21. Effects of Watershed Disturbance on Stream Seston Characteristics

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In many ecosystems disturbances are short-lived, and recovery can be followed as a gradual return to predisturbance conditions in the absence of further disturbance. However, the impact of watershed disturbances such as logging, fire, hurricanes, volcanoes, insect outbreaks, etc. on streams is long-term, often lasting as long as recovery of watershed vegetation to predisturbance structure and function (Webster and Patten 1979; Gurtz et al. 1980). Webster et al. (1983) noted that streams are easily disturbed, i.e., exhibit relatively low resistance to disturbance (sensu Webster et al. 1975), but have the potential to recover rapidly following disturbance, i.e., high resilience. However, if the disturbance continues, this potential resilience cannot be realized.

There are many long-term stream disturbances that result from disturbance to the watershed itself. In this chapter, we are concerned primarily with forest logging, although any disturbance that results in vegetation death would have similar results. Studies at Coweeta and other sites have demonstrated that logging increases streamflow (e.g., Likens et al. 1970; Chapter 22). Increased flow has been shown to last 20 to 30 years following logging (Kovner 1956; Hewlett and Hibbert 1963). Dissolved nutrient levels are elevated by logging (e.g., Likens et al. 1970; Chapter 25) and may remain elevated for many years depending on the nature of the forest disturbance. Nutrient levels on Watershed 6 (WS 6) at Coweeta were still elevated 16 years after the watershed was allowed to begin natural succession (Chapter 25). Soil disturbance, primarily due to road-building and skidding methods associated with logging (e.g., Lieberman and Hoover 1948a; Tebo 1955; Brown and Krygier 1971; Chapter 23), increases sediment inputs to streams. Although sediment input may occur only in the first few years following logging and associated activities, redistribution and transport of this material may continue for many years. Coweeta streams draining watersheds logged within the last 20 years still carry elevated sediment levels even during baseflow periods (Webster and Golladay 1984).

Logging opens the canopy, causing increased stream water temperatures (Brown and Krygier 1970; Swift and Messer 1971; Swift 1982). The open canopy and increased illumination, coupled with elevated dissolved nutrient concentrations, result in greatly increased in-stream primary production (Hains 1981). Three years after logging, autochthonous production in Big Hurricane Branch (WS 7) was significantly higher than in a reference stream (Webster et al. 1983). Six years after logging, the two streams showed differences in algal species composition and biomass that appeared to be related to shade tolerance (Lowe et al. 1986).

One of the most significant impacts of forest logging on streams is the reduction in allochthonous inputs. Leaf litter inputs to Big Hurricane Branch 2 years after logging were less than 2% of prelogging levels (Webster and Waide 1982). Seven years following logging, the quantity of litterfall had returned to near original levels (Figure 21.1), however, the quality of inputs was still different. Originally, oak leaves accounted for greater than 32% of the input. In more recent measurements, oak leaves represented < 10% of the input. In contrast, there were much higher inputs of less decay-resistant leaves, such as birch and dogwood (Webster et al. unpublished data).

In addition to the alteration of leaf inputs, logging changes the pattern of woody inputs. In undisturbed Coweeta streams, there are 20 to 30 woody debris dams per 100 m (Table 21.1). Streams draining disturbed watersheds generally have fewer woody debris dams. Similar results have been reported for other Appalachian streams (Silsbee and Larson 1983). According to Swanson et al. (1982) and Likens and Bilby (1982), the

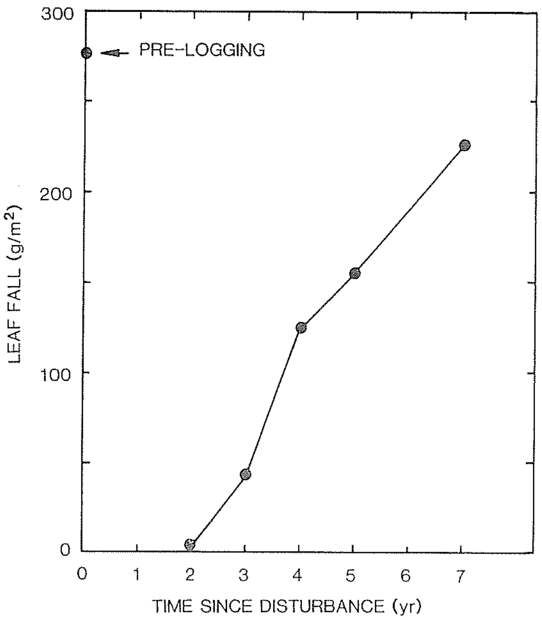

Figure 21.1. Leaffall into Big Hurricane Branch (WS 7) before and after logging. Data from Webster and Waide (1982), J. Meyer (unpublished), and Webster et al. (unpublished).

Table 21.1. Frequency of Woody Debris Dams in Coweeta Streams

Stream	Frequency of Debris Dams, No./100 m	Treatment
WS 6	1.3	Clearcut 1958, slash burned; converted to grass 1959; regrowth since 1967
WS 7	25.4[a]	Commercial clearcut 1977
WS 13	12.0	Clearcut but no products removed, 1939 and 1962
WS 17	11.3	Clearcut but no products removed, 1940; recut annually through 1955; white pine planted 1956
WS 19	20.3	Understory vegetation cut, 1948–1949
WS 22	21.3	Alternate 10-m strips cut without removal, 1955
WS 2	30.0	Reference
WS 14	23.1	Reference
WS 18	28.7	Reference
WS 21	28.7	Reference
WS 34	30.7	Reference

