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EFFECTS OF SEWAGE POLLUTION IN THE WHITE RIVER, ARKANSAS

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ABSTRACT

Recently there has been much emphasis placed on the importance of leaf detritus processing to the energetics of stream invertebrates. This study was designed primarily to assess the effects of municipal effluent on the ability of a stream community to utilize leaf detritus, and secondarily to evaluate the extent of the pollution of the White River by the Fayetteville, Arkansas, effluent discharge. Physical and chemical water quality and benthos were sampled periodically at one station upstream and two stations downstream from the discharge, and in the Richland Creek tributary. Processing of leaf detritus was also studied at each site using 5 g of red oak *(Quercus shumardi)* leaves. The physicochemistry and benthic community structure indicated moderate to heavy pollution by the effluent. Despite this, leaf detritus processing rates were extremely rapid which indicated that leaf decomposition is virtually unaffected by macroinvertebrates.

INTRODUCTION

Discharge of treated municipal wastewater into a stream always alters the stream's physical, chemical and biological characteristics. The extent of the alteration is governed by the quality and quantity of the effluent and the ability of the receiving stream to assimilate and metabolize the wastes. Degradation of the biological community is recognized to be the most important result of stream pollution. Several physicochemical studies have been performed in the upper White River (Eley, 1969; Bayliss, 1971; Stone, 1971; Carahan, 1973; Gearhart, 1973; Reed, 1973; Rowe, 1973) but we know of no studies which directly assessed the impact of the sewage on this stream's biota.

A general theory concerning the community organization and functional dynamics of lotic ecosystems has recently been developed (see Cummins, 1977; McIntire and Colby, 1978; Vannote et al., 1980; Minshall et al., 1983). The model is primarily based on the sequential utilization of decomposing organic detritus that enters streams from their watersheds primarily in the form of autumn shed leaves (Minshall, 1967; Coffman et al., 1971; Cummins, 1974). The rates and mechanisms involved in processing of leaves by stream invertebrates and decomposers have been rather extensively studied in unperturbed streams (e.g., see Petersen and Cummins, 1974; Suberkrop and Klug, 1976; Anderson and Sedell, 1979; Brown and Ricker, 1982), but no studies previous to this one have addressed leaf decomposition in a stream receiving municipal wastes. In order to successfully manage receiving streams we must first understand how they function ecologically.

The primary objective of this study was to assess the effects of polluting a stream with treated municipal wastewater on its capacity to process natural allochthonous detritus inputs. This included an assessment of the mechanisms and rates of leaf processing, determination of the benthic macroinvertebrate community structure and analysis of the physicochemical water quality. Additional benthic community samples were taken in the Illinois River, Arkansas (an adjacent drainage basin) for comparison.

STUDY SITE DESCRIPTION

The headwaters of the White River flow northward through the Ozark Mountains in northwest Arkansas into Beaver Reservoir (Figure 1). There are three major tributaries, two of which are impounded to form Lake Sequoyah, which is owned and managed by the City of Fayetteville. After the confluence with West Fork the river is a fifth order stream and remains so downstream to Beaver Reservoir. The river meanders for approximately 15 km below Lake Sequoyah before reaching Beaver Reservoir. The headwater streams flow through the sandstones and shales of the Boston Mountains. Downstream from the lake the river flows through cherty limestone of the Springfield Plateau. The different substrata have little influence on the physicochemistry of the river (Horn and Garner, 1965). Numerous springs contribute to the river flow along its course.

The White River is used for many purposes in addition to receiving treated wastewaters. These uses include irrigation of farmland, watering livestock and wild game, and as recreation by fishermen, canoeists and swimmers. The most significant aspect of its fishery is the annual white bass *(Morone chrysops)* spawning migration from Beaver Lake each spring. However, there is year around fishing for other species including crappie, various catfish, sunfish, black bass, and walleye. The intake for the municipal water supply for Fayetteville and several other communities is located in Beaver Reservoir approximately 42 km downstream from the effluent discharge.

The headwaters downstream to Beaver Reservoir have been placed in use-class A by the Arkansas Department of Pollution Control and Ecology (1975, 1981). These streams, then, are classified as suitable for primary contact recreation, propagation of desirable species of fish, wildlife and other aquatic life, raw water source for public water supplies, and other compatible uses. In addition the stream is classified as a smallmouth bass fishery. The study section of the river downstream from the sewer plant has actually experienced rather extensive fish kills during the summers of 1978, 1979, 1980, and 1982.

