10

Recovery of Particulate Organic Matter Dynamics in a Stream Draining a Logged Watershed

A Pressing Situation

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Introduction

Compared to other ecosystems, streams have been described as having low resistance to disturbance but being highly resilient following disturbance (Webster et al. 1975). Webster et al. (1983) demonstrated the low resistance of Big Hurricane Branch at Coweeta to watershed logging, documenting the many changes to the stream in the first few years after clearcutting. These changes were associated with physical disturbance (high sediment export), increased nutrient export, changes related to the reduction of the forest canopy (decreased allochthonous inputs, increased light, increased autochthonous production), and alterations in the invertebrate community. Although there had not been sufficient time to see resilience, Webster et al. (1983) noted that within 4 years following disturbance some aspects of the stream were showing significant return to pre-logging conditions. They also noted that some of the changes in the stream, particularly the shift to an autochthonous energy base and the macroinvertebrate community shift from shredder- to grazer-dominated, could be interpreted as mechanisms of resilience. They concluded that the potential resilience of the stream could not be realized because of the long-term modification of the quantity and quality of terrestrial organic matter inputs (Webster and Patten 1979; Gurtz et al. 1980).

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After several years of further study, Webster et al. (1992) predicted a postdisturbance period of accelerated sediment loss due to a decline in large wood in the stream. Because the logs existing in the stream prior to logging and those introduced during logging decay slowly, the regrowing forest will not provide new large wood, and it might be from 50 to 200 years before logs of sufficient size to form stable dams fall into the stream. However, they also pointed out that decay-resistant large wood from earlier disturbances could modify this trend. Wallace et al. (2001) found that chestnut logs resulting from the chestnut blight in the 1930s constituted 24% of the large wood in a small Coweeta stream. These large, old, decay-resistant logs are abundant in Big Hurricane Branch and may provide a bridge between logging and new inputs of large wood. The hemlock woolly adelgid (*Adelges tsugae*) is now present at Coweeta and throughout most of the Appalachian forests (Webster et al. 2012) and may cause a similar input of very large and even more decay-resistant wood to streams in the near future.

The concepts of press and pulse disturbances were introduced by Bender et al. (1984) to describe various types of community ecology experiments, but these terms can also be applied in a much broader context. Ecosystem stability theory, as adapted from mathematical theory, was based on short pulse disturbance (Rosenzweig and MacArthur 1963; Waide and Webster 1976). Pulse disturbance models may be broadly applicable to many situations; for example, following logging, the terrestrial ecosystem (viewed as the whole system within the physical space affected by the logging) is free to return to its original condition. The external factors that modified this system have returned to what they were before the disturbance; that is, the forest is no longer being logged. However, many ecological disturbances are not pulses, but continue for a long time relative to the potential rate of recovery of the system. These can be described as press disturbances. This is the case for the effect of logging on streams. Streams are tightly linked to their terrestrial surroundings (e.g., Hynes 1975; Vannote et al. 1980), and as long as this linkage is modified, the press disturbance continues. Specifically, as long as solar input, allochthonous inputs, hydrologic regime, and other terrestrial-stream linkages remain modified, a stream draining a logged forest continues to be disturbed. Many aspects of the potential resilience of the stream ecosystem cannot be realized, as the stream continually tracks a long-term press disturbance (Webster and Patten 1979).

Watershed (WS) 7 at Coweeta was logged in 1977. The stream draining this watershed, Big Hurricane Branch, was affected in many ways (Gurtz et al. 1980; Webster et al. 1983). While the stream has recovered in some characteristics, the continuing press disturbance limits many aspects of recovery. In this chapter, we report the long-term pattern of recovery of the organic matter dynamics of this stream.

Site Description

The study was conducted at the Coweeta Hydrologic Laboratory in western North Carolina. Coweeta is a US Forest Service Experimental Field Station and a Long-Term Ecological Research site supported by the National Science Foundation and the US Forest Service. The Coweeta basin is organized into multiple

Figure 10.1 View of lower section of Big Hurricane Branch (WS 7), in the first year after cutting in 1977. (Photo by J. Webster)

Figure 10.2 View of lower section of Big Hurricane Branch (WS 7) in 1982, five years after cutting. (Photo by J. Webster)

Methods

Litterfall

Annual litter inputs to Big Hurricane Branch were measured just prior to logging and have been measured six times since logging. Similar measurements of litterfall to Hugh White Creek were made in 1983–84, 1993–94, and 2003–2004. All measurements were made using overstream or streamside baskets or traps. Collection sites were located along the length of the main channel of each stream. In general, litter falling in the baskets was collected twice monthly from September through November and then monthly through the rest of the year. In the laboratory, litter was separated into leaves, wood, and miscellaneous material, leaves were separated to species, and all material was air-dried to a constant weight and weighed. Subsamples were ashed at 500°C to determine ash free dry mass (AFDM).

Leaf Breakdown

Leaf breakdown was measured in Big Hurricane Branch before logging and seven times subsequently. Concurrent measurements of leaf breakdown in Hugh White Creek were begun in 1983. All measurements were made using the mesh bag technique (Benfield 2006). Senescent leaves were collected at Coweeta just prior to abscission and weighed amounts were placed in mesh bags (3–5 mm openings). Bags were placed in the streams in late autumn and either anchored to the stream bottom with large nails or tied to roots or small trees. Replicate bags of each species were taken back to the lab to account for weight loss due to handling. Three to five bags of each species from each site were retrieved periodically, returned to the laboratory, rinsed to remove sediment, invertebrates, and debris, and then air-dried to a constant weight and weighed. Subsamples were ashed at 500°C to determine AFDM. Breakdown rates were determined by regressing natural log of mass remaining versus time (e.g., Webster and Benfield 1986). For two studies, we also determined breakdown rates by regressing log mass remaining versus cumulative degree-days (e.g., Minshall et al. 1983).

