

## Effects of forest disturbance on leaf breakdown in southern Appalachian streams

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### Introduction

Most studies of stream disturbance have been from the perspective of point or non-point discharges that impinge directly on stream communities. Streams may also receive indirect impacts when the catchments they drain are disturbed by such activities as logging. Logging has been extensive in areas drained by small to intermediate streams throughout the United States, and few streams in the Eastern United States drain forests that have escaped logging. Logging effects on streams in the southern Appalachian Mountains were recently summarized by SWANK & CROSSLEY (1988). One common effect is that increasing light and temperature due to canopy loss coupled with increase dissolved nutrients stimulate autochthonous primary production in streams. Canopy loss also reduces allochthonous organic matter input to streams which, along with increased primary production, may drastically change the stream energy base. After a few years, vegetation regrowth returns streams to an allochthonous energy base. However, the allochthonous input is dominated by foliage from successional rather than mature forest plants present prior to logging. These changes in the energy base of forested streams are probably positive in many ways, e.g., temporary increases in stream primary and secondary production (HAINS 1981, GURTZ & WALLACE 1984). Negative effects of logging include increased sediment loading to streams due to road construction and soil disturbance and long-term loss of woody debris resulting in unstable streambed substrata (SWANSON & LEIN-KAEMPER 1978, MOLLES 1982, LIKENS & BELBY 1982).

In low-order streams of Eastern United States deciduous forests, the energy base is chiefly leaves from riparian trees and shrubs. The present study was undertaken to investigate the impact of clear-cutting on the rates at which riparian tree leaves are comminuted by first-order stream communities in the southern Appalachian Mountains.

### Site description

This work was conducted in the southern Appalachian Mountains at Coweeta Hydrologic Laboratory, North Carolina, USA. Four streams were selected for study: three streams draining disturbed catchments and one

stream draining a reference catchment. Big Hurricane Branch (C7) drains Catchment 7 which was clear-cut in 1977. Regrowth is dominated by hardwood sprouts, herbs, vines, and seedlings (BORING et al. 1981). Carpenter Branch (C13) drains catchment 13 which was clear-cut in 1939-1940 and again in 1962 with no products removed (SWANK & DOUGLASS 1977). Catchment 13 is presently covered by a coppice hardwood forest dominated by yellow poplar (*Liriodendron tulipifera* L.) at lower elevations and mixed oaks (*Quercus* spp.) at higher elevations (LEOPOLD & PARKER 1985). Sawmill Branch (C6) drains catchment 6 from which riparian vegetation was removed in 1942. In 1958 all marketable timber was removed from the catchment and the slash was burned. Catchment 6 was fertilized, limed, and maintained in grass by various herbicide treatments for about 10 years (JOHNSON & SWANK 1973). In 1968 the catchment was allowed to begin natural succession and is presently old-field, with primarily black locust (*Robinia pseudoacacia* L.) at lower elevations and yellow poplar at higher elevation sites. Hugh White Creek (C14) drains catchment 14, a mixed hardwood forest and a long-term reference catchment at Coweeta (SWANK & DOUGLASS 1977). Catchment 14 was selectively logged prior to 1925 and except for chestnut blight has been undisturbed for 60 years. All four streams are high gradient and second-order. Substrate is primarily sand and cobble. Primary production is very low, and stream communities are primarily dependent on allochthonous energy (e.g. WALLACE 1988). These streams have been the subject of many ecological studies, which were recently summarized by MEYER et al. (1988), WALLACE (1988), and WEBSTER et al. (1988). All four streams are gaged by the U.S. Forest Service. General characteristics of the four streams appear in Table 1.

### Methods

Breakdown rates of dogwood (*Cornus florida* L.), red maple (*Acer rubrum* L.) yellow poplar (*Liriodendron tulipifera* L.) and rhododendron (*Rhododendron maximum* L.) leaves were measured in the four study streams. These species are common to all four catchments and have been shown experimentally to be "fast" (dogwood = DW), "medium" (red maple = RM and yellow poplar = YP) and "slow" (rhododendron = RH) pro-

Table 1. Selected morphometric variables of the study streams.

