The Effect of Large Woody Debris on Macroinvertebrate Communities and Epilithon Detritus Composition in a Channelized Headwater Stream

S.A. Ogren
Little River Band of Ottawa Indians
Natural Resources Department
Manistee, Michigan 49660 USA
E-mail: sogren@lrboi.com

and

D.K. King
Biology Department, Central Michigan University
Mt. Pleasant, Michigan 48859 USA

ABSTRACT

Large woody debris (LWD) was placed in a channelized second order reach of Cedar Creek, Michigan, to determine if its presence would alter substrate composition and macroinvertebrate community. Pre- and post-treatment cores were analyzed for macroinvertebrate composition, substrate particle size, epilithon, and detritus development. The addition of LWD in experimental sections increased the number of macroinvertebrates by 19% and total biomass by 10%. Species richness and the Shannon-Wiener diversity index increased. Inorganic substrate composition and epilithon development were not altered; however, course particulate organic matter retention was significantly increased in larger particle size classes (> 4 mm).

INTRODUCTION

Many studies have shown the primary source of energy in headwater streams is allochthonous input from riparian vegetation (Nelson and Scott 1962, Minshall 1967, Hynes 1970, Fisher and Likens 1972, Petersen and Cummins 1974, Cummins 1977, Vannote et al. 1980, King and Cummins 1989). Allochthonous input is an important source of course particulate organic matter (CPOM >1 mm) in the form of leaves and woody debris (Minshall 1967, Fisher and Likens 1973, Bilby and Likens 1980, Hall et al. 2000). Macroinvertebrates utilize energy resources stored in retained leaves. Leaf retention is a function of the probability of a particle to become trapped on a channel obstruction and the relative frequency of the obstructions (Young et al. 1978). An increase in debris dams (local aggregations of woody debris) increases retention (Speaker et al. 1984, Smock et al. 1989, Stricker 1997, Jacobson et al. 1999).

Large woody debris (LWD) can affect retention of CPOM, channel morphology and bank stability by changing erosion patterns and water velocities in specific areas. LWD alters habitat availability, hydraulic heterogeneity, sediment stability, bed topography, bank erosion, and channel width (Trotter 1990, Benke and Wallace 1990, Smith et al. 1993, Uzarski 1995). LWD can also alter channel scour and formation depending on its orientation in the stream bed (Boehne and Wolfe 1986, Collier and Baillie 1999). Because LWD affects substrate embeddedness and scour, changes in the epilithon and detritus composition of the sediment may also be affected.

As areas of CPOM retention expand, abundance and biomass of shredders increase (Hildrew et al. 1991, Prochazka 1991). When woody debris is removed from a headwater system, a decrease in macroinvertebrate abundance and biomass has been noted (Wallace et al. 1999).

Sinuosity is an important factor in dissipating stream energy, reducing erosion, and increasing retention (Heede 1972, Beschta 1979, Keller and Swanson 1979, Bilby 1981, Bilby 1984). Through channelization, streambeds are altered to increase drainage capacity of an area. Dolloff (1983) stated that availability and variety of refugia for aquatic organisms is greatly reduced in channelized streams. Tuchman and King (1993) found that addition of bricks with leaf packs provided both refugia and a food source for macroinvertebrates. Channelized streams tend to have a homogeneous substrate. Streams with heterogeneous substrates have higher species richness of macroinvertebrates (Beisel et al. 2000, Nicolas et al. 2000).

We hypothesized that addition of LWD to three channelized sections of Cedar Creek would enhance CPOM retention thus increasing macroinvertebrate abundance, diversity, and biomass. Additionally, detrital accumulation and particle size of substrate would shift, resulting in an increase in epilithon development.

METHODS

Cedar Creek in Isabella County, Michigan (N43.5674, W-84.9021) is a second order stream originating from small springs. It drains a 1,400-hectare watershed, and flows into the main branch of the Chippewa River. The first 2.8 km of Cedar Creek runs through pastureland and then enters a white cedar and mixed hardwood woodland for the last 2 km of its length. Cedar Creek was initially channelized in 1922 and was dredged in 1954 to support agriculture (Scott 1982). The study reach was approximately 4 m wide, with few bends or meanders and with an average depth of 0.21 m and average velocity of 0.34 m/s. The banks of the study site varied in height from 0.5 to 3 m and had relatively steep slopes of 45-60 degrees. There was approximately 50% canopy cover over the study site. Three reaches with similar substrate type (riffles with sand-impacted cobble) and flow regime were chosen for study sites. Each site was

Table1. Mean percent composition of inorganic particle size in control (n = 3) and experimental (n = 3) sections of Cedar Creek, Michigan.

	Control			Experimental		
	%Composition	SE	%CV	%Composition	SE	%CV
Pre-treatment (Spring 1998)						
19 mm	15.21	3.11	15.61	13.06	2.76	18.65
4 mm	26.12	1.16	3.61	24.06	3.31	20.08
1 mm	17.84	2.29	16.03	19.33	0.38	10.22
500 µm	28.68	2.14	8.48	34.55	7.27	16.29
250 µm	10.66	3.55	48.80	7.61	2.44	19.43
125 µm	1.16	0.37	31.91	1.20	0.21	18.38
63 µm	0.32	0.02	16.52	0.18	0.07	29.39
Post-treatment (Spring 1999)						
19 mm	11.72	6.02	35.61	18.72	6.64	33.55
4 mm	19.93	7.84	27.79	23.65	3.78	12.11
1 mm	16.50	2.43	16.94	14.76	2.76	23.14
500 µm	40.17	10.15	32.87	29.05	9.08	31.93
250 µm	10.37	3.52	42.36	12.17	2.32	33.72
125 µm	1.12	0.35	30.95	1.47	0.30	19.18
63 µm	0.18	0.09	42.12	0.17	0.02	10.22
Post-treatment (Fall 1999)						
19 mm	22.34	4.45	23.25	17.68	14.33	50.23
4 mm	21.03	2.03	6.55	22.43	13.20	54.03
1 mm	15.04	3.99	28.12	12.47	1.48	11.24
500 µm	29.22	2.80	10.67	33.75	1.28	4.95
250 µm	10.66	2.92	36.02	12.56	3.19	46.96
125 µm	1.47	0.12	9.85	0.99	0.34	31.56
63 µm	0.24	0.02	10.68	0.12	0.01	7.66

9 m long and contained a control area, 2 m in length, followed by a 5 m independent stretch and then a 2 m experimental section enhanced with LWD. The study stream reach totaled 186 m in length.

