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Catchment Disturbance and Stream Response: Overview of Stream Research at Coweeta Hydrologic Laboratory

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INTRODUCTION

People interested in stream pollution frequently make a distinction between point- and non-point-source pollution. Point-source pollution comes out of a pipe; nor pollution generally enters streams in run-off from surrounding land. It is our cont

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that non-point-source pollution is a major contributor to degradation of wa and ecosystem integrity in rivers; the direct effects are primarily to small strea then transmitted downstream to larger rivers. In this chapter we illustr terrestrial disturbance affects small streams and how these streams respo recover from the disturbance.

Small, first-, second-, and third-order streams represent a majority of the within any drainage network and make up 86% of total stream length in t States (Leopold et al, 1964). Because these small streams are so closely link catchments (Hynes, 1975; Vannote et al, 1980), terrestrial disturbances, such can cause severe and long-term disruption, which eventually may impact bot downstream environments.

While efforts to improve stream quality have generally been directed at poi there is fairly wide recognition of the importance of non-point pollution. N source disturbances cause water quality problems in 38.4% of all stream len United States. Specifically, 7.5% of stream length is affected detrimentally and silvicultural practices. Only 12.3% of stream length is affected by point so der Leeden et al, 1990). Put another way, 18% of streams in the United Sta fully support their designated use. In more than one-third of these cases, th non-point-source pollution. Looking specifically at eutrophication caused b inputs, total discharge of nitrogen from non-point sources in the United State 10^6 t yr^{-1} compared to 0.75×10^6 t yr^{-1} from all industrial and municip combined (Moore, 1989). The figures for phosphorus are 1.16 cf. 0.21×1 respectively.

Logging has affected nearly all forested areas of North America, an remaining areas of old-growth forests are rapidly diminishing. Many str classified as undisturbed or reference are probably still responding to p disturbances.

Our discussion of how logging affects streams is illustrated with data fro Hydrologic Laboratory (Figure 15.1). This 2270 ha Forest Service facility western North Carolina, USA, was established in 1934 primarily to study effec land management on the hydrologic cycle (Douglass and Hoover, 1988). F years Coweeta has been the site of extensive ecological studies, with an en responses of forests and streams to forestry practices (Swank and Crossley, 1 entire basin was selectively logged prior to 1923 and was also affected by ches in the 1930s (Douglass and Hoover, 1988). Reference catchments are mixed forests dominated by oaks (*Quercus* spp.), hickories (*Carya* spp.), red m *rubrum*), and yellow poplar (*Liriodendron tulipifera*). Catchments 14 and 15.1) have been used as references for many of our stream studies. Beginnin selected catchments have been experimentally deforested as part of the long-te understand effects of forest management practices on water yield, water q other forest resources.

Streams draining Catchments 6, 7, 13, and 17 (Figure 15.1) have been i studied during the past 20 years to examine effects of forest management pr stream communities and ecosystem processes. Catchment 6 (C6) is a 8.9 ha a complex history of disturbance. In 1942 all riparian vegetation was cut, and i marketable timber was removed and the slash was burned. The catchment was

FIGURE 15.1. Map of Coweeta Hydrologic Laboratory, North Carolina, USA

limed, and seeded with grass in 1959. From 1966 to 1968, all vegetation was herbicides. Since 1968 the catchment has undergone natural succession ar successional forest dominated by black locust (*Robinia psuedoacacia*) and yel C7, a 58.7 ha catchment, was clear-cut in 1977. Regrowth is dominated by sprouts, herbs, vines, and seedlings. All trees and shrubs were cut on C13 (1939–40 and again in 1962. No products were removed following cuttin catchment is presently covered by an intermediate successional forest do yellow poplar and oaks. C17 (13.5 ha) was originally cut in 1942. Regrowth annually between 1942 and 1955, and the catchment was planted with white *strobus*) in 1956. These and other catchments have been described in mor Swank and Crossley (1988) and in papers cited in that book.

Streams in the Coweeta basin are all perennial and range from first to fifth most studies have been conducted in first- and second-order streams. T streams are heavily shaded by riparian vegetation and are dependent on all energy sources. The streams are cool, high gradient, and have very low di concentrations. Further descriptions of these streams and reviews of strea have been published recently (Meyer et al, 1988; Wallace, 1988).

RESULTS

In this chapter we summarize many of the Coweeta studies that have show logging directly affects streams and (2) how streams respond to logging processes in streams are modified by logging.

Direct effects of logging on streams

Because evapotranspiration can account for 40–60% of the annual water forested catchments (Kovner, 1956), vegetation is an important regulator of s Removal of forest vegetation decreases evapotranspiration and increases s (Dunford and Fletcher, 1947; Kovner, 1956; Hewlett and Hibbert, 1961) proportion to the catchment area cleared (Hewlett and Hibbert, 1961; Hibl The greatest increases in stream flow from disturbed sites have been obser base flows at the end of the forest growing season when transpiring vegeta normally deplete most of the water stored in forest soils (Hewlett and Hibl Stream flow may remain elevated for 20 to 30 years following logging, returr disturbance levels at a rate proportional to forest re-vegetation (Swift and Sw

Forest disturbance may also affect patterns of storm run-off. Hewlett a (1970) reported that storm flow volumes increased 11% and peak discharg 7% following forest clearing in a southern Appalachian catchment. Incre flows from the disturbed area occurred during all seasons and were attribute soil moisture and lower interception losses, which resulted in more water ente source areas (Hewlett and Helvey, 1970).

Headwater streams draining forested areas are typically heavily shaded. overhanging vegetation increases insolation, resulting in increased average s peratures, especially during the forest growing season (Swift and Messer, duration of stream temperature increase is typically shortlived (less than five y temperatures returning to pre-disturbance levels once the canopy closes over the str (Swift, 1983).