Variable	Stream			
	C7	C6	C13	C14
Catchment basin area (ha)	59.5	8.9	16.1	61.1
Mainstream length (m)	1225	450	604	1077
Gradient ( $m \cdot m^{-1}$ )	0.19	0.24	0.19	0.16
Mean annual discharge ( $l \cdot s^{-1}$ )	17.7	2.30	4.70	19.0
Maximum watershed elevation (m)	1060	919	965	996
Minimum watershed elevation (m)	724	742	774	708
Catchment orientation	S	NW	E	N
Mean $NO_3-N$ concentration ( $mg \cdot l^{-1}$ )	0.04	0.67	0.04	0.003
Mean $PO_4-P$ concentration ( $mg \cdot l^{-1}$ )	0.002	0.002	0.001	0.002

cessors (WEBSTER & BENFIELD 1986). Leaves were picked just prior to abscission and air dried to constant weight. Single species artificial leaf packs were constructed by placing about 10 g of dried leaves in plastic mesh bags (mesh size = 5 mm) which were tagged for dry weight, catchment, and leaf species. On 23 November 1986, twenty-four packs of each leaf species were placed in the first-order mainstream of the catchment from which the leaves were picked. Three packs per species were retrieved at random after 6, 22, 54, 89, 118, 148, 180, and 215 days and returned to the laboratory. Remaining leaf material was rinsed of debris and sediment and air-dried to constant weight. Homogenized sub-samples were ashed at 500 °C to obtain ash free dry mass (AFDM) according to GURTZ et al. (1980). Leaf breakdown rates ( $-k$ ) were computed using an exponential model by regressing  $\log_e$  percent AFDM remaining against exposure time (PETERSEN & CUMMINS 1974).

Catchments used in the study were selected to show a range of disturbance histories as described above. Although we were unable to replicate catchment treatments, catchments 7 and 14 cells contain several first-order tributaries, which were used as treatment replicates. Packs of red maple leaves (14RM) taken from catchment 14 were placed in the main first-order stream and in two other first-order tributaries in catchments 7 and 14. In addition, natural accumulations of leaves from the three first-order streams in catchments 7 and 14 were collected and processed in a manner similar to leaves from artificial leafpacks.

### Results and discussion

Breakdown rates were significantly different from zero for all species in all streams indicating that the exponential model was appropriate for describing leaf breakdown in the study streams (regression slope  $\neq 0$ ,  $\alpha = 0.05$ ). When all data were pooled, significant differences in breakdown rates by species and catchment were obtained (ANOVA,  $p < 0.0001$ ). While species-specific breakdown rates varied among streams, the order from fast to

slow was  $DW > RM \geq RH$  in all streams confirming the frequent observation (WEBSTER & BENFIELD 1986) that "fast", "medium", and "slow" processing leaves breakdown in a predictable order regardless of incubation site (Table 2). In the present study, the reference stream (C14) most closely followed the predictable pattern in terms of statistical significance, i.e.,  $DW > RM = YP > RH$  (Table 2). Streams draining the recovering clear-cut catchments departed somewhat from the reference stream pattern. For example, in the most recent clear-cut catchment stream (C7), there were no significant differences among the "fast" and "medium" processing species but the "slow" processor (RH) was significantly different from the others. In the most severely disturbed stream (C6) the rate for the "slow" species (RH) was not different from one of the "medium" species (YP) but was different from the "fast" species. The pattern of significant differences in processing rates in the coppice-catchment stream (C13) was very similar to that of the reference stream except that DW and YP were not different.

Species	Stream			
	C7	C6	C13	C14
DW	0.0185 Aa	0.0234 Aa	0.0191 Aa	0.0160 Aa
RM	0.0138 Aa	0.0134 Ba	0.0097 Bb	0.0073 Bc
YP	0.0150 Aa	0.0105 BCab	0.0131 Aa	0.0067 Bb
RH	0.0079 Ba	0.0069 Ca	0.0042 Cab	0.0016 Cb

slow breakdown was  $DW > RM \geq RH$  in all streams confirming the frequent observation (WEBSTER & BENFIELD 1986) that "fast", "medium", and "slow" processing leaves breakdown in a predictable order regardless of incubation site (Table 2). In the present study, the reference stream (C14) most closely followed the predictable pattern in terms of statistical significance, i.e.,  $DW > RM = YP > RH$  (Table 2). Streams draining the recovering clear-cut catchments departed somewhat from the reference stream pattern. For example, in the most recent clear-cut catchment stream (C7), there were no significant differences among the "fast" and "medium" processing species but the "slow" processor (RH) was significantly different from the others. In the most severely disturbed stream (C6) the rate for the "slow" species (RH) was not different from one of the "medium" species (YP) but was different from the "fast" species. The pattern of significant differences in processing rates in the coppice-catchment stream (C13) was very similar to that of the reference stream except that DW and YP were not different.

There were no significant differences among streams in breakdown rates for the "fast" species (DW). The breakdown rate for the "slow" species (RH) in the reference stream (C14) differed significantly from those of C6 and C7 but not C13, and the three disturbed streams were not different from each other. The "medium" species, RM and YP, exhibited patterns more similar to the "slow" species (Table 2). Breakdown rates for 14RM leaf packs incubated in the tributaries in catchments 14 and 7 were compared by Student's *t*-test and found to be significantly ( $p < 0.05$ ) faster in the streams draining the clear-cut catchment.