Benthic Standing Stock of Particulate Organic Matter

Leaves

Leaf standing stock on the streambed was sampled prior to logging and six times subsequently. In the first two studies, leaves were sampled using a Surber sampler; in later studies samples were taken with a core sampler or Surber sampler in most areas and with a core in depositional areas. In general, coarse particulate organic material was removed by hand and placed in a 1-mm mesh net and rinsed to remove smaller material. In the laboratory, the material was separated into leaves, wood, and other (nuts, flowers, etc.), air-dried to constant weight, and weighed. Subsamples were ashed at 500°C to determine AFDM.

Fine Benthic Organic Matter (FBOM)

Fine benthic organic matter (FBOM) was measured along with the core measurements of larger particles in 1985–86 (Golladay et al. 1989) and again in July 1994 (Webster and Benfield, unpublished). Water from the core was pumped through a 1-mm mesh net until the water was clear. We then measured the volume of water and collected an approximately 1-L sample. The volume of sample was measured in the laboratory, and a measured subsample was filtered though a preweighed glass fiber filter (mesh opening approximately 0.5 µm). We determined the AFDM of material on the filter (Golladay et al. 1989) and used the data to estimate FBOM standing crop in the stream.

Wood

Small wood was sampled in the Surber and core samples, and larger wood was estimated either by measuring all the wood in 1-m transects or by the line-intersect method. Using the transect method, all medium-sized (1–5 cm diameter) wood was collected and weighed. Subsamples of the collected wood were wet-weighed in the field, and the rest of the material was returned to the stream. In the laboratory, the subsamples were dried, weighed, ashed, and reweighed. Data from the subsamples were used to convert field-measured wet weights to AFDM. All individual pieces of larger wood (> 5 cm diameter) were either wet-weighed, subsampled, and treated as we did the smaller pieces; or, for very large logs, we measured the length and diameter and collected subsamples with a hand saw. The subsamples of these logs were dried and weighed; and the volume was measured by water displacement. Subsamples were then taken for determination of AFDM, and the measurements were used to determine the AFDM of the logs.

In 1995 (Big Hurricane Branch) and 1999 and 2008 (Big Hurricane Branch and Hugh White Creek), wood was also measured by the line-intersect method (Warren and Olsen 1964; Wallace and Benke 1984). In 1995 and 1999 a line was placed across the stream at each of 60 cross-sections and the diameter of all wood intersecting this line was measured. In 2008 a line was placed along the thalweg of each stream. The measurements were converted to volume and then to AFDM using density measurements from the transect study or a general value of 0.4 g/cm^3.

Simulations of Leaf Dynamics

Using the leaf input and breakdown rates described earlier, we developed a computer model to predict leaf standing stocks, which we then compared against measured values. The initial model had the following form:

$$\frac{dX_i}{dt} = I_i(t) - k_i X_i$$

where X_i is leaf standing stock, t is time, $I_i(t)$ is leaf-fall, k_i is the exponential breakdown rate, and i is the leaf-breakdown-rate category. We used breakdown rates for four categories of leaves, fast, medium, slow, and very slow, based on the leaf-breakdown measurements made in 1993–94 for Big Hurricane Branch and the averages of all rates measured at Coweeta in reference streams for Hugh White Creek (Webster et al. 1999; Webster et al. 2001). Daily leaf-fall rates were calculated by linear interpolation from data collected in 1993–94. We did not include loss via transport in the model. Previous studies at Coweeta have shown that streams of this size are highly retentive, leaves breakdown very close to where they enter the stream, and leaf export is a small fraction of the total leaf input (e.g., Webster et al. 1999). The model was solved numerically using Runge-Kutta integration with a FORTRAN computer program.

We subsequently made two modifications to this initial model. First, we included blow-in, the lateral movement of leaves into the stream. Blow-in was based on measurements made in 1983–84 (Webster et al. 1990) modified to the leaf composition measured in 1993–94. Second, to include temperature, we modified the model to use degree-day breakdown rates and mean daily water temperatures.

Results

Water Temperature

During the first few years following logging, summer water temperature in Big Hurricane Branch was elevated due to the absence of a forest canopy (Swift 1983; Webster et al. 1983). However, the temperature elevation only lasted a few years. Once the forest canopy closed, water temperature in Big Hurricane Branch showed less annual variation than in Hugh White Creek (Stout et al. 1993). For example, during 1993–94 and again in 2004–2005, water temperature in Big Hurricane Branch was warmer in winter and cooler in summer than in Hugh White Creek (figure 10.3). This difference is apparently due to geomorphological differences of the two watersheds and not to logging. Annual degree-days were slightly higher in Big Hurricane Branch during both of these years.