Forest vegetation regulates nutrient inputs to streams by two primary mechani: through uptake of nutrients from soil solution and storage in biomass, and by decrea water movement through soils (Bormann et al, 1969; Vitousek and Reiners, 1 Vitousek, 1977). Following disturbance, vegetative nutrient uptake is reduced and conditions accelerate mineralization of organic matter (Marks and Bormann, 1 Bormann et al, 1974; Covington, 1981; Binkley, 1984). As a result, concentrations of K, Na, Mg, and NO_3-N are elevated in stream water, as has been demonstrate Coweeta (Swank, 1988) and many other sites. Nutrients that are relatively mobile in solution or cycle biologically appear to be most affected, and the nitrogen cycl forested catchments is extremely sensitive to disturbance (Vitousek and Reiners, 1 Vitousek, 1977; Swank, 1986, 1988; Waide et al, 1988). Concentrations of NO_3-] streams draining deforested areas usually peak within five years following deforesta (Likens et al, 1970; Brown et al, 1973; Swank, 1988). Coweeta studies show r recovery, although concentrations may remain somewhat elevated for 20 or more y (Swank, 1988). As vegetation becomes re-established and nutrients begin to accumu in biomass, nutrient concentrations in soil solution and stream water decrease (Likei al, 1970; Brown et al, 1973) and, during intermediate stages of forest succession, ma lower than reference levels (Johnson and Swank, 1973; Vitousek and Reiners, 1 Vitousek, 1977).

Soil disturbance associated with road building and timber harvest can result in sediment yields to streams (reviewed by Packer, 1967a,b; Rice et al, 1971; Everest e 1987). Soil organic matter, particularly the litter layer, is an important regulatc erodability in forest soils (Bormann et al, 1969). Accumulated litter protects soil f the erosive energy of raindrops, promotes soil particle aggregation, and accelerates water percolation. Disturbances that remove the litter layer or compact forest promote overland flow and erosion of mineral soil (sediment) into stream chanı Sediment yields decrease as vegetation regrows. However, instream redistribution transport of sediment may continue for many years (Brown and Krygier, 1971). Cow studies of roads and stream sediment were summarized by Swift (1988).

One of the most evident direct effects of logging on forest streams is the reductic allochthonous inputs. Webster and Waide (1982) reported that autumn leaf inputs stream at Coweeta were reduced to less than 2% following logging. Rapid regrowt successional vegetation returned allochthonous inputs to near-reference levels withi 10 years (Webster et al, 1990), though quantitative differences in inputs to o disturbed streams were detectable 20 years after disturbance. Data from Coweeta (T 15.1) indicated that leaf litter fall and total litter fall to disturbed streams \ significantly less than to reference streams (t-test on means, $\alpha = 0.05$). Wood litteı (twigs and small branches) was not detectably different. Blow-in, the lateral mover of litter into streams, was also reduced.

In addition to quantitative reduction in litter inputs, there are also major qualit changes resulting from logging. In the first three years following logging, leaf inpu Big Hurricane Branch at Coweeta were dominated by herbaceous material and leav woody shrubs and rapidly sprouting tree species (Webster et al, 1983). After seven y qualitative differences were still evident. The relatively refractory leaves of oaks

TABLE 15.1. Annual litter inputs to streams at Coweeta Hydrologic Labor

	Blow-in (g AFDM m^{-1} stream length)			Litter fall (g AFDM m^{-2} stre	
	Leaf	Wood	Total	Leaf	Wood
Reference streams					
Grady Branch	79.4 A	7.0 A	87.0 A	470.5 A	123.3 A
Hugh White Creek	64.6 A	3.4 A	70.2 A	409.3 AB	68.0 A
Disturbed streams					
Sawmill Branch	21.1 B	2.5 A	23.8 B	318.3 B	72.1 A
Big Hurricane Branch	21.0 B	3.3 A	24.9 B	311.9 B	16.7 B

Entries are means of 10 to 20 collection traps. Means and statistical analyses are based transformed data. Letters represent means that were not significantly different among str analysis of variance followed by a least significant difference test. The Sawmill Branch catchmen cut in 1950, but forest regrowth was prevented until 1968. The Big Hurricane Branch catchmer 1977. Data from Webster et al (1990). AFDM = ash free dry mass. Wood includes only t branches

rhododendron originally accounted for 44% of the leaf input to this stream (' Waide, 1982). In 1983–1984 these species accounted for only 18% of th whereas inputs of more labile leaves of herbs and tree species such as b dogwood, and willow had increased (Webster et al, 1990). Similar qualitativ in leaf input to Sawmill Branch were evident more than 15 years after fores began, and we anticipate that such differences will probably persist for 50–1 to the relatively slow regeneration times of oaks.

Reduced inputs of large woody debris to streams are probably much lc than reduced leaf inputs. During logging there may be a pulse input of woo In the past, general forest management procedures required removal of t from stream channels; however, this is no longer standard practice in most ai subsequent years of forest succession, there is little tree death in the young f and small trees may die as a result of self-thinning, disease, and competit ment. However, the time until the forest matures and significant tree mor may be hundreds of years (Swanson and Lienkaemper, 1978; Likens and Triska et al, 1982).

Stream responses to logging

Accelerated transport of sediment (inorganic particles) and particulate or has been reported in many studies of logging and is usually attributed t sediment input associated with forest floor disturbance caused by road constr use, and skid trails (e.g. Lieberman and Hoover, 1948; Tebo, 1955; Gurtz Golladay et al, 1987; Webster et al, 1990). Logging techniques that m disturbance generate less sediment. Experimental studies in which trees we not removed, thus eliminating most soil disturbance, resulted in no measura in stream turbidity, suggesting little or no increase in sediment transport (Lie Hoover, 1948).