Baseline macroinvertebrate abundance and sediment composition (% particle size and ash free dry mass (AFDM) of detritus and epilithon) estimates of six riffle sections were sampled in May of 1998. LWD was added to the three experimental sections in the summer of 1998. At the three experimental sites, two 10 cm diameter, 1 m long hardwood logs were installed 0.5 m from each bank, and a third was placed in the center of the stream. These logs were anchored to the substrate with steel rods and positioned with their long axis perpendicular to stream flow. Macroinvertebrate and sediment samples were taken again in May and October of 1999.

Five sediment cores (25.4 cm diameter, 10 cm deep) were collected from control and experimental sections in May and October 1999. Locations were randomly determined prior to sampling by preparing a grid of the 2 m length of stream. Cores were subsampled and macroinvertebrates were sorted under magnification, identified to lowest possible taxon (Merritt and Cummins 1984, McCafferty 1981), and placed into functional feeding groups according to Merritt and Cummins (1984). Individuals were oven dried at 60°C to a constant weight, weighed, and ashed at 550°C to determine ash free dry mass (AFDM).

In 1998 five cores from each experimental area were collected and frozen for later particle sizing and AFDM calculations. Epilithon and detritus samples were particle sized using brass sieves. The organics were elutriated from the inorganics and both components were particle sized separately to determine the substrate composition (King 1982). The inorganic substrate was sorted into 19 mm, 4 mm, 1 mm, 500 µm, 250 µm, 125 µm, and 63 µm size classes (modified Wentworth), percent volume was calculated, and AFDM was determined.

The Shannon-Wiener diversity index (H') and species richness were calculated for macroinvertebrates. A paired t-test was utilized to determine if differences between control and experimental sites were significant (Zar 1999). The baseline data were also analyzed using the paired t-test to establish that the sites were originally similar. Inorganic substrate particle size was analyzed using a paired t-test with a Bonferoni correction ($p = 0.05/7$).

RESULTS AND DISCUSSION

Substrate composition

The pre-treatment size class distribution of the sediment showed no significant differences in composition for any of the size classes ($p > 0.05$). Spring and fall of 1999 indicated no significant difference in particle size distribution for either control or experimental sections. The inorganic substrate was not significantly altered by the addition of LWD ($p > 0.05$) in this time period. However, the sediment did show a higher variability after log placement (increased CV%), which indicated a change in heterogeneity (Table 1).

In 1998 the mean total organic component of the substrate (epilithon and detritus) made up less than four percent (2,971.4 g/m^2 AFDM) of the total substrate in both control and experimental sections of the study reach ($p > 0.05$) (Table 2). Post-treatment organic matter composition increased (spring 5.8%; fall 7.7%). Though these numbers were not statistically significant ($p > 0.05$) they indicate slightly increased organic matter retention and storage in Cedar Creek after placement of the LWD.

Cedar Creek estimates of organic matter in the control and treatment areas in spring 1998 were 2,655.9 g AFDM/m^2 ($\pm$331.3 SE) and 3,286.9 g AFDM /m^2 ($\pm$1,331.4 SE) respectively (Table 2). Though not significant ($p > 0.05$) post-treatment, the experimental area increased to 4,500.0 g AFDM /m^2 ($\pm$503.8 SE) in the fall of 1999. Throughout the study Cedar Creek estimates were low in comparison to estimates reported for other headwater streams, which ranged from 3,360 g AFDM /m^2 to 5,825 g AFDM /m^2 (Bilby and Likens 1980, King 1982, Smock et al. 1989, Hax and Golladay 1998). The experimental manipulation of logs increased organic matter content closer to reported levels in natural streams.

SE). Post-treatment there was no significant difference in the total mass of the epilithon in experimental sections ($p > 0.05$). The range of values for Cedar Creek fell within the range of values determined for a shaded first order reach in Augusta Creek, Michigan (1,480 g/m^2 to 5,038 g/m^2) (King 1982). The values in Cedar Creek demonstrate the importance of the epilithon in the energy base of the system.

Pre-treatment, the larger particle size classes (19 and 4 mm) had the highest amounts of epilithon development (25-48%). The control and experimental areas showed no significant differences ($p > 0.05$) in spring of 1998 (Fig. 1). Post-treatment in spring 1999, there was a significant increase in AFDM of experimental sections in the 19 mm ($p = 0.0074$) and 4 mm ($p = 0.0057$) particle sizes. This increase was also significant in fall of 1999 ($p = 0.0026$) in the 4 mm particle size. This concurs with studies which indicated the highest amount of algal biomass (85%) were associated with substrates larger than 4 mm (McConnell and Sigler 1959, Marker 1976, King 1982, King and Cummins 1989). When larger particle sizes are available, greater epilithon mass will develop. The addition of LWD had a positive impact on epilithon development.

1998 pre-treatment control and experimental sections were not significantly different (Table 2). Post-treatment the mean AFDM of the detritus increased from 122.5 g/m^2 (±93.7 SE) in spring 1998 experimental sections to 1,081.3 g/m^2 (±535.7 SE) spring 1999 and 1,326.2 g/m^2 (±364.5 SE) in fall 1999, this is greater than a tenfold increase. The experimental sections in the

Table 2. Organic mean, standard error, percent coefficient of variance and percent epilithon and detritus pre- and post-treatment in Cedar Creek, Michigan. * indicates significant ($p < 0.05$) difference from pre-treatment composition.