Leaf-fall

Prior to logging, leaf-fall to Big Hurricane Branch was 259.2 g m^{-2} y^{-1}, slightly less than leaf-fall in Hugh White Creek (table 10.2; figure 10.4) and other reference streams at Coweeta (Webster et al. 1990). Leaf-fall was reduced to almost zero after logging but recovered to reference levels within five years (figure 10.4). Despite quantitative recovery, leaf-fall remained qualitatively different and was generally a mix of more labile leaf species than leaf-fall to the reference stream through 1993–94 (table 10.2). The near absence of oak leaves even in 1993–94 is particularly evident. The temporal pattern of leaf-fall was very similar in Big Hurricane Branch and Hugh White Creek in 1993–94, with a slightly earlier peak in Big Hurricane Branch (figure 10.5). More recently (2003–2004), the composition of leaves falling in Big Hurricane Branch has been more similar to Hugh White Creek except for the low abundance of hemlock needles in Big Hurricane Branch.

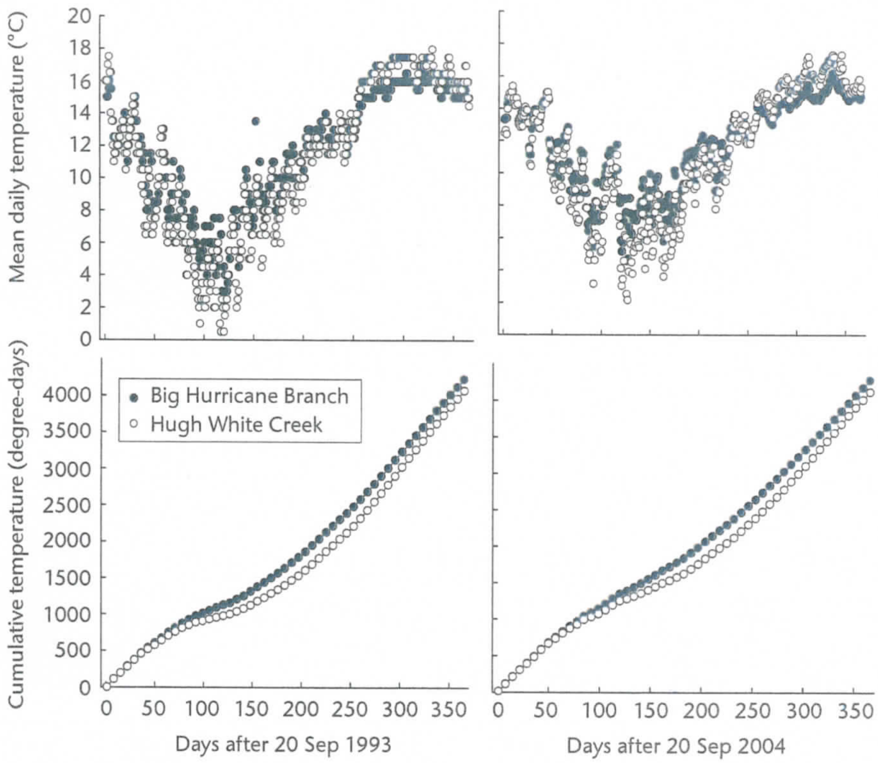

Figure 10.3 Comparison of stream water temperatures in Big Hurricane Branch and Hugh White Creek, 1993–94 and 2004–2005. Data from USDA Forest Service, Coweeta; and Webster and Benfield (unpublished).

Leaf Breakdown Rates

Several patterns are evident in the breakdown rates (figure 10.6). First, leaf breakdown rates in Big Hurricane Branch before logging were very similar to rates in Hugh White Creek. Immediately following logging, breakdown rates were slower, probably due to sediment burial of the leaf packs (Webster and Waide 1982). However, subsequent measurements indicate breakdown rates significantly faster than pretreatment rates and faster than rates measured in Hugh White Creek. Across both species and streams, the annual patterns are nearly identical—rates were fairly fast in 1983–84, slower in 1986–87, faster again in 1995–96, and slower again in 1999–2000. These annual trends are probably related to differences in winter water temperatures or annual discharge (Benfield et al. 2001). However, in the most recent measurements (2005–2006), breakdown rates of rhododendron, white oak, and red maple in Hugh White Creek were slightly faster than measurements made 6 years previously while breakdown rates of these leaf species were slightly slower in Big Hurricane Branch. Leaf breakdown rates calculated on a degree-day basis (table 10.3) show the same trend, that is, substantially faster breakdown of leaves in Big Hurricane Branch even when corrected for temperature.

Table 10.2 Total leaf-fall and species composition of leaf-fall to Big Hurricane Branch (BHB) and Hugh White Creek (HWC).

Species	Percent of annual leaf-fall						
	BHB 1974–75	BHB 1978–79	BHB 1983–84	BHB 1993–94	HWC 1993–94	BHB 2003–04	HWC 2003–04
Birch (*Betula* spp.)	5.1	15.7	11.8	11.6	24.0	11.3	17.5
Rhododendron (*Rhododendron maximum*)	11.6	26.5	11.6	14.3	18.2	23.5	21.3
Yellow poplar (*Liriodendron tulipifera*)	9.1	10.8	2.2	13.8	14.5	23.0	16.1
White oaks (*Quercus alba, Q. prinus*)	19.0	—	3.0	—	9.0	2.1	0.4
Hemlock (*Tsuga canadensis*)	—	—	—	—	6.8	1.7	13.5
Hickory (*Carya* spp.)	11.4	—	—	—	6.4	—	—
Red maple (*Acer rubrum*)	4.8	—	11.0	7.8	5.9	5.1	3.0
Red oak (*Q. rubra*)	13.4	—	2.5	—	4.4	3.9	3.4
Basswood (*Tilia americana*)	4.2	—	—	—	—	—	—
Dogwood (*Cornus florida*)	1.1	3.9	6.5		—	—	—
Black locust (*Robinia pseudoacacia*)	—	—	3.1	2.8	—	—	—
Beech (*Fagus grandifolia*)	7.9	—	1.9	5.4	—	—	—
Ash (*Fraxinus* spp.)	—	—		3.8	—	—	—
Magnolia (*Magnolia* spp.)	—	—	5.0	7.6	—	—	—
Willow (*Salix nigra*)	—	—	4.3	—	—	—	—
Others*	12.5	43.1	37.1	33.7	9.3	29.2	24.1
Total leaf-fall (gAFDM/m²/y)	259.2	4.2	354.2	342.2	327.0	292.4	305.7