Results from logging Catchment 7 (C7) at Coweeta are fairly typical of clearcut logg in mountainous terrain (Figure 15.2). Three roads were built in this catchment in 19 and it was logged in 1977 using a cable logging system to minimize soil disturbar Base-flow sediment transport was elevated for several years but in less than five years l begun dropping and appeared to be rapidly returning to reference levels (Figure 15 Other Coweeta studies showed similar results—10 to 20 years after logging, base f concentrations of particulates were not significantly different from reference le (Webster and Golladay, 1984; Golladay et al, 1987). However, storm flow transp demonstrates that the effects of forest disturbance are evident for a much longer per (Figure 15.3) (Webster et al, 1990).

Sediments transported in streams contain both organic and inorganic materials. undisturbed streams at Coweeta, this material is 40–60% inorganic, but when catchment is logged the inorganic fraction increases more than the organic fracti resulting in inorganic concentrations over 70% (Webster and Golladay, 1984; Webste al, 1988). Much of the sediment transport from C7 can be directly attributed to eros from newly built roads during a storm in 1976 (Swift, 1988). Based on estimates of loss from the roads, 80% of the eroded soil remained in the stream channel after years and was still being exported 8 years later (Swift, 1988). However, data from C indicate that not all sediment comes from roads. All trees on this catchment were c first in 1939 and again in 1962. The logs were not removed either time—there were skid trails, no roads, and almost no soil disturbance. Yet annual sediment transport still well above reference levels in 1984–1985 (Figure 15.3).

Dissolved organic carbon (DOC) may be an important component of stream ene tics. Studies at Coweeta have demonstrated that stream microflora remove DOC fr the water column and use the more labile components (Meyer et al, 1988). Howe based on estimates of annual inputs and outputs, streams at Coweeta are net genera of DOC (Meyer and Tate, 1983). Deforestation decreases export of DOC (Meyer Tate, 1983) due to decreased inputs from seeps and springs and less leachable ben organic matter (Meyer et al, 1988).

The effect of forest disturbance on nutrient processing within streams was rece studied by Golladay (1988). His results indicated no differences between disturbed reference streams in potassium, calcium, or sulphate retention. However, nitrogen phosphorus were retained less efficiently in streams draining disturbed watersheds t in reference streams. Most nitrogen and phosphorus loss was in association with orga particles. Munn (1989) found that debris dams were major sites of phosphate uptak an undisturbed Coweeta stream and that phosphate uptake was correlated with ben organic matter. Hence, as debris dams and benthic organic matter storage chang respect to disturbance, phosphate uptake should change. In another study of fo disturbance and within-stream nutrient dynamics, Webster et al (in press) found difference between dissolved nitrate and phosphate uptake in reference versus distur streams. However, they attributed the lack of difference to a complex of factors that b increased and decreased uptake. Studies by D'Angelo (1990) suggested that phys changes in streams caused by forest disturbance, i.e. elevated temperature, dischar and water velocity, more significantly affect nutrient dynamics than changes in bi uptake.

One of the short-term responses to logging is an increase in autochthonous producti i.e. instream primary production. Primary production in Coweeta streams is extrem

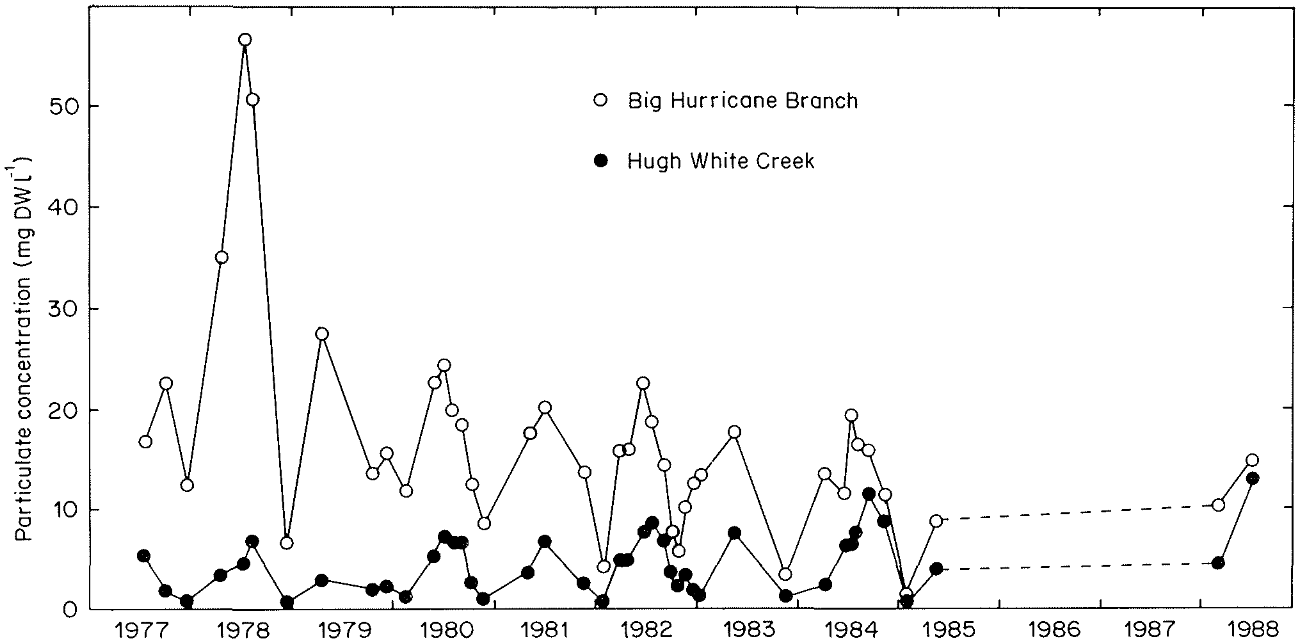


FIGURE 15.2. Baseflow particle concentrations in Hugh White Creek (reference) and Big Hurricane Branch (catchment logged in 1977) at Coweeta Hydrologic Laboratory. Data from Webster et al (1983), Golladay (1988), and Webster (unpublished). DW=dry weight.