Locations of the sampling stations are indicated on Figure 1. The first station (WR 1) was chosen to represent the environmental quality of the river before receiving secondary treated effluent from the Fayetteville sewage treatment plant. The Richland Creek site (RC) similarly provided comparative data from a relatively unpolluted tributary. Station WR 2 was about 250 m below the effluent discharge and station WR 3 was about 8 km farther downstream.

METHODS

For each station leaf packs were prepared, deployed, retrieved and analyzed similar to the methods of Petersen and Cummins (1974). Small (5.0 g) packs of air dry Shumard's Red Oak *(Quercus shumardi)* leaves were sandwiched between small plastic tabs and stapled together. This species does not shed its leaves until spring. The leaves were all collected from one tree during late January 1982 to ensure comparable leaf packs among sites. Instead of lashing the packs to bricks as recommended by Petersen and Cummins (1974) we secured them to the surface of the substrate using a 60d common nail through the center of each. This avoided the nuisance of having our experiments ruined by removal of the packs by curious passers by. On March 24 the leaf packs were placed in areas of similar depth, current and substrate type at each station. Three packs were carefully removed after three, eight, 20, and 37 days exposure at each station. Invertebrates were removed and preserved, after which the remaining leaf material was dried at moderate temperature (50 °C), allowed to air dry in the laboratory for several days, and then weighed. Processing rate coefficients (k) for the leaf packs were calculated by the method developed by Petersen and Cummins (1974) using the equation: $-k = \log_e (\%R/100) / t$ where %R is the percent leaf material remaining after the time in days (t) of exposure.

Four quantitative substrate samples of benthic macroinvertebrates were collected using a Surber square foot sampler (250 μm mesh) at each station each month from April 1982 through October 1982. Sites for these samples were chosen to best represent the variety of habitats available at each station. These invertebrate samples were preserved in 75% ethanol and returned to the laboratory where they were hand picked, sorted, identified and counted. Additional invertebrate samples were collected from a comparable study site in the fifth order reach of the Illinois River (IR), Arkansas, during April, July and October, 1982. Three samples were taken each date using a 0.05 m² vacuum sampler with a mesh size of 250 μm. Species diversity was calculated by the Shannon-Weaver index: S.D. = $\sum_{i=1}^{n} {}^{n_i}/_{n} (\log_e {}^{n_i}/_{n})$, where ${}^{n_i}/_{n}$ is the ratio of the number of individuals in the i^{th} species to the total number of organisms in the sample.

Selected physicochemical analyses were performed at each station periodically from April 1982 through March 1983. These tests included flow, dissolved oxygen, turbidity, conductivity, chlorine, nitrate nitrogen, ammonia nitrogen, orthophosphate, and fine particulate organic matter (FPOM). The FPOM was collected by filtration of 500 ml of water on Whatman GFF filters. The other tests were performed according to standard methods (American Public Health Association, 1975).

RESULTS AND DISCUSSION

Leaf processing rates observed in this study were extremely rapid. The slowest decay rate was at the site immediately below the plant (k = 0.0108) but was not very different from those observed upstream (k = 0.0129) (Fig. 2). The fastest decomposition rate was observed at the second station (WR 3) downstream from the sewage outfall (k = 0.0346). Even the slower leaf processing rates would be classified as fast by Petersen and Cummins (1974) even though oak leaves are generally slow (i.e., k $\approx$ 0.005) to decay. The processing rate at station WR 3 was faster than that recorded for the same species in a similar study in the nearby Illinois River (k = 0.025, Brown and Ricker, 1982). The faster processing rates must be due to a greater density and/or activity of the microbial organisms responsible for decomposition (bacteria and fungi) and perhaps higher stream temperatures experienced during the studies in Arkansas. The highest processing rate reported by Petersen and Cummins (1974) (k = 0.0305) was obtained from a study performed during the summer in Michigan. Summer stream temperatures in Michigan may be equivalent to Arkansas spring time temperatures during this study 9-14 °C). In any case the leaf processing rates were definitely faster than any previously reported.

The observed differences in leaf processing rates can not be explained by the numbers of macroinvertebrates which colonized the leaf packs (Figure 3), or by the functional groups (sensu Cummins, 1974; Merritt and Cummins, 1978) associated with them. Shredders were conspicuously absent from the leaf packs at all sites; only collectors and predators were on them. The paucity of invertebrates associated with the leaf packs ($<$8 spp) and the absence of shredders indicates that invertebrates have little effect on leaf processing rates. This agrees with the conclusion from a leaf processing study in an Ozark cave stream (Brown and Schram, 1982). A shredder species (*Tipula* sp) was collected by Surber sampler at stations 1, 3 and 4 (see Table 1) but was never collected with a leaf pack.