	Pre-treatment	Post-treatment	
Component	Spring 1998	Spring 1999	Fall 1999
Control			
Total Organic			
AFDM/m^2	2655.9	2321.9	2624.8
SE	331.4	760.1	344.8
%CV	12.5	32.7	13.1
Epilithon			
AFDM/m^2	2542.0	2092.0	2400.1
SE	267.9	896.7	350.9
%CV	10.5	42.9	42.9
% of Organic	80.8	90.1	91.4
Detritus			
AFDM/m^2	114.0	229.9	224.7
SE	63.8	169.5	25.7
%CV	56.0	73.7	73.7
% of Organic	19.2	9.9	8.6
Experimental			
Total Organic			
AFDM/m^2	3286.9	4110.8	4500.0
SE	1331.4	1982.7	503.8
%CV	40.5	48.2	11.2
Epilithon			
AFDM/m^2	3164.4	3029.5	3173.8
SE	1239.0	1935.6	326.9
%CV	39.2	63.9	63.9
% of Organic	93.1	73.7	70.5
Detritus			
AFDM/m^2	122.5	*1081.3	*1326.3
SE	93.7	535.7	364.5
%CV	76.5	49.5	49.5
% of Organic	7.6	26.3	29.5

spring and fall of 1999 were significantly higher ($p = 0.0327, 0.0348$) than control areas.

Cedar Creek exhibited a significant increase in the detrital component of the organic portion of the substrate. Examining the particle size distribution of the detritus revealed a significant ($p < 0.05$) difference after treatment (Fig. 2). In the spring of 1998 there were no significant differences in partitioning of size classes between the control and experimental sections. Detrital retention was primarily in the form of larger particle sizes (19 mm, 4 mm, and 1 mm) in control and experimental sections. One year later, after addition of LWD, there was an overall increase in detrital material in experimental sections and a significant increase in large particulate substrate in both spring (19 mm $p = 0.0217$ 4 mm, $p = 0.0016$) and fall (19 mm $p = 0.0042$, 4 mm $p = 0.0347$, 1 mm $p = 0.0439$). These results reflect the retention capacity of LWD. The increase in the 1 mm particle size in the fall reflects the storage and processing of the CPOM retained in the spring.

LWD has been directly linked to the retention and storage of organic matter (Speaker et al. 1984, Lamberti and Berg 1995, Haapala and Muotka 1998, Wallace et al. 1999). The results of the study on Cedar Creek indicated retention and storage of CPOM increased within the sediment surrounding the experimental area as demonstrated by the random experimental sampling design.

When AFDM of epilithon was compared to AFDM of detritus there was a shift post-treatment (Table 2). The percent composition of detritus in the experimental sections increased

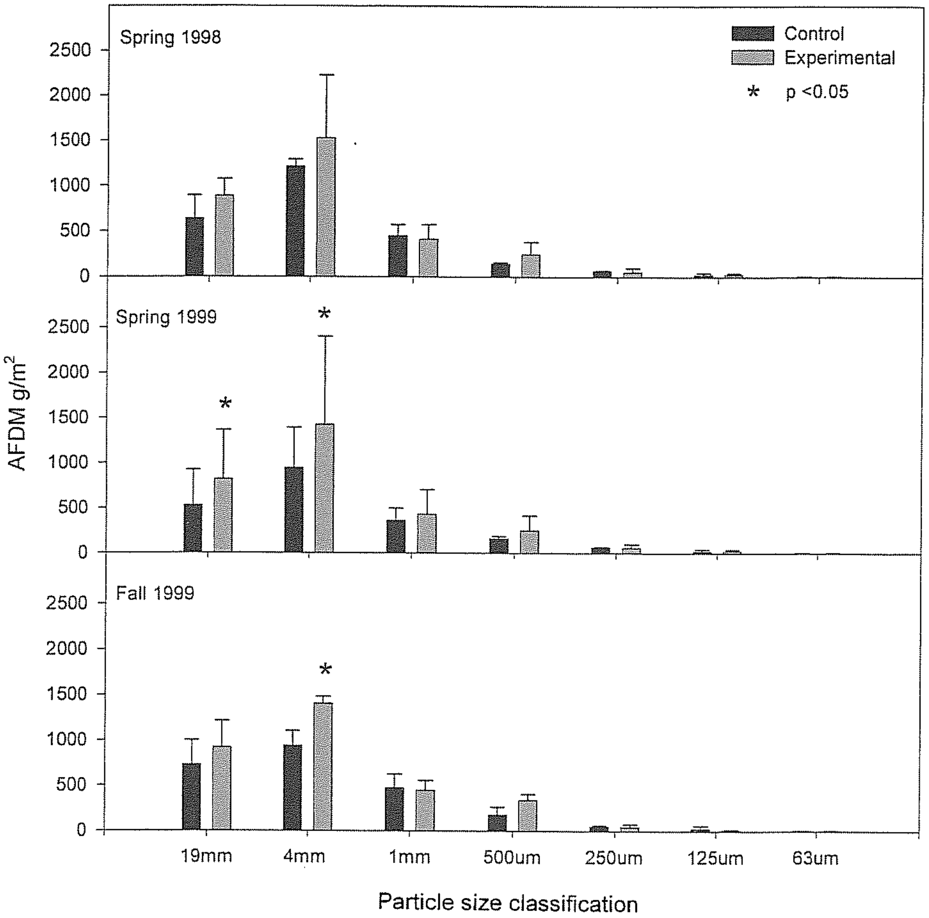

Figure 1. Epilithon development (AFDM g/m^2) analyzed by particle size in control and experimental sections of Cedar Creek, Michigan.

from spring 1998 (7.6 %) to the spring of 1999 (26.3 %) and remained at an elevated level in the fall of 1999 (29.5%). Even though there was a particle size shift in epilithon development the overall epilithon values remained constant throughout the study in control and experimental areas. Detrital composition increased significantly in experimental sections post-treatment. This indicated that the increase in organic matter was primarily due to an increase in detritus that was being retained and stored in the substrate, not an overall increase in epilithon development. The increase in post-treatment epilithon development on larger size classes indicates more stable large sediment. This increase in organic matter retention and shift in composition indicated that addition of LWD significantly impacted CPOM storage and retention.