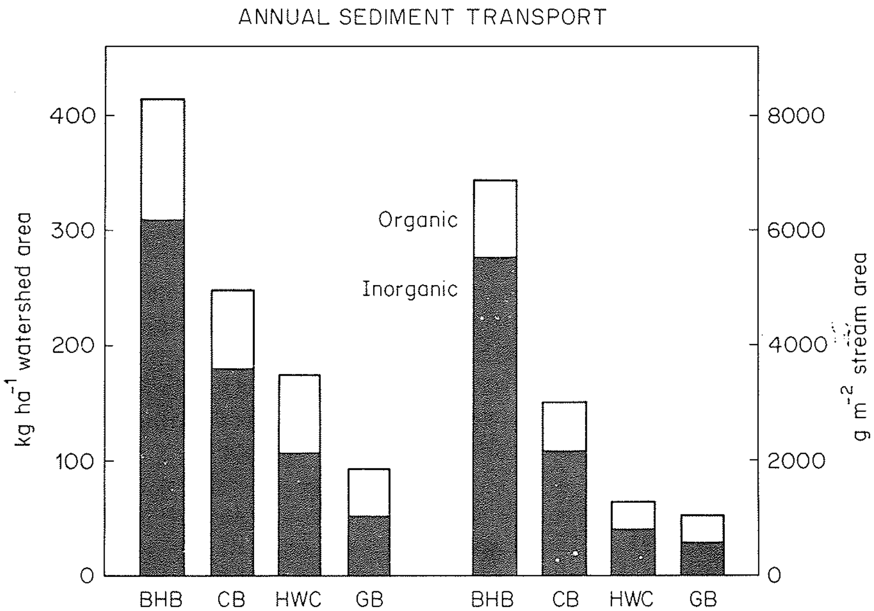


FIGURE 15.3. Annual particle transport in streams at Coweeta Hydrologic Laboratory. White Creek (HWC) and Grady Branch (GB) drain reference catchments. The Big Hurr Branch (BHB) catchment was logged in 1977, and trees on the Carpenter Branch (CB) catch were cut but not removed in 1939 and 1962. The results are based in a computer simul (Webster et al, 1990) using data from Golladay et al (1987) and Golladay (1988)

low, dominated by diatoms, and limited by light (Hains, 1981; Webster et al, 1983, L et al, 1986). Following logging, filamentous green algae often increase in abund (Lowe et al, 1986), and there may be significant increase in total primary produ (Hains, 1981; Webster et al, 1983). This pulse of autochthonous production can doubtedly be attributed primarily to the absence of shading, but increased nut availability and higher temperatures may also be important in stimulating algal gro As regrowth of riparian vegetation again shades the stream, primary production ret to low levels (Webster et al, 1983).

Accompanying the shift in the stream energy base, a switch in the dominant be invertebrates has been observed in Coweeta streams (Woodall and Wallace, 1972; C and Wallace, 1984; Wallace and Gurtz, 1986; Wallace, 1988). Shredders, which dependent on allochthonous inputs, become less important, while production of scra and collectors that feed on algae increases. For example, *Baetis* spp. (Ephemerop abundances and production (Wallace and Gurtz, 1986) have been shown to inc following logging. Available evidence strongly suggests that such increases are cl linked with increasing periphyton resources and that species with short generation ti e.g. *Baetis* and many chironomids, respond rapidly following disturbance (Wallace Gurtz, 1986). Once the canopy closes over the stream reducing light and periph production, these species become less important. At Coweeta, five years after log C7, scraper populations declined from 30% to 13.3% of the total stream macroinv brate assemblage (Wallace, 1988). The decline in scrapers was consistent wi autochthonous production. With regrowth of the forest and shading of the litter inputs recovered to 85% of pre-logging levels within seven years (W 1990) whereas autochthonous production decreased ten-fold compared tc levels (Webster et al, 1983). As streams return to an allochthonous e shredder production again increases (Haefner and Wallace, 1981).

Transport and accumulation of sediment also influence stream fauna. ' observed significant reductions in densities of macroinvertebrates in a 1 stream downstream of the mouth of a smaller logged catchment. Tebo attri reductions to accumulated sediments exported from the logged catchment. stream sedimentation was ameliorated to some extent by high water during s re-suspended the sediments and transported them further downstream. Wallace (1984) found that the impact of road construction and logging on m brate populations in the stream draining C7 at Coweeta was strongly in substrate and geomorphology. Road building and logging resulted in increa trations of inorganic and organic seston (Gurtz et al, 1980). Sediment depos a redistribution of stream fauna among substrate types. Accumulation of s depositional habitats such as pools and sandy reaches reduced macroinverteb ances, whereas macroinvertebrates increased in steep-gradient, boulder outc (Gurtz and Wallace, 1984).

Effects of logging on leaf breakdown rates in streams are complex. St Hurricane Branch (C7) shortly after logging indicated an initial decrease in rates, apparently because leaves were often buried in sediment (Webster 1982). In subsequent years, breakdown rates were higher than before loggin than reference stream rates (Table 15.2) (Benfield et al, in press). Meyer a (1983) also reported accelerated leaf breakdown in a stream draining a lo

TABLE 15.2. Leaf breakdown rates (d^{-1}) in Hugh White Creek (reference) and B Branch (catchment logged in 1977) at Coweeta Hydrologic Laboratory

	1974–1975 pre-logging	1976–1977 during logging	1977–1978	1982–1983	1
Big Hurricane Branch					
Dogwood	0.0219	0.0134	0.0219	0.0536	
Red Maple	–	–	–	0.0237	
White Oak	0.0064	0.0038	0.0090	0.0116	
Rhododendron	0.0037	0.0011	0.0105	0.0128	
Hugh White Creek					
Dogwood	–	–	–	0.0297	
Red Maple	–	–	–	0.0109	
White Oak	–	–	–	0.0056	
Rhododendron	–	–	–	0.0047	

Data from 1974 to 1978 are from Webster and Waide (1982); 1982–1983 data were determined b Webster (1988); and 1986–1987 rates are from Benfield et al (in press). Leaf breakdown rates as the slopes of regression lines relating the logarithm of percentage ash-free dry weight rem ment. While higher temperatures and nutrients might in part contribute to acceler breakdown, invertebrate consumption is probably also important. Due to decre abundance of leaves in disturbed streams, experimentally added leaves are ra colonized and consumed by detritivores (Webster and Waide, 1982). Golladay Webster (1988) reported that small woody debris also breaks down more ra following logging, perhaps associated with higher nutrient levels, greater channel i bility, and greater invertebrate consumption.