*'Others' category includes all species making up less than 2% of annual leaf-fall.

Sources: Data from Webster and Waide (1982); Webster et al. (1983); Webster et al. (1990); Webster et al. (2001); and Webster and Benfield (unpublished).

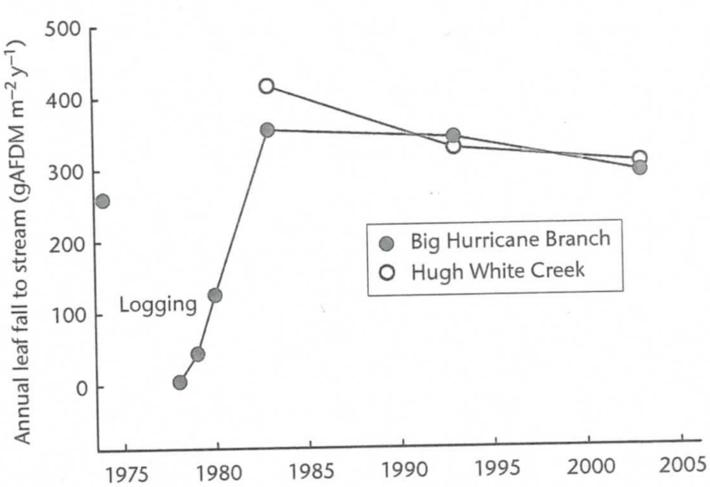

Figure 10.4 Long-term recovery of leaf inputs to Big Hurricane Branch. Data from Webster and Waide (1982); Webster et al. (1983); Webster et al. (1990); and Webster and Benfield, unpublished.

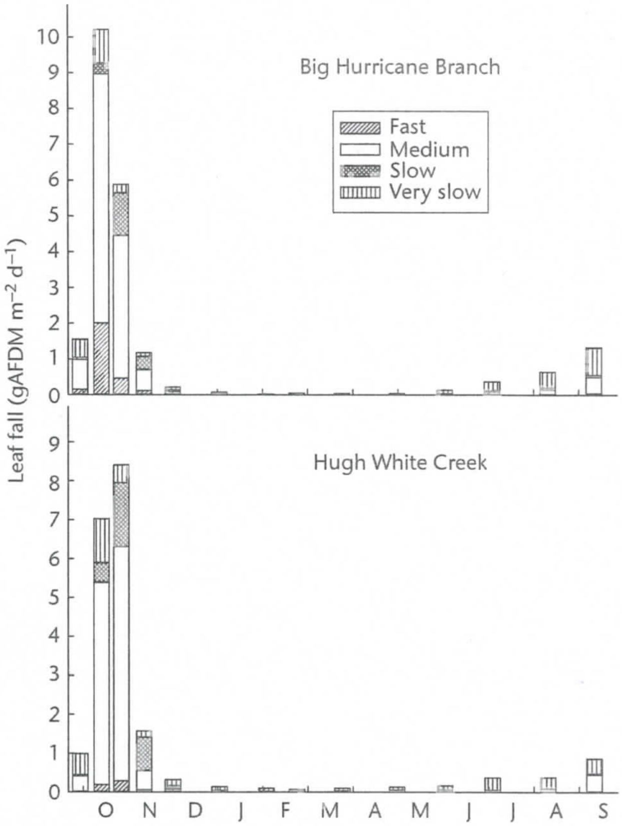

Figure 10.5. Comparison of leaf-litter inputs to Big Hurricane Branch and Hugh White Creek, 1993–94. Data from Webster and Benfield, unpublished.

Leaf Standing Stock

Interpretation of the differences of leaf standing crop between streams is difficult because of differences in sampling techniques among studies (table 10.4). However, the more intensive studies (1985–86 and 1993–94) demonstrated lower standing crop in Big Hurricane Branch than in Hugh White Creek. The difference between streams was not due to quantitative differences in input as pointed out earlier. For example, in 1993–94 and again in 2004–2005, the standing crops of leaves in the two streams were very similar just after leaf-fall, but in Big Hurricane Branch leaf standing crop declined much more rapidly through winter, spring, and early summer before increasing in late summer (figure 10.7).

Fine Benthic Organic Matter

The standing crop of FBOM in Big Hurricane Branch in 1985–86 was lower than in Hugh White Creek, both on an annual average and in July (table 10.5). Nine years later, FBOM in Big Hurricane Branch was still lower, though the difference was not statistically significant.