Macroinvertebrate composition

Macroinvertebrate abundance in spring 1998, pre-treatment, ranged from 493.0 (± 93.8 SE) to 906.6 (± 206.6) individuals/m^2 (Fig. 3). The control and experimental sections demonstrated no significant difference ($p > 0.05$) in all three sampling sites.

In 1999 all experimental sections showed a significant difference in the total number of macroinvertebrates ($p < 0.05$) (Fig. 3). Spring 1999 experimental sections all exceeded 3,000 macroinvertebrates/m^2 and were significantly higher (mean = 3,617.7/m^2) than control sections (mean = 1,188.7/m^2) ($p = 0.0072$). Fall of 1999 experimental sections (mean = 3,662.5/m^2) were also significantly higher than control sections (mean = 988.8/m^2)($p = 0.0071$). These data indicate a continued increase in macroinvertebrate abundance through spring and fall 1999.

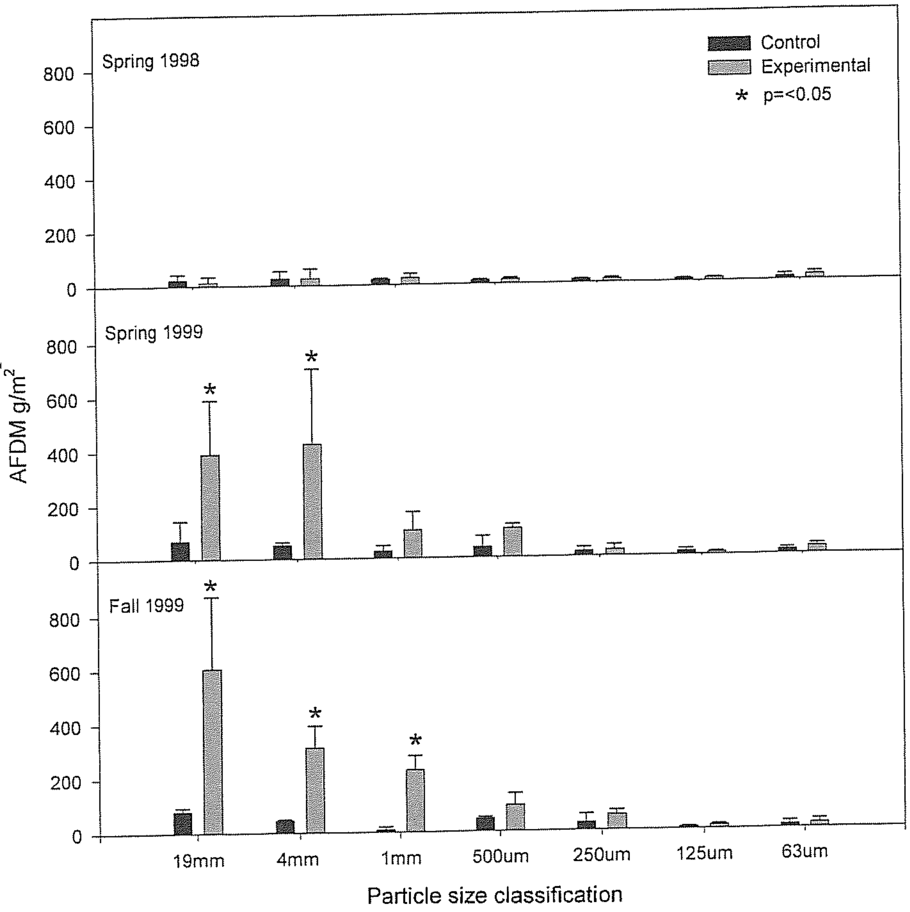

Figure 2. Detritus accumulation (AFDM g/m^2) in sediment of control and experimental sections in Cedar Creek, Michigan.

Low abundance in 1998 reflected a poor macroinvertebrate population, which may be attributed to channelized stream morphology, sand substrate, organic matter retention, or a combination of factors. When compared to other streams, 705.1 (± SE 123.6) macroinvertebrates/m^2 is very low (Minshall et al. 1983, Smock et al. 1989, Hilderbrand et al. 1997, Wallace et al. 1999, Li et al. 2001). Macroinvertebrate values similar to those found in the experimental sections in 1999 are much more common (Spring = 3617.7 ± 551.5 SE; Fall = 3662.5 ± 500.3 SE) for Michigan streams. Minshall et al. (1983) reported that in four Michigan streams (first-third order) the total number of macroinvertebrates, regardless of season, was greater than 2,000/m^2. Cedar Creek experimental sections were above this value after addition of LWD.

The mean total biomass of macroinvertebrates in the spring of 1998 control sections was 119.8 mg/m^2 (± 17.03 SE). The control and experimental sections showed no significant difference ($p > 0.05$) in all three sampling sites (Fig. 3). Post-treatment the total biomass of macroinvertebrates in the spring of 1999 control sections remained constant (mean = 133.2 mg /m^2 ± 19.2 SE). In the spring and fall 1999 experimental sections the biomass increased significantly (spring 3,258.6 ± 439.7 SE, p = 0.0056; fall 3,720.0 ± 523.3 SE, p = 0.0057). Pre-