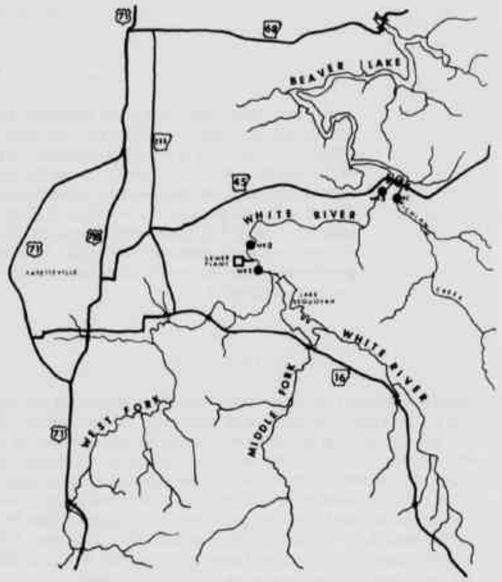

Figure 1. Map of the headwaters region of the White River, Arkansas, with study sites indicated.

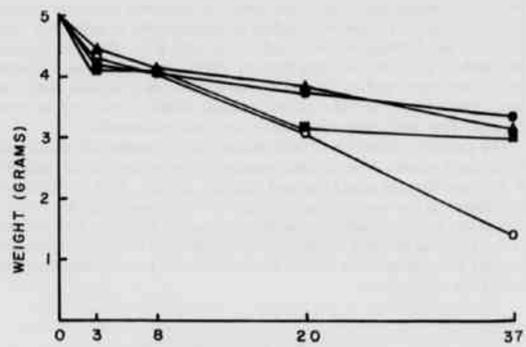

Figure 2. Leaf pack weight loss at four sites in the White River, Arkansas. WR1 = ■, WR2 = ●, WR3 = ○, RC = ▲. See Figure 1 for location of study sites.

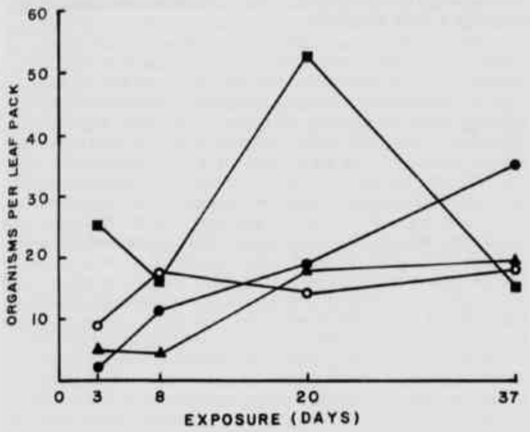

Figure 3. Benthic macroinvertebrates which colonized leaf packs (n/pack) at four sites in the White River, Arkansas. WR1 = ■, WR2 = ●, WR3 = ○, RC = ▲. See Figure 1 for location of study sites.

The benthic macroinvertebrate community, as indicated by collections with Surber samplers, was most diverse above the effluent discharge with a total of 25 taxa (see Table 1). Twenty taxa were present in Richland Creek, 17 were collected at WR 3 about eight km downstream, and only eight taxa could be found 250 m below the outfall. Mayflies and molluscs were fairly abundant upstream but were conspicuously absent immediately below the sewer plant. Gordon (1976, 1982) in studies of the Mollusca of the White River reported 47 species from the headwaters and noted the complete extirpation of species from below the Fayetteville sewage outfall to the headwaters of Beaver Reservoir. When he collected in this area, the Asiatic clam, *Corbicula*, was in Beaver but not above it in the headwaters. It was very abundant during this study upstream from the sewage plant (WR 1) but was absent from the other sampling stations (Table 1). Perhaps fishermen who use them for bait have unintentionally introduced them at this site.

The macroinvertebrate fauna was not very rich in species or numbers at any of the sampling stations, which indicates a generally depauperate situation within this reach of the stream. This observation is supported by the low species diversity indices given in Table 1. Wilhm and Dorris (1968) considered streams with a diversity index between one and three to be moderately polluted. Considering the other facts for this stream, including the absence of mayflies and molluscs below the sewage outfall and the recurrent fish kills, we would suggest that it is heavily polluted at the other sites. The Richland Creek site was primarily bedrock with little suitable habitat for benthos or it may have had a higher diversity. The Shannon-Weaver index is quite responsive to evenness (Wilhm, 1967), so the large number of *Corbicula* at the upstream site depressed the value there.