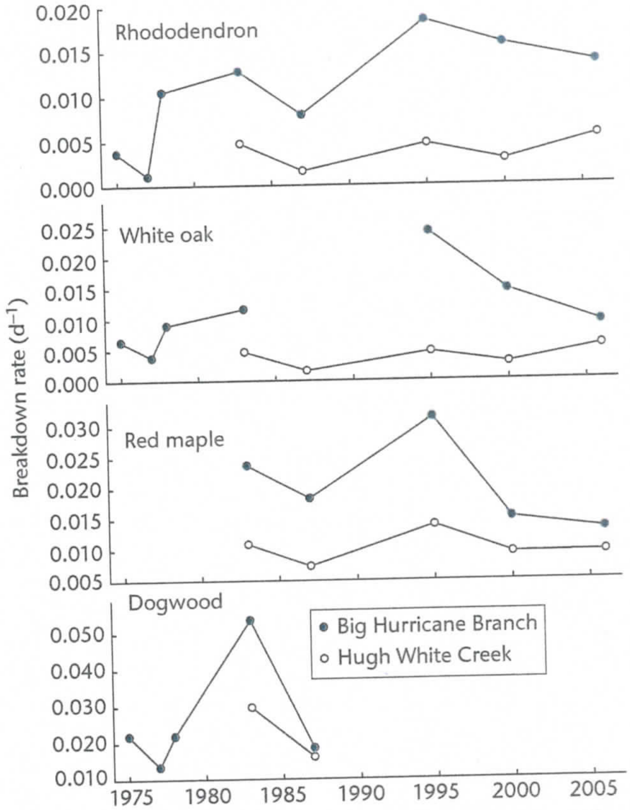

Figure 10.6 Long-term trends in leaf breakdown rates in Big Hurricane Branch and Hugh White Creek. Data from Webster and Waide (1982); Golladay and Webster (1988); Benfield et al. (1991, 2001); and Benfield and Webster, unpublished.

Table 10.3 Degree-day adjusted leaf breakdown rates* (degree-day^{-1}) in Big Hurricane Branch (BHB) and Hugh White Creek (HWC).

Variable	Big Hurricane Branch	Hugh White Creek
1994–95		
Red maple	0.00347 (0.00032)	0.00157 (0.00016)
White oak	0.00256 (0.00019)	0.00129 (0.00017)
Rhododendron	0.00194 (0.00023)	0.00054 (0.00016)
1999–2000		
Red maple	0.00132 (0.00037)	0.00102 (0.00015)
White oak	0.00171 (0.00047)	0.00082 (0.00008)
Rhododendron	0.00160 (0.00047)	0.00029 (0.00003)

*Each rate is the mean (standard error) of rates measured at three (1999–2000 and BHB 1994–95) or four (1994–95 HWC) sites in each stream.

Source: Data from Benfield and Webster (unpublished).

Table 10.4. Benthic leaf standing crop (gAFDM/m^2) in Big Hurricane Branch (BHB) and Hugh White Creek (HWC).

Year of sampling	Big Hurricane Branch	Hugh White Creek	Sampling methods	References and notes
1974–76	86.2 (10.7)	—	Ten mid-stream Surber samples monthly for 2 y. Mean (standard error) of 27 sampling dates.	Webster et al. (1983); probably low because of midstream sampling.
1977–78	54.7 (11.0)	33.2 (4.5)	Weighted means of 16 Surber samples monthly for 21 mo, stratified over four habitat types. Mean (standard error) of seven seasonal values.	Gurtz (1981); Gurtz and Wallace (1984); Webster et al. (1983). HWC only sampled in second-order reach with substantial bedrock substrate.
1985–86	124 (17)	213 (18)	Seasonal sampling of 60 core (0.071 m^2) samples on transects stratified along the stream. Mean (standard error) of 20 transects.	Golladay et al. (1989)
1986–87	59.9 (16.1)	102.5 (21.4)	Monthly core samples in headwater tributaries. Mean (standard error) of 11 sampling dates.	Stout et al. (1993)
1993–94	83.7 (8.2)	119.6 (18.7)	One hundred core samples on transects stratified over distance of stream, six sampling dates. Mean (standard error) of five transects.	Webster et al. (2001) and Webster and Benfield (unpublished)
1993–94	35.4	28.2	Weighted means of nine Surber or core samples collected every 2 mo for 1 y on four habitat types	Stone and Wallace (1998)
2004–05	43.7	56.2	Means of 30 core samples collected seasonally in ten transects for each stream.	Webster and Benfield (unpublished)

Wood Standing Crop

Differences in wood standing crops are also difficult to interpret because of differences in sampling techniques (table 10.6). Also, measurements of large wood can be highly biased by the presence of a single large log. Measurements of large wood in Big Hurricane Branch in 1995 were very high because of the presence of one massive log near the headwaters of this stream. However, measurements made at the same cross-sections of Big Hurricane Branch in 1995 by transect and line-intersect methods were almost identical, strengthening the case for the much simpler line-intersect method (Wallace et al. 2001). Since we began sampling large wood in 1995 there has been a substantial decrease in the amount of wood larger than 20-cm diameter (table 10.6). Though slash was removed from some of the stream, it was left in other reaches, and these data undoubtedly represent the decay of this slash, decay of residual material from before logging, and the lack of recruitment into the stream. Small wood