The result of decreased allochthonous leaf inputs, greater particulate organic m (POM) export, and accelerated leaf breakdown is a decline in the standing cro benthic organic matter (BOM) in streams. In a study at Coweeta, we found no differ in the mean annual standing crops of fine particulate organic matter (FPOM), but cc particulate organic matter (CPOM) standing crops were significantly higher in refer streams than in two of the disturbed streams (Table 15.3) (Golladay et al, 1989). high standing crop of BOM in Carpenter Branch was apparently the result of a r unusual channel morphology. Large amounts of organic matter accumulated in a l low gradient, and deeply incised section of this stream.

More recent data comparing three tributary streams draining C7 (logged in 1977) three reference streams on C14 showed that CPOM was fairly similar in autumn after leaf fall but that the leaves disappeared much more rapidly from the distu streams (Stout, 1990; Figure 15.4). Throughout the summer there was little CI available for detritus-feeding invertebrates in streams draining logged areas.

Woody benthic material also declines following forest disturbance (Table 15.3). V slash left in or over the stream may contribute to a short-term increase in woody mat (Webster et al, 1983), rapid wood decay (Golladay and Webster, 1988) and the la large wood input results in a long-term depletion of wood within stream cha (Golladay et al, 1989). Small wood that enters streams during forest successi

TABLE 15.3. Benthic organic matter (g AFDM m^{-2}) in Coweeta streams

	FPOM (<1 mm)	CPOM[a] (>1 mm)	Small wood (1–5 cm)	Large wood (>5 cm)	Total BOM	Debr dam (No. per
Reference streams						
Grady Branch	147.1	244.0	300.0	4580	5270	0.6
Hugh White Creek	165.8	213.0	311.8	5130	5820	0.4
Disturbed streams						
Sawmill Branch (cleared 1958, regrowth since 1968)	157.0	129.1	78.5	1460	1820	0.0
Big Hurricane Branch (logged, 1977)	112.8	124.2	383.2	2830	3450	0.1
Carpenter Branch (trees felled 1939 and 1962)	386.6	255.2	261.4	230	1130	0.2

Data are arithmetic means reported by Golladay et al (1989). Data are from 1985 to 1986
[a]Includes wood <1 cm

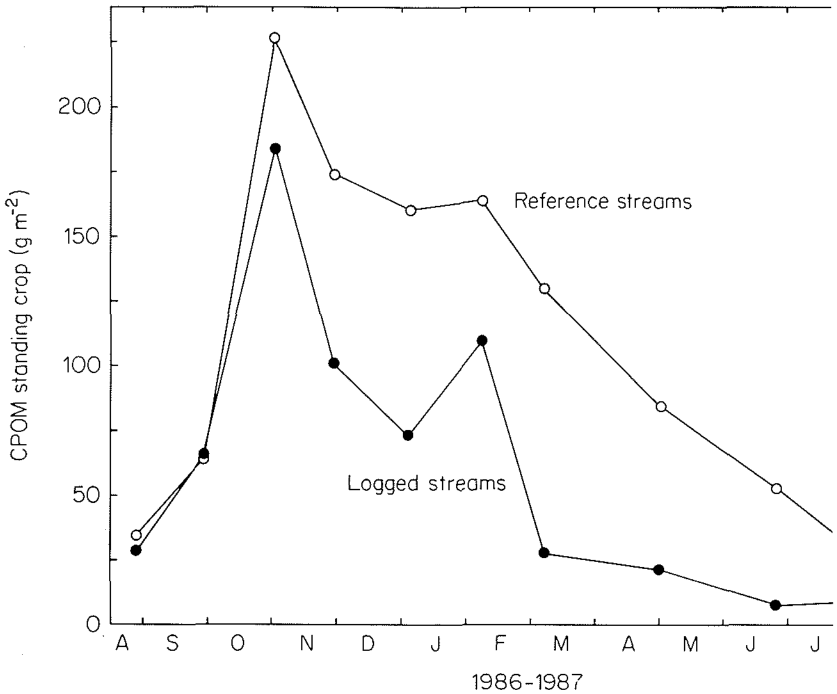


FIGURE 15.4. Standing crops of coarse particulate organic matter (CPOM > 1 mm streams draining reference and logged (1977) catchments. Each point is the mean of t Each stream value is the mean of five samples. Data from Stout (199C

generally not large enough to form stable debris dams and also decays rap and Bilby, 1982). Logs of sufficient size to form stable debris dams do n stream until the forest matures.

DISCUSSION

In most studies of forest disturbance, streams and forests have been treated a units (e.g. Likens et al, 1970; Johnson and Swank, 1973; Bormann et al, 1 there is no question that streams and the areas they drain are closely linked, catchment units has resulted in the perception of streams as conduits a obscured differences in the ways forests and streams respond to disturbance of forests to respond to disturbance is linked to two primary components— vegetation and dead organic matter stored in forest soils (Bormann et al, 19(and Reiners, 1975). Together, vegetation and dead organic matter confer forest ecosystems. Rapid regeneration of vegetation facilitates recovery c function while the persistence of soil organic matter minimizes effects o turbance.