In this survey a debris dam was defined as an aggregation of organic material spanning the stream that included woody material with a diameter greater than 2.5 cm. At least 150 m of each stream were surveyed.
[a] Thirty-one percent of these logs were slash from recent logging

quantity of woody material in streams may be high immediately following logging, depending on the input of logging slash and the extent of channel clearing. During the next 100 or more years of forest regrowth, wood inputs will probably be low since there is little tree death, and the number of woody debris dams in the stream will probably decline as old logs decay. There may be small inputs of wood when successional trees die, such as the death of pin cherry at Hubbard Brook (Likens and Bilby 1982), aspen in western mountains (Molles 1982), or black locust on WS 6 at Coweeta, but this material is generally small, does not span the channel, does not form stable debris dams, and is rapidly washed out of the stream (Molles 1982). Consequently, the number of woody debris dams in streams may remain low for many years (100+) following logging. Since debris dams have been reported to play an important role in stabilizing stream channels (Bilby and Likens 1980; Bilby 1981; Mosley 1981), their absence may result in elevated dissolved nutrient and particle transport especially during storms.

In this chapter we evaluate the effects of long-term disturbances on stream function. We selected 17 Coweeta streams for study, including seven reference streams and 10 streams draining watersheds that had been disturbed 7 to 34 years prior to our study. We made quantitative and qualitative measurements of transported particulate material (seston) in each of these streams. Studies by Wallace et al. (1982b) and Webster (1983) demonstrated experimentally and through computer models that much of the seston in Coweeta streams during baseflow periods results from biological activity. Consequently, we are using seston as an integrative measure of in-stream biological function.

Study Sites

The 17 study streams can be roughly divided into three categories (Table 21.2). Undisturbed streams drain reference watersheds which were selectively logged in the early 1900s. Since Forest Service acquisition in 1929, they have remained undisturbed

Table 21.2. Description of Coweeta Streams Used in this Study

Stream	Watershed Area (ha)	Time Since Disturbance (yr)	Midstream Elevation (m)	Treatment	
WS 6	8.9	16	770	Clearcut 1958, slash burned; converted to grass 1959; regrowth since 1967	
WS 7	58.7	7	853	Commercial clearcut 1977	
WS 10	85.8	27	899	Commercial logging 1942-1956	
WS 13	16.2	21	899	Clearcut but no products removed, 1939 and 1962	
WS 17	13.4	27	808	Clearcut but no products removed, 1940; recut annually through 1955; white pine planted 1956	
WS 19	28.3	34	876	Understory vegetation cut, 1948-1949, 22% of basal area	
WS 22	24.3	28	960	Alternate 10 m strips cut without removal, 1955	
WS 37	43.7	20	1173	Clearcut but no products removed, 1963	
WS 40	20.2	28	990	Selective logging, 1955	
WS 41	28.7	28	1036	Selective logging, 1955	
WS 2	12.1	60	686	Reference	
WS 14	61.1	60	808	Reference	
WS 18	12.5	60	754	Reference	selective logging prior to
WS 21	24.3	60	899	Reference	1930; chestnut blight
WS 27	38.8	60	1188	Reference	1930s
WS 34	32.8	60	975	Reference	
WS 36	48.6	60	1211	Reference	

except for chestnut blight in the 1930s. The second category of streams includes six streams draining watersheds that were moderately disturbed by cutting and/or forest species conversions. The third category includes three streams draining watersheds that were more severely disturbed by road construction, logging, and/or species conversion. A complete description of watershed characteristics and treatment histories is given in Chapter 1.

Methods

Water samples were collected in July and November 1983 and March and July 1984 from each of the 17 streams. Collections were made during baseflow periods. Samples for analysis of larger particle sizes were concentrated by pouring measured volumes (40 to 200 L) of stream water through a 20-μm mesh plankton net. Material collected in the net was rinsed into a 1-L nalgene container. In addition, 8-L carboys of unfiltered stream water were collected for analysis of particles smaller than 25 μm. Samples were processed in the laboratory within 12 hr and usually within 2 to 3 hr.

Plankton net samples were separated into four size classes using a wet filtration system consisting of stainless steel sieves (Gurtz et al. 1980): medium large (ML), >280 μm; small (S), 105 to 280 μm; fine (F) 43 to 105 μm; and very fine (VF), 25 to 43 μm.

Material collected on the screens was washed onto glass fiber filters (preweighed and pre-ashed) with distilled water. To collect the ultrafine size fraction (UF, 0.5 to 25 μm), measured volumes (2 to 8 L) of unfiltered stream water were wet sieved and then filtered on glass fiber filters. All samples were oven dried (50°C, 24 hr), desiccated (24 hr), weighed, ashed (500°C, 20 min), rewetted, dried, desiccated, and reweighed. The difference between dried mass and ashed mass provided an estimate of organic seston (ash-free dry mass, AFDM), and the difference between ashed mass and filter mass gave an estimate of inorganic seston (ash). Three replicate samples were collected from each stream for all five size classes.

Samples for density measurements were collected by passing stream water through the 20-μm plankton net until there appeared to be sufficient material for measurement. These samples were subsequently fractioned into ML, S, F, and VF size classes and the material was frozen for later analyses. Density was measured by soaking oven-dried particles in 1-chloronaphthalene (density = 1.19 g/cm^3) and adding bromoform (density = 2.89 g/cm^3) until the particles became suspended. The density was then determined from a standard curve developed by measuring the refraction of the known mixtures of the two chemicals on a refractometer (Kazmierczak et al. in press). Five replicate measurements were made from each size fraction for each sample collected in July and November 1983 and March 1984.

The fall velocities of each particle size class were measured using a 15-cm diameter settling tube. Wet particles were released into the water column with a Pasteur pipette and were allowed to sink 15 cm before velocity measurements were taken. The time for particles to fall 10 cm was then measured. Ten replicate measurements were made on each size fraction from samples taken from each watershed in July and November 1983 and March 1984.