Species-specific breakdown rates from our artificial leaf-packs were similar in most cases to breakdown rates computed for natural leaf accumulations (Table 3). Statistical comparisons of breakdown rates between pack types were not done because of potential differences in behavior between the two types of leaf packs. For example, natural accumulations may lose or gain entire leaves, and leaf fragments are not easily identified to species. Whereas leaves and fragments in our artificial packs were confined and thus identifiable over the incubation period. However, several parallel trends are evident. Within each pack type, DW disappeared fastest and RH slowest in most cases and RM and YP disappeared at intermediate rates with the exception of C7 where there was no difference among species. With one exception (DW, C7), breakdown rates were faster in natural accumulations than in artificial packs although this apparent difference may be an artifact resulting from our inability to identify leaf fragments in the natural accumulations.

It is clear from our data that breakdown rates of tree leaves were generally faster in streams draining logged catchments than in the reference stream. This general pattern may result from a collection of biotic and abiotic variables. For ex-

ample, disturbed streams at Coweeta tend to have heavily sedimented streambeds (WEBSTER & WAIDE 1982), less large wood, and fewer debris dams (GOLLADAY et al. 1987) than do reference streams. As a result, there are fewer retention obstacles so that leaves are moved during high flows which, along with the abrasive action of transported sediments, may contribute to faster processing in disturbed streams. Further, nitrogen concentrations are generally elevated in streams draining clear-cut catchments at Coweeta (SWANK 1988) and have been related to increased microbial growth resulting in faster processing rates in C6 (MEYER & JOHNSON 1983). There are seasonal temperature differences between disturbed and reference streams at Coweeta, but the differences are not sufficient to fully account for observed differences in biological activity between stream types (MEYER & JOHNSON 1983, STOUT 1989).

Differences in leaf-shredding insect feeding activity between streams may be important in accounting for differences in leaf breakdown rates between streams. STOUT (1989) found significantly greater shredder density and production in C7 than in C14 during 1986–87. In contrast, HAEFNER & WALLACE (1981) and O'HOP et al. (1984) found shredder density to be significantly greater in a reference stream than in C6, but shredder production was not significantly different between the two streams (O'HOP et al. 1984). Opposite trends in shredder density and production between C6 and C7 may be due to differences in severity of treatment and time since treatment. For example, C6 has about half the wood present in C7 and leaf litter is virtually absent from C6 within 2–3 months of autumnal leaf-fall. Wood in C7 is about half that in C14 and leaves persist a month or two longer than in C6. Wood is abundant in C14 and natural leaf material is present in the streambed most of the year (GOLLADAY et al. 1989). Our artificial leaf-packs may have functioned as resource patches (WEBSTER & WAIDE 1982, MEYER & JOHNSON 1983) for shredders in the disturbed streams where natural accumulations were sparse. Conversely, the "patch effect" may have been dampened by abundant natural leaf material in the reference stream (BENFIELD & WEBSTER 1985) thus partially accounting for faster breakdown of artificial packs in disturbed streams.

Table 3. Mean species-specific breakdown rates ( $-k$ ,  $d^{-1}$ ) for the four leaf species in artificial leaf packs and natural leaf accumulations in two catchment streams. Values with the same letter are not significantly different and compare species within streams.

Species	Streams			
	C7		C14	
	Packs	Accumulations	Packs	Accumulations
DW	0.0185 A	0.0170 A	0.0160 A	0.0218 A
RM	0.0183 A	0.0190 A	0.0073 B	0.0092 BC
YP	0.0150 A	0.0218 A	0.0067 B	0.0137 AB
RH	0.0079 B	0.0098 A	0.0016 C	0.0059 C