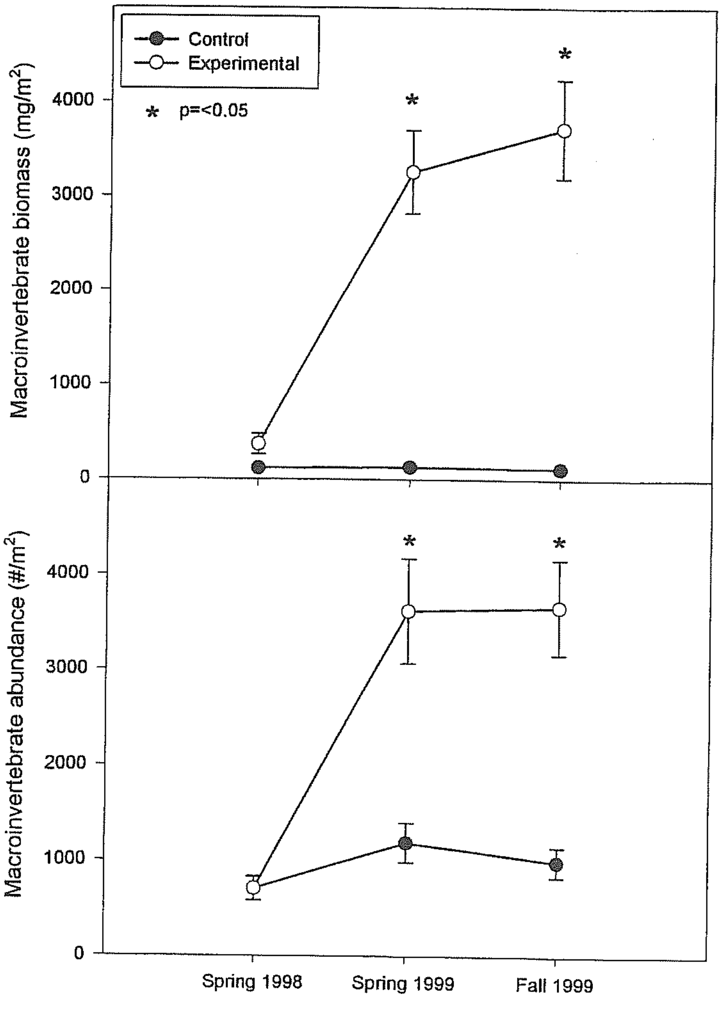

Figure 3. Mean abundance (#/m^2) and biomass (mg/m^2) of macroinvertebrates in control and experimental sections in Cedar Creek, Michigan.

treatment, the majority of biomass was attributed to Hydropsychidae in the control sections (41.5 mg/m^2 ± 38.1 SE), and Limnephilidae in the experimental sections (245.6 mg/m^2 ± 45.3 SE). Even though Chironomidae were dominant when considering total numbers, their small size minimized the total biomass. In spring of 1999 the control section biomass was dominated by Amphipods (60.6 mg/m^2 ± 34.5 SE), while the experimental section was still dominated by Limnephilidae (1,559.2 mg/m^2 ± 763.6 SE). There was greater than a five fold increase in biomass of Limnephilidae in experimental sections. As a shredder, this correlates with increased detritus. In fall of 1999 the biomass in control sections was composed predominately of Amphipods (38.0 mg/m^2 ± 32.9 SE) while the family Hydropsychidae composed the majority of biomass (2,093.5 mg /m^2 ± 118.9 SE) in experimental sections. Post-treatment biomass found in Cedar Creek was increased by the addition of LWD, and was closer to ranges reported for other headwater streams (300-1,815 mg/m^2) (Smock et al. 1989, Hilderbrand et al. 1997, Wallace et al. 1999).

The macroinvertebrate community complexity was determined as a function of total number and diversity of taxa. Pre-treatment mean total number of taxa was 6.7/m^2 (± 1.5 SE) in control areas and 6.3/m^2 (± 1.5 SE) in the experimental areas (Table 3). In the spring of 1999 the average number of taxa was 4.7/m^2 (±1.5 SE) in control areas and 13.0/m^2 (±1.7 SE) in experimental areas. There was an increase in taxa richness in the experimental areas. That trend continued in the fall of 1999 when mean number in control areas was 5.3/m^2 (±2.1 SE) and experimental areas had a mean of 10.7 /m^2 (± 0.6 SE) macroinvertebrate taxa.

The Shannon-Wiener diversity index revealed an increase in experimental sections after log placement (Table 3). Pre-treatment H' values were 1.596 and 1.591 in the control and experimental areas respectively, while post-treatment they increased in the spring (1.629) and fall (1.874) experimental areas. The H' values were consistently low; however, in another sand-impacted headwater stream in Michigan, H' values were similar to Cedar Creek values (Alexander 1998). Macroinvertebrate diversity, biomass, and density are improved in heterogeneous environments composed of numerous substrates with high patchiness (Allan 1995, Minshall 1984, Beisel et al. 2000). Cedar Creek contained homogeneous substrates prior to log placement and a slightly more heterogeneous habitat after experimental additions, which provided for increased diversity.

When the macroinvertebrate assemblages were evaluated as number/m^2 of organisms in each functional feeding group no significant differences ($p>0.05$) were found pre-treatment (Fig. 4). Post-treatment, spring 1999, the control and experimental sections had significant differences (shredder $p = 0.0223$; collector $p = 0.0096$; predator $p = 0.0431$; scraper $p = 0.0414$) in total number. The mean of the experimental sections increased by 50 % in the total number of shredders, 33% collectors, 4% predators and 6% scrapers. The fall 1999 data indicated the same trend with significant differences in the shredders ($p = 0.0352$), collectors ($p = 0.0164$) and predators ($p = 0.0446$).

Table 3. Mean taxa richness and Shannon-Wiener diversity index for control and experimental sections pre- and post-treatment in Cedar Creek, Michigan.

	Pre-treatment	Post-treatment	
Metric	Spring 1998	Spring 1999	Fall 1999
Control			
Total Taxa	6.7	4.7	5.3
SE	1.5	1.5	2.1
%CV	22.9	32.7	39.6
S-W index	1.596	1.415	1.498
Experimental			
Total Taxa	6.3	13.0	10.7
SE	1.5	1.7	0.6
%CV	24.1	13.3	5.4
S-W index	1.591	1.629	1.874

Although the total number of macroinvertebrates in the functional groups increased, when compared by percent composition there was no community shift. In Cedar Creek both pre- and post-treatment, shredders accounted for more than 10% of the macroinvertebrates by number. Post-treatment the number of shredders increased dramatically; however, the collectors also increased. This increase in both functional groups diluted an alteration in community structure based on proportion of functional groups. Placement of LWD increased total number and biomass in the experimental sections proportionally similar to pre-treatment.