Median particle size was estimated by regressing the cumulative mass of seston against particle size and then determining the 50% intersection on the particle size axis. In all but 13 of the 204 samples the linear regression was significant ($r > 0.95$, $N = 5$). In each of the other cases the correlation coefficient was >0.90.

Results and Discussion

Our study confirmed the observation by Webster and Golladay (1984) that elevation has a major effect on seston quantity and quality. AFDM, ash, dry mass concentrations, percent ash, and particle size were all correlated with mid-watershed elevation (Table 21.3). Concentrations and percent ash were negatively correlated with elevation; particle size was positively correlated with elevation. Densities of the largest (ML) and smallest (VF) size fractions were also negatively correlated with elevation (Table 21.4) as were the fall velocities of the three smaller particle size fractions (Table 21.5). Webster and Golladay (1984) attributed the correlations of seston concentration and percent ash with elevation to the effect of temperature on biological production of seston. Measurements of stream temperature made in May and July of 1984 on undisturbed watersheds showed that midday stream water temperatures decreased about 5°C/1000 m elevation increase (linear regression, $r^2 = 0.54$, $N = 10$, in May; $r^2 = 0.69$, $N = 13$, in July). Although winter temperature differences may not be as

Table 21.3. Results of Analysis of Covariance for Dependent Variables as a Function of Date, Elevation, and Time Since Disturbance

Dependent Variable	Coefficient of Determination (r^2)	PR > F		
		Date	Elevation	Time Since Disturbance
AFDM	0.61	0.0001	0.0001	0.0001
Ash	0.60	0.0001	0.0001	0.0001
Dry mass	0.62	0.0001	0.0001	0.0001
Percent ash	0.45	0.06	0.0001	0.0001
Median particle size	0.27	0.0001	0.02	0.03

PR > F is the probability that the F value would occur randomly ($n = 204$). The coefficient of determination applies to the multiple regression equation including all three independent variables.

Table 21.4. Results of Analysis of Covariance for Dependent Variables as a Function of Date, Elevation, and Time Since Disturbance

Dependent Variable	Coefficient of Determination (r^2)	PR > F		
		Date	Elevation	Time Since Disturbance
ML density	0.40	0.0001	0.001	0.0002
S density	0.21	0.0001	0.14	0.0001
F density	0.24	0.0001	0.67	0.09
VF density	0.58	0.0001	0.02	0.0001

PR > F is the probability that the F value would occur randomly ($n = 255$). The coefficient of determination applies to the multiple regression equation including all three independent variables.

Table 21.5. Results of Analysis of Covariance for Dependent Variables as a Function of Date, Elevation, and Time Since Disturbance

Dependent Variable	Coefficient of Determination (r^2)	PR > F		
		Date	Elevation	Time Since Disturbance
ML fall velocity	0.25	0.0001	0.37	0.0001
S fall velocity	0.26	0.0001	0.02	0.0001
F fall velocity	0.32	0.0001	0.0001	0.0001
VF fall velocity	0.38	0.0001	0.0001	0.001

PR > F is the probability that the F value would occur randomly ($n = 510$). The coefficient of determination applies to the multiple regression equation including all three independent variables.

great, summer temperature differences of this magnitude would cause measurable differences in the annual biological seston production over the elevational range of Coweeta streams. Also, because seston processing rates are more rapid at lower elevations, particles contain less organic matter (higher percent ash) and tend to be smaller.

This study also supported the observation that nonstorm seston concentrations are highest in summer and lowest in winter (Gurtz et al. 1980; Webster et al. 1983; Webster and Golladay 1984). All measured factors except percent ash were significantly affected by date of sample collection (Tables 21.3 through 21.5). While the seasonal trend in concentrations might be partly explained by winter dilution, Webster and Golladay (1984) showed that transport (concentration × discharge) was highest with warmer temperatures in spring and summer. This further supports the conclusion that much of the nonstorm seston in the streams is the result of biological activity.

Organic seston concentration (AFDM) ranged from 5.06 mg/L to 0.90 mg/L (Table 21.6, Figure 21.2) and was significantly correlated with time since disturbance (Table 21.3). The AFDM concentration was significantly highest on WS 6 and relatively high on four fairly recently disturbed watersheds (Table 21.6). The concentration of ash followed a trend similar to that of AFDM. The correlation of ash concentration with time since disturbance was statistically significant (Table 21.3, Figure 21.2). Ash concentrations were high for WS 6, WS 7, and WS 13, all of which are low-elevation and recently disturbed. Lowest AFDM and ash concentrations were found on high elevation watersheds (Table 21.6).

As noted above, seston percent ash did not change seasonally, but differed significantly among watersheds (Table 21.6). Percent ash was significantly correlated with