The White River is quite similar to the adjacent Illinois River regarding their topography, geology, and agricultural practices in their watersheds. However the Illinois receives less municipal sewage. A comparable fifth order site on the Illinois River had 53 species and a species diversity index of 2.49 despite the fact that only nine 0.05 m^2 samples were represented compared with 28 0.1 m^2 samples at each of the four sites on the White. The abundance and diversity (18 taxa) of mayflies attests to the relatively unpolluted status of the Illinois.

Table 1. Benthic macroinvertebrates distribution and abundance (N/M^2) in the White River, Arkansas, upstream and downstream from the Fayetteville sewage discharge. See Figure 1 and the text for station locations.

TAXA	WR1	WR2	WR3	RC
Insecta				
Ephemeroptera				
Baetis	9.99		14.60	50.34
Caenis			0.38	
Isonychia	5.38		3.46	1.15
Rhithrogena	1.15			4.23
Stenonema pulchellum	6.15		14.60	24.59
S. terminatum	1.54			
S. femoratum	1.92		1.54	0.77
S. mediopunctatum	0.38			6.15
Tricorythodes atratus	1.92		8.84	4.99
Stenacron interpunctatum				0.77
Tricoptera				
Chimarra	5.38	0.77	0.38	98.76
Cheumatopsyche	8.07		2.31	19.98
Hydropsyche	13.83	3.07	6.92	17.68
Diptera				
Chironimidae	22.67	64.18	80.70	27.67
Simuliidae	9.22	14.22	80.70	32.28
Tipula	1.54		0.38	0.77
Plecoptera				
Acroneuria	13.45	0.77	0.77	4.99
Megaloptera				
Corydalus cornutus	11.91	7.69	30.70	2.31
Coleoptera				
Psephenis				0.38
Stenelmis	3.46	1.15	4.99	0.77
Hemiptera				
Gerris remigis				6.53
Crustacea				
Decapoda				
Orconectes nana	0.38			
Isopoda				
Lirceus	1.15	1.15	0.38	
Mollusca				
Gastropoda				
Corbicula fluminea	443.08			
Tritogonia verrucosa	0.38			
Lampsilis ventricosa	0.38			
Anodonta grandis	0.38			
Physa gyrina			0.77	
Annelida				
Oligochaeta	1.15		0.77	
TOTALS	561.79	93.00	253.19	305.83
Species Diversity	1.10	1.05	1.60	2.05

Table 2. Physical and chemical characteristics of the White River, Arkansas, upstream and downstream from the Fayetteville sewage plant effluent discharge from April 1982 through March 1983. See text for station locations (WR 1, 2, 3, and RC).

	April 23				June 8				June 29			
	WR1	WR2	WR3	RC	WR1	WR2	WR3	RC	WR1	WR2	WR3	RC
DO (mg/ℓ)	9.9	9.5	9.6	11.4	8.2	8.1	7.8	9.3	7.6	6.8	6.6	8.4
Conductivity (μmho/cm)	60	95	65	110	82	122	82	112	60	140	140	150
Turbidity (NTU)	24	26	29	8	30	32	33	19	38	36	42	22
Temperature (°C)	13	14	14	14	23	28	23	23	23	23	23	21
O-Phosphate (mg/ℓ)	.05	.05	–	<.05	<.05	<.05	<.05	<.05	.30	.30	.68	.39
NH_3 (mg/ℓ)	0	0	0	0	0	0	0	0	.35	.52	.58	.20
NO_3 (mg/ℓ)	.60	.60	.50	2.2	.80	<.05	.20	0	.60	3.6	8.3	.40
Cl^- (mg/ℓ)	25	38	25	25	25	25	25	25	25	25	25	25
FPOM (mg/ℓ)	.0064	.0084	.0091	.0027	.0111	.0109	.0119	.0053	.0217	.0319	.0110	.0025

	July 20				August 24				September 21			
	WR1	WR2	WR3	RC	WR1	WR2	WR3	RC	WR1	WR2	WR3	RC
DO (mg/ℓ)	6.9	6.6	6.0	9.0	6.7	6.3	4.3	7.7	6.6	6.2	3.9	6.9
Conductivity (μmho/cm)	192	183	300	200	8.3	233	210	197	60	260	180	195
Turbidity (NTU)	17	16	20	11	21	22	24	12	22	23	28	14
Temperature (°C)	21	29	28	25	29	29	26	26	28	28	25	26
O-Phosphate (mg/ℓ)	.32	.37	.30	.40	.22	.73	.47	.41	.24	.25	.38	.50
NH_3 (mg/ℓ)	.22	.10	.50	.05	.10	.50	.50	.10	.22	2.0	3.5	.10
NO_3 (mg/ℓ)	.40	.40	.60	.40	.60	.30	.50	.80	2.9	5.2	4.1	2.0
Cl^- (mg/ℓ)	25	25	63	25	.25	.85	.62	.72	25	88	75	25
FPOM (mg/ℓ)	.0076	.0070	.0087	.0014	–	–	–	–	.0069	.0072	.0083	.0031