The family Chironomidae had the highest numbers throughout Cedar Creek in the three sample seasons (Table 4). In both experimental and control sections pre- and post-treatment communities were composed of over 50 % Chironomidae by density. This is common in most aquatic communities (Merritt and Cummins 1984). In this study they were not identified below the family level, and it was assumed that Chironomidae represented collectors. The Amphipod *Gammarus sp.* (10.9% - 23.3%) and Oligochaeta (9.3%-14.9%) were the next most dominant taxa and are common in headwater streams (McCafferty 1981).

The addition of new taxa, even in small numbers, throughout the study indicated a change in community composition that is indicative of higher quality habitat. Post-treatment, in the spring of 1999 three new scrapers (Molannidae, Heptaganeidae, and Glossosomatidae), two predators (Corydalidae and Ceratopogonidae), and two collectors (Baetidae and Isonychiidae) were sampled in the experimental areas (Table 4). This was an increase of seven additional taxa. The addition of scrapers resulted from a shift to a larger particle size substrate and epilithon development as noted previously (Fig. 1).

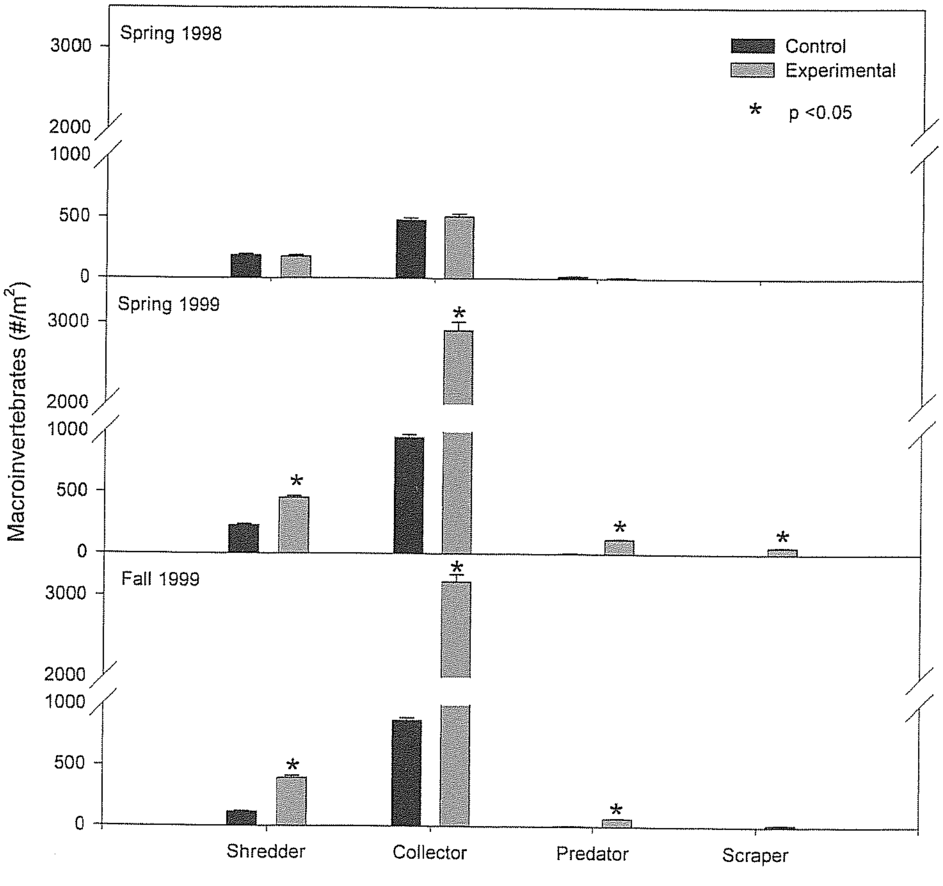

Figure 4. Macroinvertebrate abundance divided into functional feeding groups in control and experimental sections in Cedar Creek, Michigan.

In fall of 1999 there was an increase in Hydropsychidae from 4.3% (control) to 9.1% (experimental) of the total number of macroinvertebrates. Members of the family Hydropsychidae are collectors (Merritt and Cummins, 1984). This increase coincided with an accumulation of detritus in the sediment in experimental sections that supported higher densities of collectors and detritivores (Fig. 2).

In fall of 1999, new taxa found in the experimental sections were Simuliidae, Philopotamidae, and Ephemerellidae (Table 4). Ephemerellidae was also observed in the control sections. The higher diversity in the experimental sections indicated a change in habitat availability and suitability. Habitat heterogeneity was created by addition of LWD to a previously homogeneous system and supported greater macroinvertebrate diversity.

Substrate and habitat have played important roles in structuring stream macroinvertebrate communities in other similar streams. In a small woodland stream in a beech-alder forest in

Table 4. Macroinvertebrate composition as percent total number/m^2 in control and experimental sections pre- and post-treatment in Cedar Creek, Michigan.