Vitousek and Reiners (1975) and Vitousek (1977) extended the conce stability to include changes that occur over succession. They identified thre forest ecosystems pass through following disturbance. During the initial stag degradation phase, the net organic matter increment of forest ecosystems is neg The negative increment results from reduced vegetative growth and condition: favour decomposition in forest soils; net ecosystem production (NEP) is negative ar storage pool of organic matter decreases. During the second (aggradation) phase, tl organic matter increment becomes positive as production of rapidly growing vege exceeds ecosystem respiration (NEP>0). Finally, as forests mature, the net oı matter increment becomes zero as vegetative production is balanced by ecos respiration (NEP = 0).

Forest disturbance has a greater impact on streams than on forests because of its term nature. Cutting and burning are short-term disturbances to forests, and i absence of further disturbances, forests undergo succession and recovery. Forests re relatively rapidly because organic matter is internally generated. In contrast, stream organic matter is derived from external sources and stream net ecos production is usually negative (e.g. Fisher and Likens, 1973). Being depende imported organic matter, streams cannot fully recover from disturbance until disturbance patterns of organic matter input are re-established (Webster and P 1979; Gurtz et al, 1980; Webster and Swank, 1985).

The sequence of events occurring in Coweeta streams following logging (and p other forest disturbances) conforms quite well to the scenario proposed by Likeı Bilby (1982), Swanson et al (1982), and Likens (1984). There is an initial change fr allochthonous to an autochthonous production base resulting from the opening canopy (Period 1 in Figure 15.5). As riparian vegetation regrows, instream pı production decreases as leaf inputs increase (Period 2). Within 10–20 years, leaf quantitatively approach reference levels but differ qualitatively by being more labil leaf fall in mature forests. Sediment export during these early periods is high, pr resulting from redistribution of material that entered the stream during road buildi logging. Benthic organic matter standing stocks are low because of low input and breakdown; hence less DOC is generated by leaching of organic matter stored channel. Woody material that existed in the stream prior to logging, and that ma been left in the stream during the logging operation, decays rapidly and is not repla the rapidly growing successional forest.

The initial period of autochthonous production and high sediment transport a following period of decreasing sediment transport with a return to allochth production apparently take 20–30 years. Based on very little hard evidence, we s that there is a third period during which there is again accelerated sediment loss re from poor retention within the stream and erosion of material from within the s channel (Figure 15.4). Bilby (1981) and Bilby and Likens (1980) demonstrat importance of woody debris dams to particle retention in streams. Studies in the west United States (e.g. Keller and Swanson, 1979; Swanson et al, 1982; Triska 1982; Speaker et al, 1984) also emphasized the role of woody debris dams in stı Molles (1982) and Trotter (1990) found a similar role for wood in New Mexico stı We suggest that continued, and perhaps increased, sediment export 20–30 year logging is associated with the loss of debris dams. Observations of two Coweeta st support this suggestion. Trees on the catchment drained by Carpenter Branch were felled in 1939 and again in 1962. However, the logs were not removed. The

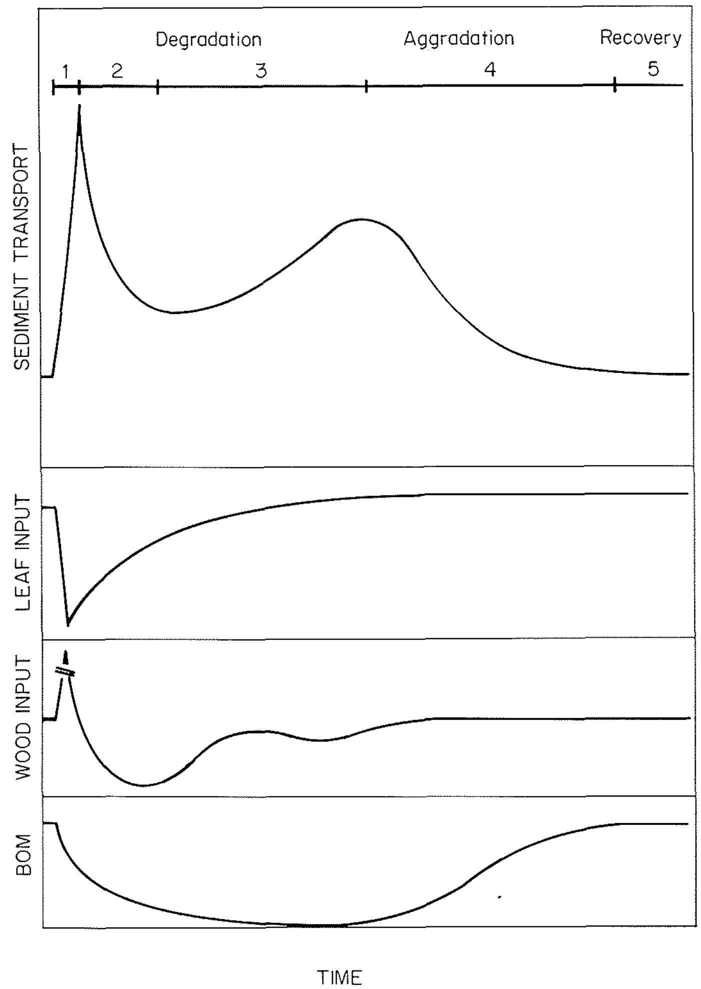


FIGURE 15.5. Hypothetical trends in stream processes following forest disturbanc
periods of stream response are: (1) high autochthonous production and sediment tr
decreasing sediment transport and return to allochthonous production; (3) minimum
benthic organic matter and accelerated sediment loss; (4) aggradation of stream bed ı
formation of long-lasting debris dams; and (5) recovery of pre-disturbance conc