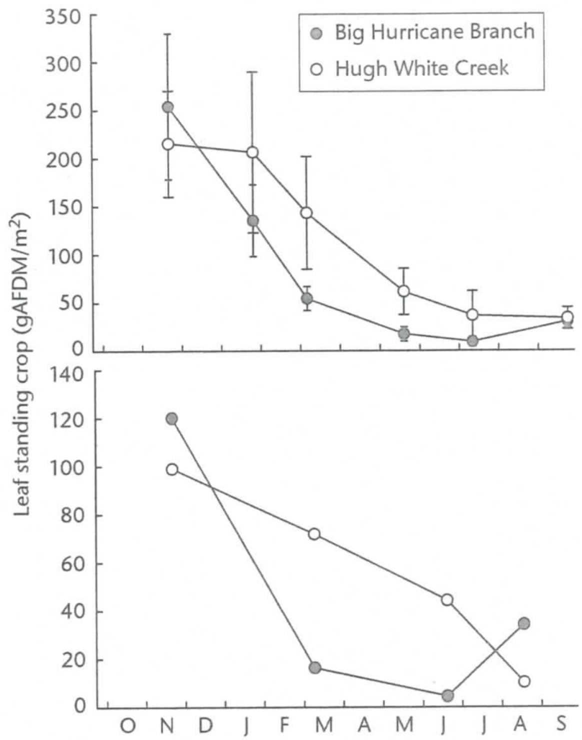

Figure 10.7 Benthic leaf material in Big Hurricane Branch and Hugh White Creek in 1993–94 (*upper panel*) and 2004–2005 (*lower panel*). The error bars for 1993–94 are 95% confidence limits using the means of the four samples from each cross section as replicates (N = 25). Data from Webster et al. (2001); and Webster and Benfield, unpublished.

Table 10.5. Fine benthic organic matter (FBOM, $gAFDM/m^2$) in Big Hurricane Branch and Hugh White Creek.

	Big Hurricane Branch	Hugh White Creek
Annual average, 1985–1986	112.8 (240, 7.6)	165.8 (240, 10.1)
July 1985	27.0 (27, 4.5)	76.2 (36, 9.7)
July 1994	50.2 (24, 10.7)	94.4 (24, 33.4)

Note: Data are means (number of samples, standard errors) of all samples.
Sources: Data from Golladay et al. (1989); and Webster and Benfield (unpublished).

(1–5 cm diameter) has remained very stable and similar to reference stream levels, suggesting that decay of this material is balanced by inputs of twigs in this size range.

Leaf Simulations

Our simulations of leaf standing crops in the reference stream, Hugh White Creek (figures 10.8–10), provide general support for the prediction of standing crop from measurements of input and breakdown (Webster et al. 2001). In this stream, the

Table 10.6 Wood (gAFDM/m^2) in Big Hurricane Branch (BHB) and Hugh White Creek (HWC).

Year of sampling	Diameter	Big Hurricane Branch	Hugh White Creek	Sampling methods	References and notes
1974–76	Small wood	27.0	—	Ten mid-stream Surber samples seasonally for 1 y.	Webster et al. (1983)
1977–78	Small wood	123.1	35.6	Weighted means of 16 Surber samples monthly for 21 mo, stratified over four habitat types.	Gurtz (1981); Gurtz and Wallace (1984); Webster et al. (1983)
1985–86	1–5 cm > 5 cm	383 (69) 2,833 (1,108)	312 (66) 5,134 (2,011)	All wood measured in 1-m transects along the stream. Mean (standard error) of 20 transects.	Golladay et al. (1989)
1993–94	< 2 cm	105.5 (17.9)	106.6(19.0)	One hundred core samples on transects stratified along stream, 6 sampling dates. Mean (standard error) of means in five transects.	Webster, Benfield, Hutchens, and Tank (unpublished)
1993–94	Small wood	107.6	62.2	Weighted means of nine Surber or core samples collected every 2 mo for 1 y on four habitat types.	Stone and Wallace (1998)
1995	1–5 cm 5–20 cm > 20 cm	310 (83) 1,983 (647) 13,198 (1,396)	362 (75) 1,258 (435) 3,209 (1,362)	All wood measured in 1-m transects along the stream. Mean (standard error) of 60 transects.	Webster and Golladay (unpublished)
1995	< 1 cm 1–5 cm 5–20 cm > 20 cm	51 (6) 364 (49) 2,188 (514) 14,771 (4,841))	— — — —	Line intercept method with lines across the width of the stream. Mean (standard error) of 60 lines. Volume converted to mass using measured densities of 0.41 (BHB) and 0.46 g/cm^3 (HWC).	Webster and Golladay (unpublished)
1999	5–20 cm > 20 cm	3,680 (677) 6,680 (1,990)	2,251 (342) 4,187 (1,612)	Line intercept method, same as 1995	Webster and Golladay (unpublished)
2004–05	< 1 cm	54.0	38.8	Means of 30 core samples collected seasonally at ten transects along each stream	Webster and Benfield (unpublished)
2008	1–5 cm 5–20 cm > 20 cm	404 1,294 1,982	431 1,792 2,559	Line intercept method along 710 m of BHB and 200 m of HWC. Volume converted to density using 0.4 g/cm^3	Webster and Benfield (unpublished)