	Control			Experimental		
		Post-treatment			Post-treatment	
Taxon	Sp1998	Sp1999	Fall 1999	Sp1998	Sp1999	Fall 1999
Oligochata	2.26	7.08	14.89	2.26	4.80	9.33
Crustacea						
Amphipoda						
Gammaridae						
Gammarus sp.	23.31	18.58	1.60	15.79	10.90	3.30
Insecta						
Ephemeroptera						
Ephemerellidae	0.00	0.00	0.53	0.00	0.00	1.15
Isonychiidae	0.00	0.44	0.00	0.00	0.29	0.00
Heptageniidae	0.00	0.00	0.00	0.00	0.29	0.00
Baetidae	0.00	0.44	0.00	0.00	1.16	0.72
Plecopetera						
Perlodidae	2.26	0.00	0.00	0.75	1.31	0.00
Coleopetera						
Elmidae	2.26	1.33	1.06	7.52	4.51	5.31
Megaloptera						
Corydalidae						
Chauliodes sp.	0.00	0.00	0.00	0.00	0.58	0.72
Diptera						
Tipulidae						
Tipula sp.	0.00	0.00	0.53	1.50	0.15	0.14
Antocha sp.	2.26	0.88	4.26	3.01	1.45	3.35
Simulidae	0.00	0.00	0.00	0.00	0.00	0.43
Ceratopogonidae	0.75	0.00	0.00	0.00	0.58	0.57
Chironomidae	55.64	69.91	68.09	60.90	63.52	61.61
Tabanidae	0.75	0.00	0.00	0.75	1.02	0.29
Tricopetera						
Hydropsychidae	8.27	1.33	4.26	3.01	5.23	9.05
Philopotamidae	0.00	0.00	0.00	0.00	0.00	2.15
Glossosomatidae						
Glossosoma sp.	0.00	0.00	0.00	0.00	0.73	0.00
Limnephilidae	2.26	0.00	4.26	4.51	2.18	1.44
Brachycentridae	0.00	0.00	0.53	0.00	0.00	0.00
Molannidae						
Molanna sp.	0.00	0.00	0.00	0.00	1.31	0.43

Sweden, Malmqvist et al. (1978) found scrapers dominant in the upper reaches ($2,056/m^2$), while in the sandy lower reaches, which had a very homogeneous substrate, Chironomidae and Oligochaeta were dominant ($9,181/m^2$). This correlates with the findings in Cedar Creek post-treatment.

Stream order, land use, sedimentation, substrate, and allochthonous inputs are factors influencing community structure (Allan 1995). Anderson and Sedell (1979) stated that first and second order streams have the greatest proportional amount of wood habitat where few grazers many collectors, and moderate amounts of shredders would be expected. Even with channelization and morphological changes associated with the modification in Cedar Creek after enhancement with LWD, macroinvertebrate community structure was similar to that predicted by Anderson and Sedell (1979). Cedar Creek research supports the importance of instream retention mechanisms to community structure.

ACKNOWLEDGMENTS

We thank the Central Michigan University College of Science and Technology for financial support of this project. We thank S. McNaught, D. Wujek, J. Brown and S. Noffke for their assistance throughout this project.

LITERATURE CITED

Alexander, G., R. Brown, D. Cozad, and R. King. 1998. Comprehensive surface resource assessment Big South Branch Pere Marquette River. Unpublished Report. Great Lakes Fisheries Trust. 37 pp.

Allan, J. D. 1995. Stream ecology: structure and function of running waters. Chapman and Hall Publishing Company. London. 388 pp.

Anderson, N. H. and J. R. Sedell. 1979. Detritus processing by macroinvertebrates in stream ecosystems. Ann. Rev. Entomol. 24:351-377.

Benke, A. C. and J. B. Wallace. 1990. Wood dynamics in coastal plain blackwater streams. Can. J. Fish. Aquat. Sci. 47:92-99.

Bescheta, R. L. 1979. The suspended sediment regime of an Oregon coast range stream. Watr. Res. Bull. 15:144-154.

Beisel, J. N., P. P Usseglio, and J. C. Moreteau. 2000. The spatial heterogeneity of a river bottom: A key factor determining macroinvertebrate communities. Hydrobiologia 423:163-171.

Bilby, R. E. 1981. Role of organic debris dams in regulating the export of dissolved and particulate matter from a forested watershed. Ecology 62:1234-1243.

Bilby, R. E. 1984. Removal of woody debris may affect stream channel stability. J. For. 8:609-613.

Bilby, R. E. and G. E. Likens. 1980. Importance of organic debris dams in the structure and function of stream ecosystems. Ecology 61:1107-1113.

Boehne, P. L. and J. R. Wolfe. 1986. Use of explosives to add large organic debris to streams. N. Am. J. Fish. Manage. 6:599-600.

Collier, K. J., and B. R. Baillie. 1999. Decay state and orientation of *Pinus radiata* wood in streams and riparian areas of the central North Island. N. Z. J. For. Sci. 29:225-235.

Cummins, K. W. 1977. From headwater streams to rivers. Am. Biol. Teacher. pp 305-312.

Dolloff, C. A. 1983. The relationship of wood debris to juvenile salmonid production and microhabitat selection in small southeast Alaska streams, Ph.D. Dissertaion. Montana State University. Bozeman, Montana. 100 pp.

Fisher, S. G. and G. E. Likens. 1972. Stream ecosystem: organic energy budget. Bioscience 22:33-35.

Fisher, S. G. and G. E. Likens. 1973. Energy flow in Bear Brook, New Hampshire: an integrative approach to stream ecosystem metabolism. Ecol. Monogr. 43:421-439.

Haapala, A. and T. Muotka. 1998. Seasonal dynamics of detritus and associated macroinvertebrates in a channelized boreal stream. Arch. Hydrobiol. 142:171-189.

Hall, R. O. J. B. Wallace, and S. L. Eggert. 2000. Organic matter flow in stream food webs with reduced detrital resource base. Ecology 81:3445-3463.

Hax, C. L. and S. W. Golladay. 1998. Flow disturbance of macroinvertebrates inhabiting sediments and woody debris in a prairie stream. Am. Mid. Nat. 139:210-223.

Heede, B. H. 1972. Influences of a forest on the hydraulic geometry of two mountain streams. Water Resource Bulletin 8:523-530.

Hilderbrand, R. H., D.A. Lemly, C. A. Dolloff, and K. L. Harpster. 1997. Effects of large woody debris placement on stream channels and benthic macroinvertebrates. Can. J. Fish. Aquat. Sci. 54:931-939.

Hildrew, A.G., D.K. Dobson, A. Groom, A. Ibbotson, J. Lancaster, and S. D. Rundle. 1991. Flow and retention in the ecology of stream invertebrates. Verh. Internat. Verein. Limnol. 24:1742-1747.