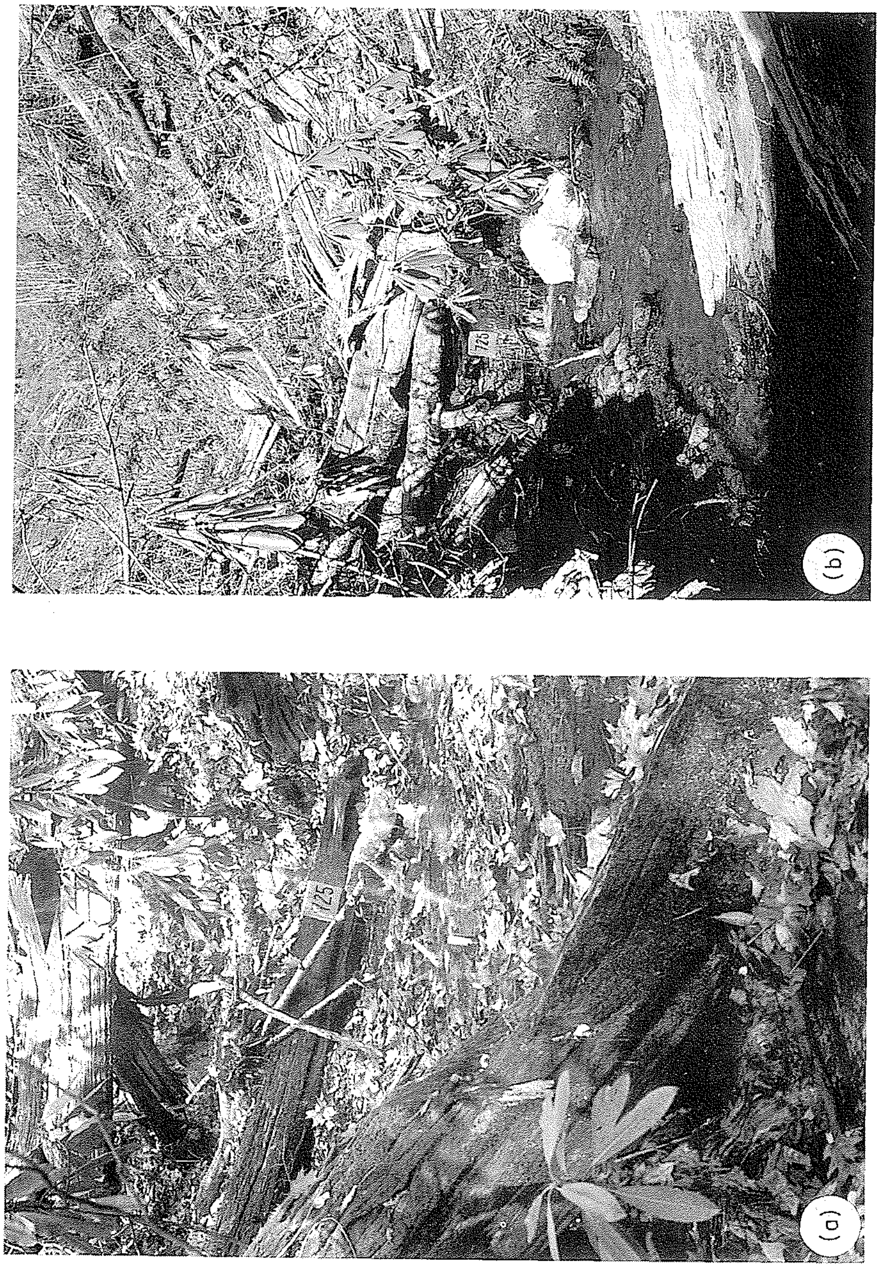
no skidding, and no roads were built in the area. Very little sediment entered as a result of soil surface disturbance (Lieberman and Hoover, 1948). Howe sediment transport was above reference levels in 1985–1986 (Figure 15.3). A time, the amount of wood and the number of debris dams in the stream wei (Table 15.3). Catchment 6, which is drained by Sawmill Branch, was cleared i logs were removed, and the remaining residue was burned. The catchment v with grass and maintained in grass from 1959 until 1965. Since 1967 the cat reverted to successional vegetation. In a survey of the stream, we found no c (logs with organic debris accumulated upstream, Golladay et al, 1987). Sediment ex by this stream continues to be higher than any other stream at Coweeta (Webster Golladay, 1984; Webster et al, 1988). Active erosion from within the stream chanr evident in both Carpenter Branch and Sawmill Branch.

During this third period, there is also rapid turnover and depletion of partic organic material. Comparing inputs (Table 15.1) and outputs (Figure 15.3), it is evi that annual export of POM from disturbed streams exceeds inputs. Comparison o net loss with the standing crop BOM (Table 15.3) shows that benthic material is b rapidly depleted.

The aggradation stage in the post-disturbance history (Period 4 in Figure 15.5) w begin when relatively large logs fall into the channel and form long-lasting debris (that stabilize sediment movement and begin POM accumulation. Hedin et al (1 suggested that this may begin about 25 years after disturbance, but at Coweeta probably does not occur until 50–200 years after logging. The time until the numb debris dams and accumulated BOM reaches pre-disturbance levels may be anothe years.

There is a major difference between our prediction for the long-term respons Coweeta streams and the recently proposed model for Hubbard Brook (Hedin e 1988). The Hubbard Brook model suggests that as soon as debris dams begin to f they act as sinks for sediment, reducing sediment export below pre-disturbance le This is a period when the number of debris dams in the streams is minimal and st bed stability is very low. Since during this period the stream bed itself is the major so of transported sediment (Likens et al, 1970; Likens, 1984), sediment export shoul well above pre-disturbance levels. Answers to questions like these concerning long- responses to disturbance will only come from sustained research efforts in areas w documented disturbance histories already exist.