Table 21.6. Mean Seston AFDM, Ash, and Percent Ash for the 17 Streams

Stream	Ash Free Dry Mass (mg/L)	Stream	Ash (mg/L)	Stream	Percent Ash
WS 6	5.06 (0.88)	WS 6	14.88 (2.68)	WS 7	73.5 (1.7)
WS 7	3.48 (0.41)	WS 7	11.23 (1.90)	WS 6	73.5 (1.4)
WS 10	3.37 (0.54)	WS 13	8.80 (2.51)	WS 13	69.0 (1.5)
WS 13	3.33 (0.57)	WS 40	7.29 (1.72)	WS 2	68.7 (1.1)
WS 40	3.27 (0.61)	WS 2	6.90 (1.41)	WS 17	65.7 (3.2)
WS 34	2.96 (0.48)	WS 10	5.56 (0.87)	WS 41	65.4 (0.8)
WS 2	2.81 (0.48)	WS 41	4.68 (0.95)	WS 40	64.7 (1.9)
WS 41	2.34 (0.43)	WS 34	4.14 (0.82)	WS 10	62.9 (0.7)
WS 37	2.31 (0.57)	WS 17	3.84 (1.03)	WS 18	58.7 (1.8)
WS 18	2.08 (0.31)	WS 18	3.32 (0.63)	WS 14	57.8 (0.8)
WS 14	1.89 (0.29)	WS 14	2.56 (0.39)	WS 34	57.2 (2.0)
WS 17	1.51 (0.17)	WS 37	1.55 (0.37)	WS 36	53.1 (1.9)
WS 21	1.06 (0.14)	WS 36	1.28 (0.26)	WS 21	52.3 (2.3)
WS 19	1.03 (0.14)	WS 21	1.15 (0.18)	WS 22	49.4 (2.3)
WS 36	1.01 (0.17)	WS 22	0.93 (0.14)	WS 19	45.1 (1.3)
WS 27	0.94 (0.19)	WS 19	0.83 (0.10)	WS 27	42.4 (1.6)
WS 22	0.90 (0.13)	WS 27	0.65 (0.12)	WS 37	41.0 (0.8)

Standard errors of the means are in parentheses; $n = 12$ for each mean. Vertical bars indicate values that are not significantly different; multiple t tests with a protected α of 0.05.

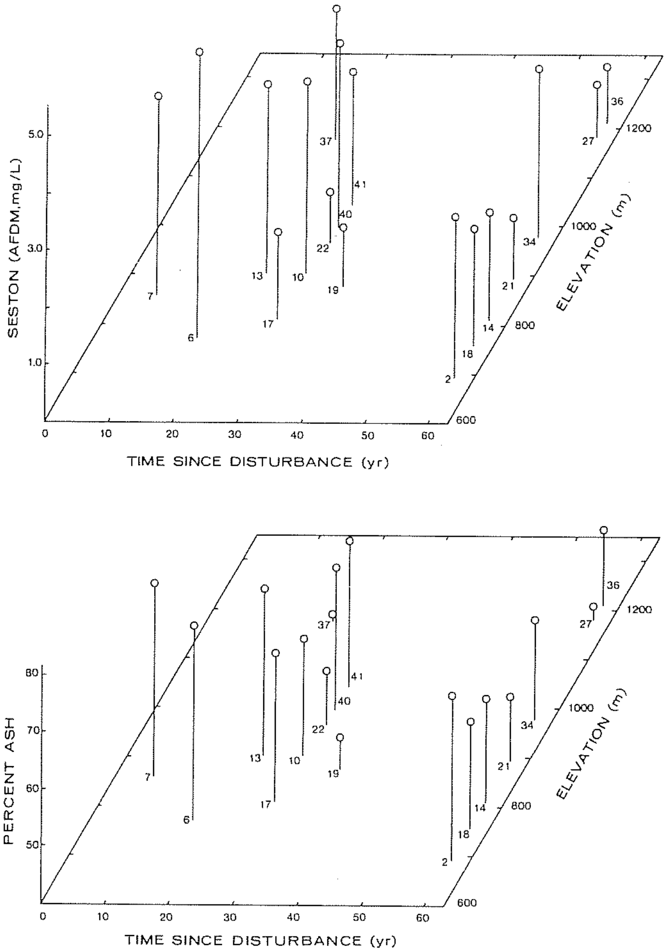

Figure 21.2. Seston concentrations, percent ash, and median particle size vs. time since disturbance and stream elevation. Numbers with each line are watershed numbers. Each point is the mean of 12 samples.

both elevation and time since disturbance (Table 21.3). The range in percent ash was large (41% to 73.5%, Table 21.6) and was highest on WS 6 and WS 7, the low-elevation, recently disturbed watersheds. Lowest percent ash was found on high-elevation watersheds (Table 21.6).

The similar trends for both AFDM and ash suggest that these measurements do not represent different particles types. Rather, we propose that most particles are conglomerates of organic and inorganic material. This proposition is supported by several other measurements discussed below and by observations made while measuring densities and fall velocities. In general, all the particles within one size class from an individual sample exhibited similar densities and fall velocities. The exception was the largest size class (ML), where we sometimes observed high-density sand grains

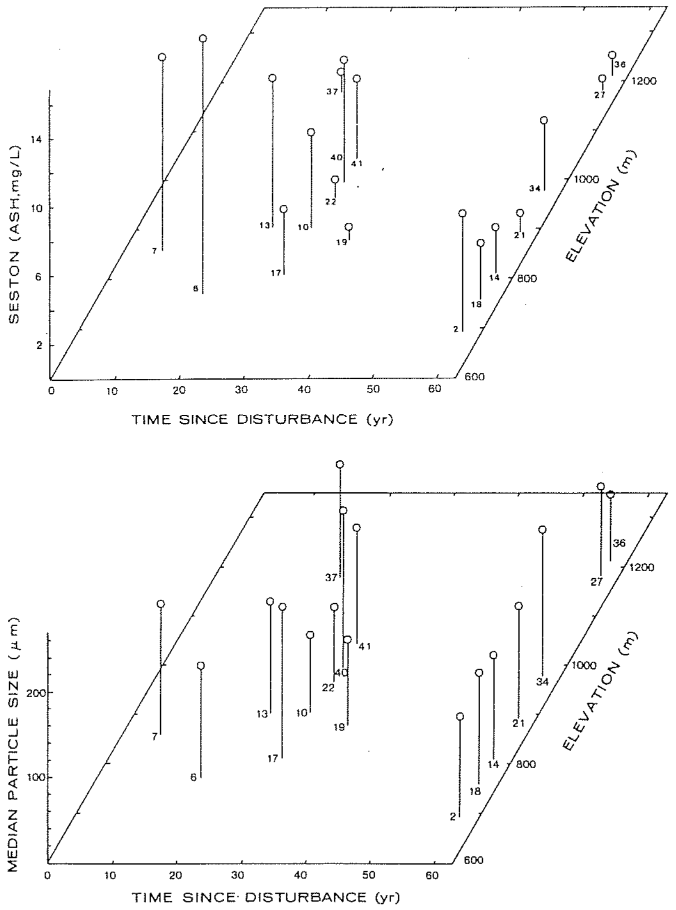

Figure 21.2. *(Continued)*

separating from lower density leaf particles. However, particles in this size range represented only a small fraction of the total seston.