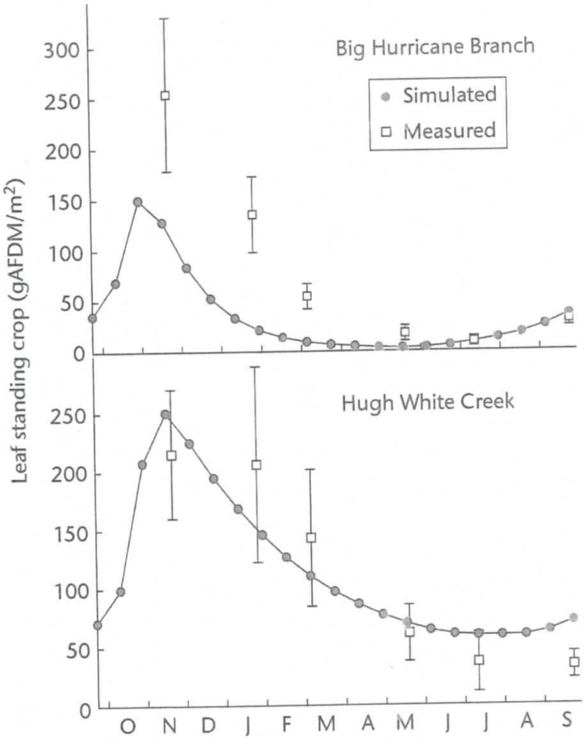

Figure 10.8 Simulation of benthic leaf material in Big Hurricane Branch and Hugh White Creek with just leaf-fall and simple leaf breakdown rates in a four compartment model. Measured data are from 1993–94.

rates of leaf disappearance from mesh bags agree with the loss of leaf mass for the stream. However, this was not the case for Big Hurricane Branch—our simulations were consistently lower than measured standing crop (figures 10.8–10). It appears that leaves disappear from the mesh bags considerably faster than leaves actually disappear from this stream.

Discussion

Our studies indicate that except for the first few years after logging, leaves that fall into Big Hurricane Branch disappear faster than leaves falling into Hugh White Creek. This conclusion is based on both leaf breakdown rates (figure 10.6) and disappearance of benthic leaves (figure 10.7). There are several possible reasons for this difference. First, more leaves may simply wash out of Big Hurricane Branch during storms. Based on measurements made in 1977–78 (Gurtz et al. 1980) and again in 1984–85 (Golladay et al. 1987), particulate organic matter transport

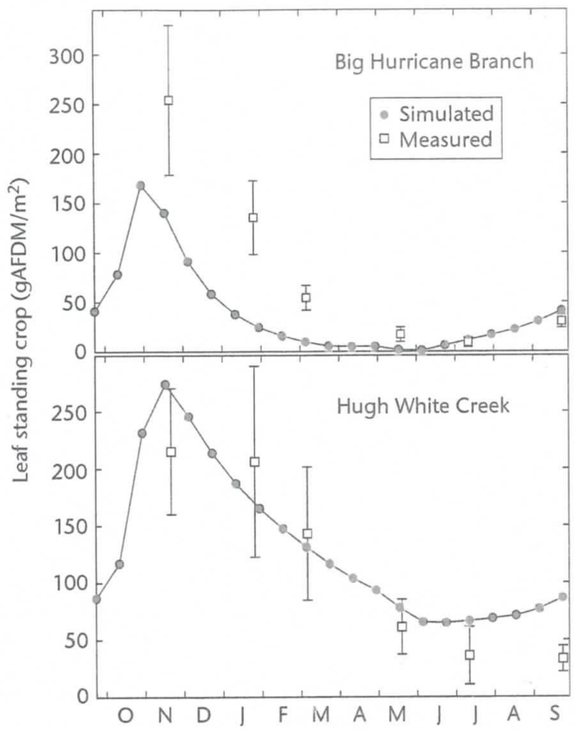

Figure 10.9 Simulation of benthic leaf material in Big Hurricane Branch and Hugh White Creek including leaf-fall, leaf blow-in, and simple leaf breakdown rates in a four compartment model. Measured data are from 1993–94.

from Big Hurricane Branch has been significantly greater than from Hugh White Creek. However, whole leaves and leaf fragments are a small fraction of particulate transport (Gurtz et al. 1980) and cannot account for the observed differences in leaf-disappearance rates.

A factor that clearly did contribute to the differences in disappearance rates was the more labile composition of the litterfall to Big Hurricane Branch for the first 15–20 years following logging (table 10.2). However, more recent data suggest that the leaf species composition falling in the stream is converging toward the characteristics of reference forests. Yet this does not explain the faster species-specific leaf breakdown rates in Big Hurricane Branch.

Temperature is a major factor affecting leaf breakdown rates (Webster and Benfield 1986), and the warmer winter temperature in Big Hurricane Branch (figure 10.3) may contribute to faster leaf disappearance. However, when we take temperature into account by using degree-day adjusted breakdown rates, leaf breakdown rates in Big Hurricane Branch are still much higher than in Hugh White Creek (table 10.3).

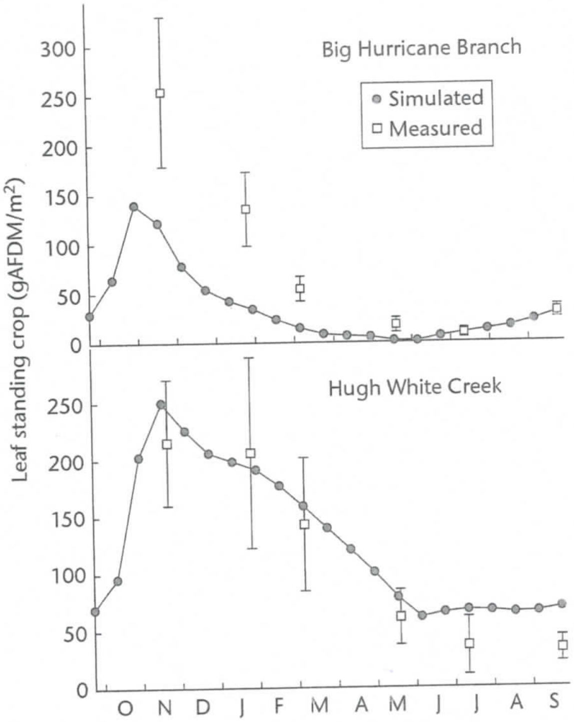

Figure 10.10 Simulation of benthic leaf material in Big Hurricane Branch and Hugh White Creek including leaf-fall, leaf blow-in, and degree-day leaf breakdown rates in a four compartment model. Measured data are from 1993–94.

