIOTT *et al.* (1998) found about 73% mortality for black locust stems between the 15th and 28th year of a grassland to forest succession compared to 35.3% mortality for all tree stems on a nearby catchment. Forest inventories on C 55 show pronounced declines in black locust stem densities (stems/ha) from 1934 (= 48); to 1972 (= 5.9), and 1993 (= 3.4). Hence, evidence suggests that between 1934 and 1972 there was high LWD input of black locust and American chestnut (Fig. 5). Ironically, death of chestnuts probably facilitated increased basal area of black locust as this tree probably increased in abundance more than any other species as it rapidly entered gaps created by dead chestnuts (WOODS and SHANKS, 1959). The increase in abundance of locust was followed by outbreaks in locust leaf miners and borers, which accelerated the demise of locust to its subordinate rank in southern Appalachian forests by the late 1950s (WOODS and SHANKS, 1959).

It has been suggested that the decline in American chestnut, a species of high quality litter (SMOCK and MCGREGOR, 1988), led to a number of potential effects on headwater streams, including: decreased leaf litter processing rates, decreased quality of litter inputs, decreased growth rates of aquatic invertebrates, increased input of woody debris into streams, and other subtle changes in populations and communities (SMOCK and MCGREGOR, 1988). Large inputs of wood from dead chestnuts were obviously important sources of LWD in streams as shown by our data as well as HEDMAN *et al.* (1996). However, the timing of the chestnut blight, within a few years following extensive lumber harvesting, may have been extremely fortuitous from the standpoint of Appalachian streams. The wood loading associated with chestnut blight added LWD to stream channels that predated the second logging of these forests. Thus, chestnut blight facilitated retention of sediment as well as stability to stream channels during subsequent logging (1960s to present) long after the blight's initial appearance in the southern Appalachians in the mid 1920s (WEBSTER *et al.*, 1992).

Our results as well as those of HEDMAN *et al.* (1996) indicate that earlier forest disturbances such as chestnut blight and increasing abundance of black locust, a early successional species, following logging were important sources of LWD to streams. Interestingly, the eastern deciduous forest is presently undergoing another pest introduction, the hemlock woolly adelgid, *Adelges tsugae* ANNAND, which is spreading southward from the northeastern states. This introduced insect is producing over 95 percent mortality in many hemlock stands (ORWIG and FOSTER, 1998; JENKINS *et al.*, 1999). Hemlock is frequently abundant in riparian forests of the southern Appalachians, and its decomposition is very slow (e.g., HEDMAN *et al.*, 1996). Thus we predict additional pulses of LWD into headwater streams of the area during the next two decades. Such disturbances leave legacies that persist for generations and extend beyond structure of forest stands to streams as well. The structure and function of present day streams are influenced by forest disturbances that occurred over six decades ago. Furthermore, these past land-use histories can influence diversity of stream animals and result in long-term modifications of animal populations (HARDING *et al.*, 1998). We anticipate that the ongoing dynamics of forest stands such as that generated by the hemlock woolly adelgid will continue to produce long-term changes that can have profound influences on stream processes.

5. Acknowledgements

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