Median particle size was significantly correlated with time since disturbance (Table 21.3). Particle size was generally larger on more recently disturbed watersheds (Figure 21.2). Median particle size ranged from 78 to 183 μm (Table 21.7), which is substantially larger than what has been found for many other streams (e.g., Naiman and Sedell 1979), but similar to other studies of Coweeta streams (Gurtz et al. 1980; Wallace et al. 1982a). Though the general trend with time since disturbance was statistically significant, WS 34, a mid-elevation reference watershed, had larger particles than most other streams (Table 21.7). Also, WS 10, a disturbed, low-elevation watershed, had relatively small particles.

Particle density varied with particle size (Kazmierczak et al., in preparation); larger particles were less dense than smaller particles (ANOVA, $p = 0.0001$; multiple t test

Table 21.7. Median Seston Particle Size

Stream	Median Particle Size (μm)
WS 40	183 (14)
WS 17	179 (21)
WS 34	166 (15)
WS 7	153 (15)
WS 41	137 (7)
WS 37	133 (10)
WS 18	133 (11)
WS 13	133 (9)
WS 6	131 (15)
WS 21	131 (16)
WS 14	122 (7)
WS 2	119 (6)
WS 27	106 (11)
WS 19	104 (7)
WS 10	92 (13)
WS 22	89 (8)
WS 36	78 (10)

Values are means over all dates. $n = 12$ for each mean. Standard errors of the means are in parentheses. Vertical bars indicate values which are not significantly different based on multiple t tests with a protected α of 0.05.

Table 21.8. Mean Density (g/cm³) of Seston Particles

	Particle Size Class			
Stream	ML	S	F	VF
WS 6	1.43 (0.02)	1.49 (0.03)	1.58 (0.11)	1.77 (0.04)
WS 7	1.32 (0.02)	1.45 (0.03)	1.45 (0.01)	1.57 (0.01)
WS 10	1.41 (0.06)	1.44 (0.03)	1.48 (0.04)	1.57 (0.04)
WS 13	1.38 (0.05)	1.57 (0.02)	1.52 (0.02)	1.67 (0.06)
WS 17	1.22 (0.03)	1.26 (0.03)	1.35 (0.04)	1.57 (0.08)
WS 19	1.30 (0.02)	1.39 (0.02)	1.41 (0.04)	1.55 (0.02)
WS 22	1.28 (0.03)	1.43 (0.04)	1.53 (0.07)	1.60 (0.05)
WS 37	1.22 (0.02)	1.37 (0.01)	1.49 (0.04)	1.61 (0.05)
WS 40	1.33 (0.03)	1.23 (0.03)	1.36 (0.02)	1.56 (0.02)
WS 41	1.25 (0.03)	1.31 (0.02)	1.45 (0.01)	1.67 (0.06)
WS 2	1.34 (0.02)	1.34 (0.02)	1.58 (0.04)	1.66 (0.07)
WS 14	1.22 (0.02)	1.39 (0.03)	1.46 (0.01)	1.52 (0.02)
WS 18	1.28 (0.02)	1.36 (0.03)	1.36 (0.04)	1.49 (0.08)
WS 21	1.26 (0.02)	1.33 (0.02)	1.34 (0.01)	1.47 (0.02)
WS 27	1.19 (0.01)	1.30 (0.01)	1.43 (0.01)	1.53 (0.03)
WS 34	1.24 (0.01)	1.27 (0.02)	1.43 (0.02)	1.56 (0.03)
WS 36	1.37 (0.01)	1.45 (0.02)	1.50 (0.02)	1.49 (0.02)

$n = 12$ for each mean. Standard errors of the means are in parentheses.

comparison of means with a protected alpha of 0.05, Table 21.8). For three out of four particle sizes, density decreased with time since disturbance (Table 21.4, Figure 21.3). This trend was partially explained by the increase in percent ash that resulted from disturbance (Table 21.3). Density and percent ash were significantly correlated for the smaller two size classes, though not for the two larger size classes (ML, $p = 0.37$; S, $p = 0.06$; F, $p = 0.05$; VF, $p = 0.004$). However, percent ash accounted for at most 16% of the variance in density, suggesting that other, unmeasured factors may influence particle density.

Fall velocities of particles also varied with particle size; larger particles had faster fall velocities than smaller particles (ANOVA, $p = 0.0001$; multiple t test comparison of means with a protected α of 0.05, Table 21.9). Fall velocities of all four size classes were significantly negatively correlated with time since disturbance (Table 21.5, Figure 21.4). This is consistent with the trend for percent ash, and there was a significant correlation between fall velocity and percent ash for all size classes except the largest (ML, $p = 0.17$; S, $p = 0.0003$; F, $p = 0.001$; VF, $p = 0.0005$).