	October 21				January 5				March 26			
	WR1	WR2	WR3	RC	WR1	WR2	WR3	RC	WR1	WR2	WR3	RC
DO (mg/ℓ)	9.1	7.3	6.5	8.8	11.4	11.4	11.1	11.8	12.5	12.3	11.6	13.6
Conductivity (μmho/cm)	120	260	460	241	72	58	63	71	60	92	90	76
Turbidity (NTU)	14	14	16	7	17	16	19	15	20	18	17	5
Temperature (°C)	–	–	–	–	12	13	12	12	10	11	11	11
O-Phosphate (mg/ℓ)	.40	5.5	.70	.70	0	.12	.15	0	.12	.20	.17	.03
NH_3 (mg/ℓ)	0	2.0	2.0	0	.05	.08	.10	.06	.22	.47	.32	.32
NO_3 (mg/ℓ)	–	–	–	–	.30	.40	.40	.30	.14	.19	.17	.13
Cl^- (mg/ℓ)	25	75	125	38	25	25	25	25	25	25	25	25
FPOM (mg/ℓ)	.0096	.0102	.0109	.0041	.0075	.0081	.0097	.0038	.0072	.0068	.0084	.0036

The physical and chemical analyses corroborate with the other data to indicate that the effluent from Fayetteville's sewer plant is degrading the water quality of the White River and exceeding the standards set by the Arkansas Department of Pollution Control and Ecology (1981) (see Table 2). The abuses are especially severe during times of normal or low flow conditions. Substantial increases in orthophosphates, ammonia nitrogen, chlorides, conductivity and turbidity were observed downstream from the plant. Dissolved oxygen (DO) was considerably below recommended levels for this stream at the second station downstream during the August and September samples. The first station downstream may have been too near the outfall (250 m) to have been maximally affected regarding DO levels. During normal flow, oxygen depletion was just beginning as the water passes this station and was always lower at the second station except in April 1982, when the flow was above average. During the week of 12 September the DO consistently ranged from less than 1 to a maximum of 3 mg/ℓ for several kilometers below the outfall and resulted in a fish kill. We observed that most of the fish killed were carp *(Cyprinus carpio)* and green sunfish *(Lepomis cyanellus)* which are pollution tolerant species, although other less tolerant species were included. This could indicate that the reach of river no longer produces many game fish, or that the poor water quality developed gradually and the more sensitive species left before the conditions became lethal.

Results of this study indicate that the headwaters portion of the White River in the vicinity of the Fayetteville, Arkansas, sewage treatment facility has rather poor water quality and supports very few species of benthic macroinvertebrates in relation to an adjacent stream, the Illinois River. Effluent from the sewage treatment plant further degrades the stream at least as far as the upper reaches of Beaver Reservoir. Oxygen depletion caused by the effluent resulted in a fish kill in September 1982 and similar conditions probably caused the fish kills in previous years in this stream.

The depauperate condition of the aquatic invertebrate fauna upstream from the effluent discharge could be the result of nonpoint source agricultural pollution, faulty septic tanks and run off from small towns in the watershed. However, the fauna upstream could have been depleted by the harsh conditions downstream. Aquatic invertebrates drift downstream in large numbers (Waters, 1967, 1972; Miller, 1974) and the adults of aquatic insects then fly upstream to complete what Muller (1954, 1982) has called their recolonization cycle. If they are killed as they disperse downstream they can not subsequently recolonize upstream locations.

The benthic macroinvertebrate community structure distinctly indicated the water quality conditions at each station. Despite the poor water quality and the depauperate benthic fauna, the leaf detritus decomposition rates were very high, in fact there was some indication that the decomposition (processing) rate was enhanced by the effluent at station 3 downstream (see Figure 2). This result was unexpected because benthic macroinvertebrates, especially shredders, are generally thought to strongly influence leaf decomposition rates (see Cummins, 1974, 1977; Vannote et al., 1980; and Minshall et al., 1983).

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