Hynes, H.B N. 1970. The ecology of running waters. Liverpool University Press, Liverpool. 555 pp.

Jacobson, P. J., K. M. Jacobson, P. L. Angermeier, and D. S. Cherry. 1999. Transport, retention, and ecological significance of woody debris within a large ephemeral river. J. N. Am. Benthol. Soc. 18:429-444.

Keller, E. A. and F. J. Swanson. 1979. Effect of large organic material on channel form and fluvial processes. Earth. Surf. Process. Landforms. 4:361-380.

King, D. K. 1982. Community metabolism and autotrophic-heterotrophic relationships of woodland stream riffle sections. Ph.D. Dissertation. Michigan State University. East Lansing, Michigan. 356 pp.

King, D. K. and K. W. Cummins. 1989. Factors affecting autotrophic-heterotrophic relationships of a woodland stream. J. Freshwater Ecol. 5:219-230.

Lamberti, G. A. and M. Berg. 1995. Invertebrates and other benthic features as indicators of environmental change in Juday Creek, Indiana. Nat. Areas. J. 15:249-258.

Li, J., A. Herlith, W. Gerth, P. Kaufmann, S. Gregory, S. Urquhart, and D. Larsen. 2001. Variability in stream macroinvertebrates at multiple spatial scales. Freshwater Biol. 46:87-97.

Malmqvist, B., L.M. Nilsson, and B. S. Sveensson. 1978. Dynamics of detritus in a small stream in southern Sweden and its influence on the distribution of the bottom animal communities. Oikos. 31:3-16.

Marker, A. F. H. 1976. The benthic algae of some streams in southern England. I. Biomass of the epilithon in some small streams. J. Ecol. 64:343-358.

McCafferty, W. A. 1981. Aquatic Entomology. Jones and Bartlett. Boston. 448 pp.

McConnell, W. J. and W. F. Sigler. 1959. Chlorophyll and productivity in a mountain river. Limnol. Oceanogr. 4:335-351.

Merritt, R. W. and K. W. Cummins. 1984. An introduction to the aquatic insects of North America. Second Edition. Kendall/Hunt Publishing Company, Dubuque, Iowa. 722 pp.

Minshall, G.W. 1967. Role of allochthonous detritus in the trophic structure of a woodland springbrook community. Ecology 48:139-149.

Minshall, G.W. 1984. Aquatic insect-substratum relationships. Pages 358-400 In: Resh, V.H. and D.M. Rosenberg (eds.), The ecology of aquatic insects. Praeger, New York.

Minshall, G. W., R. C. Petersen, K. W. Cummins, T. L. Bott, J. R. Sedell, C. E. Cushing, and R. L. Vannote. 1983. Interbiome comparison of stream ecosystem dynamics. Ecol. Monog. 53:1-25.

Nelson, D. J. and D. C. Scott. 1962. Role of detritus in the productivity of a rock-outcrop community in a piedmont stream. Limnol. Oceanogr. 7:396-413.

Nicolas, B. J., P. P. Usseglio, and J. C. Moreteau. 2000. The spatial heterogeneity of a river bottom: a key factor in determining macroinvertebrate communities. Hydrobiologia 1:422-423.

Petersen, R. C. and K. W. Cummins. 1974. Leaf processing in a woodland stream. Freshwater Biol. 4:343-368.

Prochazka, D. B., and B. R. Davies. 1991. Leaf litter retention and its implications for shredder distribution in two headwater streams. Arch. Hydrobiol. 120:315-325.

Scott, S. J. 1982. Habitat analysis and influences on the ecology of brook trout (*Salvelinus fontinalis)* in Cedar Creek, Michigan. M.S. Thesis. Central Michigan University. Mt Pleasant, Michigan. 72 pp.

Smith, R. D., R. C. Sidle, P. E. Porter, and J. R. Noel. 1993. Effects of experimental removal of woody debris on the channel morphology of a forest, gravel-bed stream. J. Hydrol. 152:153-178.

Smock, L.A., G.M Metzler, and J.E. Gladden. 1989. Role of debris dams in the structure and function of low-gradient headwater streams. Ecology 70:764-775.

Speaker, R. W., K. Moore, and S. V. Gregory. 1984. Analysis of the process of retention of organic matter in stream ecosystems. Verh. Int. Verein. Limnol. 22:1835-1841.

Stricker, C.A. 1997. Leaf litter retention dynamics of a low gradient, second order Michigan stream. Masters Thesis. Central Michigan University, Mt. Pleasant, Michigan. 161 pp.

Trotter, E. H. 1990. Woody debris, forest-stream succession, and catchment geomorphology. J. N. Am. Benthol. Soc. 8:36-50.

Tuchman, N. C. and R. H. King. 1993. Changes in mechanisms of summer detritus processing between wooded and agricultural sites in a Michigan headwater stream. Hydrobiologia 268:115-127.

Uzarski, D.G. 1995. Effects of large woody debris on channel morphology and substrate embeddedness in a sand impacted, low gradient stream. Masters Thesis, Central Michigan University, Mt. Pleasant, Michigan. 135 pp.

Vannote, R. L., G. W. Minshall, K. W. Cummins, J. R. Sedell, and C.E. Cushing. 1980. The river continuum concept. Can. J. Fish. Aquat. Sci. 37:130-137.

Wallace, J. B., S. L. Eggert, J. L. Meyer, and J.R. Webster. 1999. Effects of resource limitation on a detrital-based ecosystem. Ecol. Monogr. 69:409-442.

Young, S.A., W.P. Kovalak, and K.A. DelSignore. 1978. Distances traveled by autumn-shed leaves introduced into a woodland stream. Am. Midl. Nat. 100:217-222.

Zar, J. H. 1999. Biostatistical analysis. 4th edition, Simon and Schuster. Upper Saddle River, New Jersey. 212 pp.

Received: 23 July 2007

Accepted: 17 September 2007