Our analyses of the effects of date of sample collection, elevation, and time since disturbance on various seston parameters showed many statistically significant relationships (Tables 21.3 through 21.5). However, these three variables only explained (as indicated by coefficient of determination) 21 to 62% of the variance in seston measurements. While some of the variance was certainly measurement error, several unmeasured watershed and stream characteristics could also explain some of the variance. These include such factors as the nature of the streambed material, e.g., some streams have extensive sections of bedrock, and other streams cut through old debris

Table 21.9. Fall Velocity (cm/s) of Seston Particles

	Particle Size Class			
Stream	ML	S	F	VF
WS 6	0.886 (0.104)	0.450 (0.040)	0.199 (0.011)	0.117 (0.008)
WS 7	0.741 (0.138)	0.382 (0.057)	0.146 (0.007)	0.070 (0.006)
WS 10	0.635 (0.078)	0.392 (0.024)	0.168 (0.011)	0.062 (0.003)
WS 13	0.748 (0.080)	0.377 (0.023)	0.185 (0.012)	0.080 (0.004)
WS 17	0.490 (0.030)	0.265 (0.013)	0.137 (0.008)	0.071 (0.004)
WS 19	0.343 (0.047)	0.200 (0.018)	0.110 (0.009)	0.067 (0.004)
WS 22	0.518 (0.029)	0.364 (0.037)	0.187 (0.018)	0.060 (0.003)
WS 37	0.485 (0.062)	0.263 (0.020)	0.135 (0.011)	0.054 (0.004)
WS 40	0.637 (0.077)	0.300 (0.018)	0.153 (0.013)	0.059 (0.005)
WS 41	0.635 (0.076)	0.298 (0.021)	0.134 (0.006)	0.083 (0.004)
WS 2	0.528 (0.042)	0.341 (0.018)	0.190 (0.013)	0.094 (0.005)
WS 14	0.411 (0.039)	0.272 (0.014)	0.119 (0.007)	0.056 (0.006)
WS 18	0.430 (0.060)	0.215 (0.009)	0.129 (0.006)	0.076 (0.003)
WS 21	0.434 (0.042)	0.244 (0.018)	0.112 (0.005)	0.074 (0.006)
WS 27	0.443 (0.052)	0.272 (0.022)	0.098 (0.007)	0.052 (0.003)
WS 34	0.428 (0.035)	0.226 (0.012)	0.127 (0.009)	0.050 (0.002)
WS 36	0.596 (0.045)	0.292 (0.013)	0.128 (0.006)	0.063 (0.003)

$n = 30$ for each mean. Standard errors of the means are in parentheses.

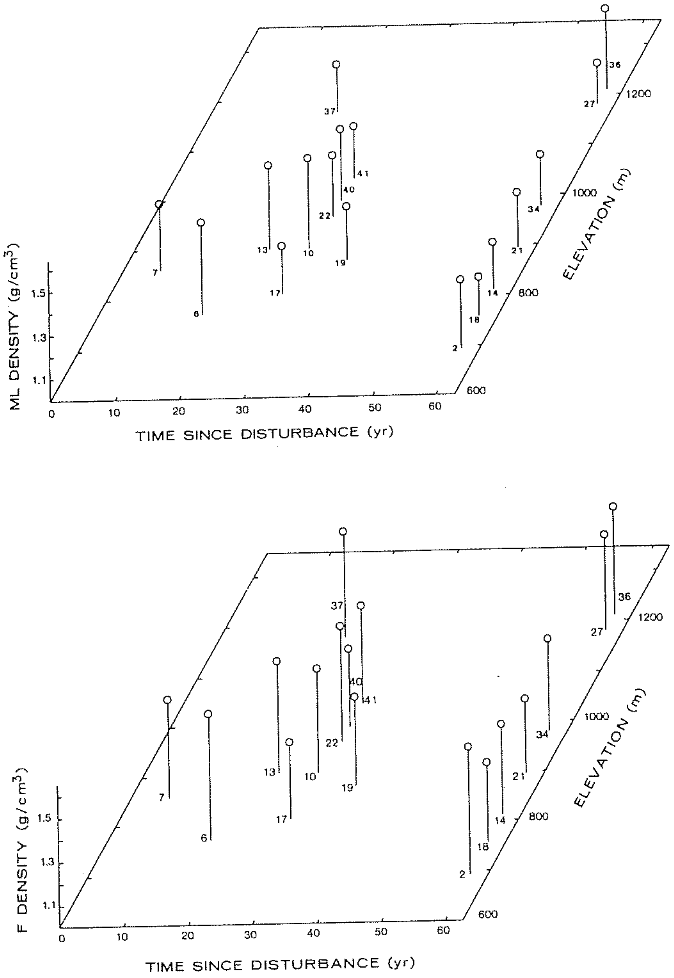

Figure 21.3. Densities of seston in the four larger size classes as functions of time since disturbance and stream elevation. Numbers with each line are watershed numbers. Each point is the mean of 15 samples.

avalanches. Pre-1900 history might also be important, e.g., there was once a crop field on WS 2, WS 7 was heavily damaged by a wind storm in 1835 (Hertzler 1936), and remains of an old logging road can still be seen in sections of the stream on WS 14. We have also not evaluated effects of watershed and stream morphology.