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## References

- BENFIELD, E. F. & WEBSTER, J. R., 1985: Shredder abundance and leaf breakdown in an Appalachian Mountain stream. - *Freshw. Biol.* 15: 113-120.
- BORING, L. R., MONK, C. D. & SWANK, W. T., 1981: Early regeneration of a clear-cut southern Appalachian forest. - *Ecology* 62: 1244-1253.
- GOLLADAY, S. W., WEBSTER, J. R. & BENFIELD, E. F., 1989: Changes in stream benthic organic matter following watershed disturbance. - *Holarct. Ecol.* 12: 96-105.
- GURTZ, M. E. & WALLACE, J. B., 1984: Substrate-mediated response of stream invertebrates to disturbance. - *Ecology* 65: 1556-1569.
- GURTZ, M. E., WEBSTER, J. R. & WALLACE, J. B., 1980: Seston dynamics in southern Appalachian streams: effects of clear-cutting. - *Can. J. Fish. Aquat. Sci.* 37: 624-631.
- HAEFNER, J. D. & WALLACE, J. B., 1981: Shifts in aquatic insect populations in a first-order southern Appalachian stream following a decade of old field succession. - *Can. J. Fish. Aquat. Sci.* 38: 353-359.
- HAINS Jr., J. J., 1981: The response of stream flora to watershed perturbation. In Masters Thesis. - Clemson University, Clemson, South Carolina.
- JOHNSON, P. L. & SWANK, W. T., 1973: Studies of cation budgets in the southern Appalachians on four experimental watersheds with contrasting vegetation. - *Ecology* 54: 70-80.
- KOOPMANS, L. H., 1981: *An Introduction to Contemporary Statistics*. - Duxbury Press, Boston, Mass.
- LEOPOLD, D. J. & PARKER, G. R., 1985: Vegetation patterns on a southern Appalachian watershed after successive clearcuts. - *Castanea* 50: 164-186.
- LIKENS, G. E. & BILBY, R. E., 1982: Development, maintenance and role of organic detritus dams in New England streams. - In: SWANSON, F. J., JANDA, R. J., DUNNE, T. & SWANSON, D. N. (Eds.): *Sediment Budgets and Routing in Forested Drainage Basins*: 122-128. - USDA Forest Service, Gen. Tech. Rep. PNW-141, Portland, Oregon.
- MEYER, J. L. & JOHNSON, C., 1983: The influence of elevated nitrate concentration on rate of leaf decomposition in a stream. - *Freshw. Biol.* 13: 177-183.
- MEYER, J. L., TATE, C. M., EDWARDS, R. T. & CROCKER, M. T., 1988: The trophic significance of dissolved organic carbon in streams. - In: SWANK, W. T. & CROSSLEY Jr. D. A. (Eds.): *Forest Hydrology and Ecology at Coweeta*: 269-278. - Springer-Verlag, New York, New York.
- MOLLES Jr., M. C., 1982: Trichopteran communities of streams associated with aspen and conifer forests: long-term structural change. - *Ecology* 63: 1-6.
- O'HOP, J., WALLACE, J. B. & HAEFNER, J. D., 1984: Production of a stream shredder, *Peltoperla maria* (Plecoptera: Peltoperlidae) in disturbed and undisturbed hardwood catchments. - *Freshw. Biol.* 14: 13-21.
- PETERSEN, R. C. & CUMMINS, K. W., 1974: Leaf processing in a woodland stream. - *Freshw. Biol.* 4: 345-368.
- STOUT, B. M., 1989: Effects of forest disturbance on leaf quality and shredder production in headwater streams. - Ph. D. Dissertation, Virginia Polytechnic Institute & State University, Blacksburg, Virginia.
- SWANK, W. T., 1988: Stream chemistry responses to disturbance. - In: SWANK, W. T. & CROSSLEY Jr., D. A. (Eds.): *Forest Ecology and Hydrology at Coweeta*: 339-357. - Springer-Verlag, New York, New York.
- SWANK, W. T. & CROSSLEY Jr., D. A., 1988: *Forest Hydrology and Ecology at Coweeta*. - Springer-Verlag, New York, New York.
- SWANK, W. T. & DOUGLASS, J. E., 1977: Nutrient budgets for undisturbed and manipulated hardwood forest ecosystems in the mountains of North Carolina. - In: CORRELL, D. L. (Ed.): *Watershed Research in Eastern North America*: 343-362. - Smithsonian Institution, Washington, D.C.
- SWANSON, F. J. & LIENKAEMPER, G. W., 1978: Physical consequences of large organic debris in Pacific Northwest streams. - USDA Forest Service Technical Report PNW-69.
- WALLACE, J. B., 1988: Aquatic invertebrate research. - In: SWANK, W. T. & CROSSLEY Jr., D. A. (Eds.): *Forest Hydrology and Ecology at Coweeta*: 257-268. - Springer-Verlag, New York, New York.
- WEBSTER, J. R. & BENFIELD, E. F., 1986: Vascular plant breakdown in freshwater ecosystems. - *Ann. Rev. Ecol. Syst.* 17: 567-594.
- WEBSTER, J. R., BENFIELD, E. F., GOLLADAY, S. W., KAZMIERCZAK Jr., R. F., PERRY, W. B. & PETERS, G. T., 1988: Effects of watershed disturbance on stream seston characteristics. - In: SWANK, W. T. & CROSSLEY Jr. D. A. (Eds.): *Forest Ecology and Hydrology at Coweeta*: 279-294. - Springer-Verlag, New York, New York.
- WEBSTER, J. R. & WAIDE, J. B., 1982: Effects of forest clearcutting on leaf breakdown in a southern Appalachian stream. - *Freshw. Biol.* 12: 331-344.

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