Several factors might modify the sequence of events illustrated in Figure 15.5. F the time from logging until Period 3 may be greatly shortened if woody debris is rem from the stream as part of the logging clean-up operation. Historically, wood considered detrimental in streams, primarily because of possible detrimental effec salmonids (e.g. Narver, 1971; Bisson et al, 1987), and debris removal was stan procedure (Froehlich, 1973; Bilby, 1984). Second, death of successional vegetation pin cherry in north-eastern and black locust in south-eastern United States) moderate sediment loss during intermediate stages of succession (Likens and B 1982). Also, the pattern will be affected by the decay characteristics of woody de Conifer wood decays much more slowly than hardwoods (e.g. Harmon et al, 1986), a conifer logs are left in the channel following logging, their decay may be sufficiently to retain stream bed stability until the forest matures and tree mortality begins. managed forest, the time when significant tree mortality begins to occur (the begin of Period 4 in Figure 15.5) would indicate a mature forest ready for another rotati logging. This next period of logging would occur at a time when the lack of debris (would cause the stream to be most sensitive to further disturbance. The cumul effects of successive logging would keep the stream in a condition of rapid degrada Forest management alternatives must be considered with an understanding of both s and long-term effects on streams and an evaluation of potential cumulative effec logging rotation intervals.


(b)
(a)

Throughout the deciduous forest area of eastern United States, forests are alre being logged for the second, third, or fourth time. However, we are not yet seeing extensive erosion of small stream channels that we would predict based on Figure 1 Smock and MacGregor (1988) discussed some of the subtle effects the demise American chestnut has had on detritus consumers in streams. Perhaps chestnut blight also had much broader effects on erosion from stream channels. Death of chestn which occurred during the 1930s in the southern Appalachians, added considerable la woody debris to stream channels, providing the channels with a much greater stab and retentiveness than might have been anticipated following the second logging of th forests (Figure 15.6).

In other areas of the United States, the long-term recovery of streams from fo disturbance may be somewhat different. Hedin et al (1988) suggested that sedin export may be minimal during the period of debris dam reformation as sedimen accumulating behind these dams. In another situation, following forest fire in west United States, there is a very rapid decline in stream debris dams as increased run from fire-denuded slopes causes severe flooding (Minshall et al, 1989). Howe subsequent recovery is very rapid due to the undercutting and blow-down of fire-ki snags.

Downstream effects

While the impact of logging is greatest in small streams actually within logged ca ments, some effects are transferred downstream. A drainage network is like a fun with headwater streams acting as collectors for downstream reaches.

Increases in base and storm flows resulting from deforestation are generally prop tional to area and extent of vegetation removal. While logging one small catchment n cause little change in a large stream, the accumulation of deforested areas withi drainage network may result in significant downstream flooding.

Statzner and Higler (1985) described river systems as being characterized by ero headwaters, transitional mid-reaches, and accumulative lower reaches. Sediment ger ated in headwater streams is routed eventually to larger streams. Sediment resul from catchment disturbance adds to this general pattern, increasing inputs and accele ing erosion within headwater streams. Storms, with flows augmented by reduced fo transpiration and accelerated by the lack of hydraulic retention devices within headwa streams, move the sediment downstream in major pulses. For example, poor l management practices in south-eastern United States have caused massive inputs sediments to Piedmont rivers, completely changing the structure of these rivers. They now sediment-laden channels that run red with every storm—very different from rivers described by Bartram (1791) in his travels through the area.

Various studies have shown that nutrient uptake lengths in headwater streams are v short; that is, headwater streams effectively retain essential nutrients (e.g. Mulhollan al, 1985; Munn, 1989; Webster et al, in press). However, with the possible exceptio the loss of gaseous nitrogen (Swank and Caskey, 1982), these nutrients continue t journey downstream, alternating between dissolved and immobilized forms, eventu contributing to the enrichment of downstream systems. In addition to being a sourc these nutrients, terrestrial disturbance also accelerates downstream transpoı elevated flows and reduced hydraulic and particulate retention.

Studies at Coweeta have demonstrated that headwater stream fauna aı important to the downstream transport of particulate organic material amounts, timing, and quality (Wallace et al, 1982, 1986; Cuffney et al, 199(al, in review). Continuous measurements of organic particle export from water streams showed that about 36 kg AFDW of FPOM was exported per y 100 m reach of headwater stream. Experimental reductions of stream macro communities indicated that feeding by these organisms contributed 56– export (Cuffney and Wallace, 1989; Wallace et al, in review). Reduced expoı streams has important consequences for downstream communities depen stream sources for organic matter and nutrients. Preservation of faunal c production within headwater streams should be an important consideraı management (Wallace et al, in review).

Forest management practices in the United States have changed conside the past 50 years. Special attention is now paid to soil surface disturbance a especially where roads cross stream channels. Even more recently, guidelin debris removal have changed in response to concerns over degradatio ecosystems. Buffer strips and riparian zone management are integral coı present-day forestry practices and are effective in maintaining fish and m brate communities (Burns, 1972; Newbold et al, 1980). However, we feel th concern must be placed on the long-term and large-scale aspects of defore cumulative effects of a mosaic of small-scale logging within a large drain; have been little studied. Small-stream research is essential for evaluation o effects of land-use practices from upland areas to downstream river systeı nally, the small-scale studies must be considered in the context of the landscape—the whole drainage basin of the large river.

A practical question is whether it is better to log many small patches over and have many small streams disturbed a little, or to log some stream intensively. Where even minor disturbance is critical, the latter practice m (R. Hauer, pers. comm.). For example, spawning habitat for some upstrea fish is destroyed by even small increases in sediment load. Just a little reducti of all headwater streams may mean total loss of critical habitat. While thi: clearly debatable and in need of further study, it illustrates the need foı terms of large drainage areas. With land ownership seldom following drain stream management often requires co-operation of many land owners.

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