General Discussion

Results of this study show that watershed disturbance increases seston concentrations in streams. Concentrations of both organic and inorganic materials are increased;

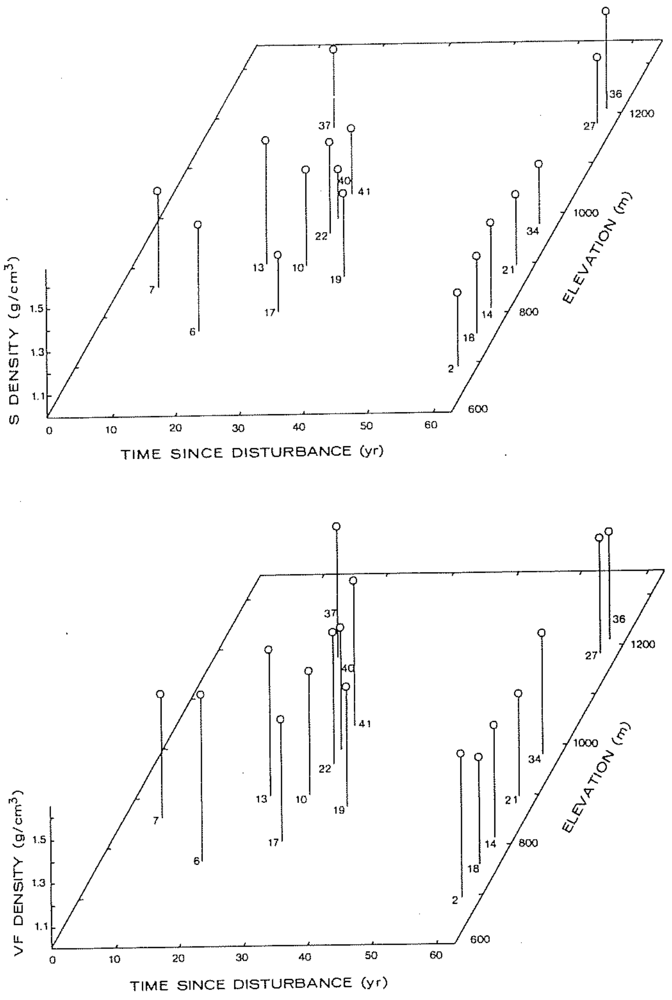

Figure 21.3. *(Continued)*

however, since the inorganic fraction increases more, the percent ash of seston carried by streams draining disturbed watersheds is higher. In addition, the particles are generally larger and have higher density and fall velocity. Depending on the nature of the disturbance, effects on seston concentration and composition may be seen for 30 to 40 years following disturbance.

For commercially logged watersheds, increases in particulate inorganic material might be explained as the transport of sediment that entered the stream during logging. This appeared to be the case for WS 7 for the first few years after logging (Gurtz et al. 1980). Lieberman and Hoover (1948b) and Tebo (1955) attributed the high turbidity of the stream draining WS 10 primarily to material eroded from logging roads and skid trails. However, it is less easy to explain why concentrations of particulate organic