Heterotrophic processes in Coweeta streams appear to be limited by availability of both nitrogen and phosphorus (Tank and Webster 1998; Gulis and Suberkropp 2003; Greenwood et al. 2007). Dissolved phosphorus levels in Big Hurricane Branch have been very low and apparently little affected by logging (Swank 1988). However, dissolved inorganic nitrogen increased in Big Hurricane Branch following logging, decreased for about 10 years, and then returned to relatively high levels (Swank and Vose 1997) and remains elevated (see Qualls et al., chapter 5, this volume). The availability of inorganic nitrogen is likely a contributing factor to the faster disappearance of leaves in Big Hurricane Branch. This appears to be especially true for rhododendron, which is the most refractory leaf species we studied. Experimental addition of nutrients to a small stream at Coweeta had the same effect—rhododendron leaf breakdown was accelerated more than breakdown of relatively labile red maple leaves (Gulis and Suberkropp 2003; Greenwood et al. 2007).

Physical scouring of leaf packs by transported sediment may also accelerate leaf breakdown in Big Hurricane Branch. Sediment movement and its effect on leaf breakdown may become more evident as large wood continues to decline.

These various factors, quality of leaf inputs, higher winter temperature, higher nutrient availability, and sediment scouring together can probably account for the differences in the rates leaves disappear from the two streams. However, they do not explain why measured leaf breakdown rates in Big Hurricane Branch were so much faster than actual leaf disappearance, whereas these rates were similar in Hugh White Creek (figures 10.8–10). One possibility is that the scarcity of leaves in Big Hurricane Branch in late winter and throughout spring and summer (figure 10.7), results in introduced bags of leaves being a rare resource that was rapidly colonized and broken down by shredding invertebrates (Webster and Waide 1982). Stout et al. (1993) found higher shredder biomass and production in Big Hurricane Branch than in Hugh White Creek in 1986–87, and Stone and Wallace (1998) found a similar pattern in 1993–94. Leaf-shredding invertebrates in Big Hurricane Branch may have responded to the high availability of more labile leaf material in late fall and early winter, and then, in late winter and spring, they congregated in our packs of more refractory litter. As a result, our measured leaf breakdown rates, especially for the more refractory rhododendron, were exceptionally high.

There has been insufficient time since logging to evaluate the prediction that a long-term decrease in large wood will result accelerated sediment movement from Big Hurricane Branch (Webster et al. 1992). Large, slow-decaying logs remain in the stream and undoubtedly contribute to the physical stability of the streambed. In other aspects, 30 years after its watershed was logged, Big Hurricane Branch still shows many effects of the disturbance. Though the stream rapidly returned to a dependence on allochthonous detrital inputs, the continued altered quality of these inputs, coupled with elevated available nitrogen, results in substantially altered detrital dynamics within the stream. Thus Big Hurricane Branch exhibits some evidence of high resilience, but in other aspects potential resilience is still limited by the press-type nature of forest clearing. Until the riparian forest returns to its predisturbance state, we expect Big Hurricane Branch to show signs of altered ecological structure and function. Even with eventual forest recovery, we predict that stream recovery will show a significant temporal lag. In reality, with the permanent forest changes that have occurred in the region, such as the loss of chestnut and the alteration of atmospheric nutrient inputs as well as future changes, such as loss of hemlocks and climate change, we predict that no stream within the southern Appalachians will return to presettlement conditions. The best we can hope for in recently or intensively disturbed streams, like Big Hurricane Branch, is a return to a state that that contains many of the original species of the stream community and regains most of its functional characteristics.

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Long-Term Response of a Forest Watershed Ecosystem

CLEARCUTTING IN THE SOUTHERN APPALACHIANS

EDITED BY

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Our North American forests are no longer the wild areas of past centuries; they are an economic and ecological resource undergoing changes from both natural and management disturbances. A watershed-scale and long-term perspective of forest ecosystem responses is requisite to understanding and predicting cause and effect relationships. This book synthesizes interdisciplinary studies conducted over thirty years, to evaluate responses of a clear-cut, cable-logged watershed at the Coweeta Hydrologic Laboratory in the Nantahala Mountain Range of western North Carolina. This research was the result of collaboration among Forest Service and university researchers on the most studied watershed in the Lab's 78-year history. During the experiment, a variety of natural disturbances occurred: two record floods, two record droughts, a major hurricane, a blizzard of the century, major forest diseases, and insect infestations. These disturbances provided a unique opportunity to study how they altered the recovery of the forest ecosystem. This book also shows that some long-term forest trends cannot be forecast from short-term findings, which could lead to incorrect conclusions of cause and effect relationships and natural resource management decisions.

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