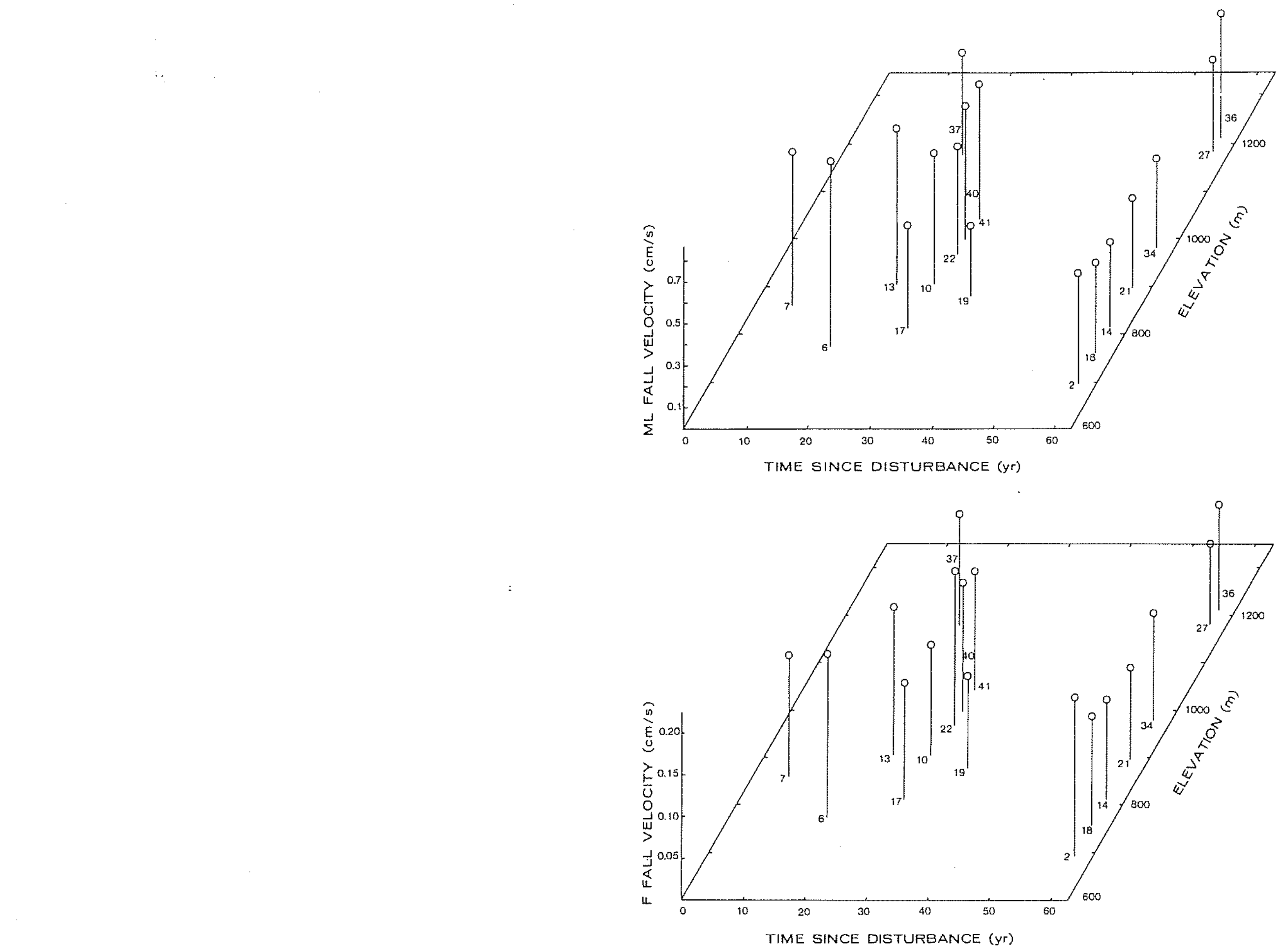

Figure 21.4. Fall velocities of seston vs. time since disturbance and stream elevation. Numbers with each line are watershed numbers. Each point is the mean of 30 samples.

materials are elevated. This might partly be the result of erosion of soil organic materials, but that is probably not a major source of organic seston for more than 2 or 3 years following logging. Also, in-stream biological production of seston should be down, as studies have shown a reduction of invertebrate seston producers (shredders) on disturbed watersheds (e.g., Woodall and Wallace 1972; Molles 1982; Silsbee and Larson 1983; Gurtz and Wallace 1984) and a reduction of allochthonous inputs. Algae may contribute a small amount of organic seston. We suggest that the continued elevated concentrations of both inorganic and organic seston beyond the first few years after logging is primarily due to downcutting of the stream channel and erosion of particles stored in the stream bed. This downcutting can be largely attributed to the decrease in the amount of woody material in the stream (Table 21.1).

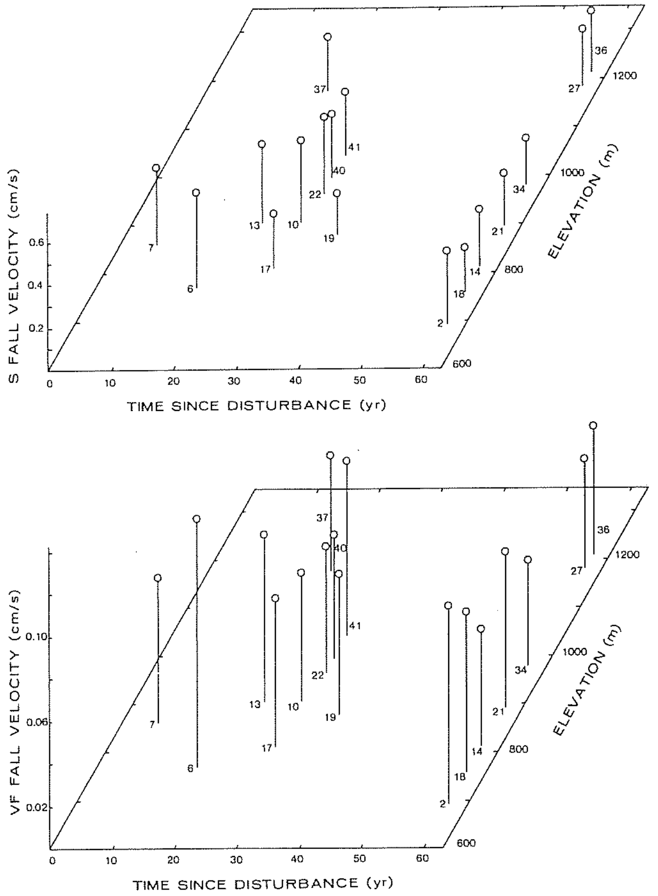

Figure 21.4. *(Continued)*

Seventeen years after disturbance, WS 6 carries very high concentrations of seston (Table 21.6). This is correlated with the absence of woody debris in this stream (Table 21.1). For over 40 years there has been little input of wood to this channel; most old wood has decayed, and there is little to stabilize the stream bed. A similar situation exists on WS 13, except that some slash was left in the stream during the original clear-cutting (1939) and a few of the older logs remain in the channel. Tree regrowth has been rapid and some death of smaller trees is already occurring; in a few years we may begin to see a substantial decline in seston transported by this stream. In other streams, such as WS 7, we may begin to see increasing seston concentrations a few years from now as old debris dams decay and break down.

Based on studies cited above, we assume that much of the seston in reference streams results from biological processing of allochthonous inputs. Our results suggest that more of the seston collected from disturbed watersheds is produced by physical forces. Since our samples were taken during baseflow periods, our results probably minimize effects of disturbance. Samples taken during storms would probably show much greater differences. For example, samples taken from WS 7 and WS 14 during a storm in 1981 showed a greater than sixfold difference in peak seston concentrations—much greater than the threefold difference in prestorm seston concentrations (Webster and Golladay, unpublished data).

Seston carried by small streams eventually reaches larger streams. As shown by studies of WS 10 (Lieberman and Hoover 1948a; Tebo 1955), input from just one small turbid stream can significantly affect the turbidity and invertebrate community of a larger receiving stream. Seston is also an important food resource for many filter feeding invertebrates. The less organic-rich seston of disturbed streams is probably lower quality food than is the seston from the undisturbed streams. Also, because of its higher density and fall velocity, seston from disturbed streams would tend to drop from suspension faster and accumulate in pools of lower gradient streams.

In summary, disturbances to forest ecosystems are reflected in the transport of particulate materials draining these watersheds. In the first few years after disturbance, inputs of sediment directly from the disturbed watershed are probably the major impact. In subsequent years, indirect effects caused by the decline of woody debris dams within the stream are of greater importance. The resulting increased erodibility of the stream channel may cause a stream disturbance that lasts much longer than any observable disturbance of the adjacent terrestrial ecosystem.

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