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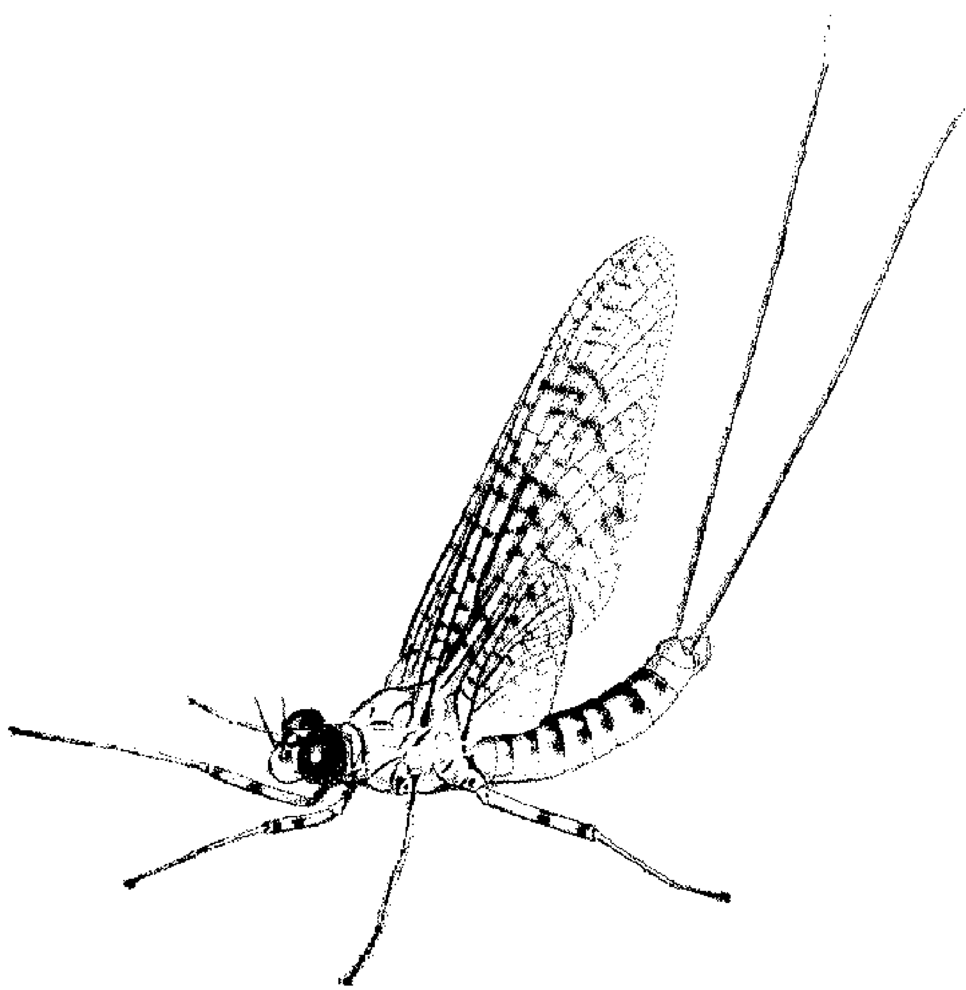
BENTHIC BIOCRITERIA ASSESSMENT of the LOWER ROANOKE RIVER, NORTH CAROLINA

A Final Report to Weyerhaeuser Paper Company



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Benthic Biocriteria Assessment of the Lower Roanoke River, North Carolina

Final Report

to

Weyerhaeuser Paper Company
Forestry Research Station
New Bern, North Carolina 28560

by

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EXECUTIVE SUMMARY

Recent changes in environmental monitoring procedures of industrial activities suggest that future environmental assessments will be made using biocriteria methodology. Benthic macroinvertebrates have been the most often used group of organisms in assessing water quality. This study was conducted to determine the present composition of the benthic macroinvertebrate community and to evaluate the results using several biological indices that will likely form the basis for the development of biocriteria.

Sediments. The dominant sediment components of the ten stations sampled were sand (31%) and silt (47%). The clay fraction was less than 30%. Stations 4 and 7 showed extremes: station 4 had low percent sand (7.6%) and station 7 had high percent silt (70.4%).

Organic content. Organic content ranged from 5.4% to 8.1% (average 0f 6.8%) but there was no statistically significant difference between shallow and deep stations nor was there any significant difference between organic values found in this study and those reported previously.

Water quality. There was no evidence of temperature stratification during September, February, or May. The lowest monthly mean temperature (5.5^{o} C) occurred in February and the highest occurred in September (27.4^{o}C). Dissolved oxygen (percent saturation) was lowest in September (43.0 to 54.5%) and highest in February (88.8 to 92.9%). pH ranged from 6.6 to 7.8 and was slightly higher in February than in September or May. Salinity and conductivity were below the detection limit of the instrument used (0.1 ppt; 500 μmhos, respectively) but salinity as high as 0.39 ppt has been documented in recent years.

Macroinvertebrates. The macroinvertebrates, composed of predominantly freshwater organisms, were dominated by three groups: Oligochaeta (53.6%), Mollusca (20.4%), and Chironomidae (16.9%) which together accounted for 90.9% of the 62 taxa collected. Oligochaetes were not identified beyond the phylum level.

Mollusca was composed of nine genera, five of which were bivalves. The molluscs were dominated by *Corbicula fluminea* (Asian freshwater clam, 86.9%) which was found at all stations. Recruitment of *Corbicula* occurred in the spring months. Two juveniles of the unionid mussel genus *Alasmidonta* were collected above the Plymouth mill discharge. This genus is represented in North Carolina by six species, all of which are endangered, threatened, or of special concern. The small size of these mussels prevented any identification to species.

The family Chironomidae was composed of 19 genera but was dominated by *Coleotanypus* (11.3% of the total organisms collected) and *Polypedilum* (2%). Each of the remaining chironomid genera accounted for less than 1% of the total organisms collected. Previous studies agreed with the findings in the present study that

Coleotanypus, *Polypedilum*, and *Chironomus* were the most abundant genera. There were no genera collected in the present study that have not been previously reported.

Many of the taxa collected were low in abundance and could not be adequately represented with the amount of sampling in this study. The abundant taxa were adequately represented in the samples and would present a reliable view of the benthic macroinvertebrate community.

Community indices. Eight indices commonly found in benthic evaluations were utilized in this study. The Shannon-Weaver mean diversity index and the Shannon diversity index both indicated a significant difference in diversity among months but not among stations. Diversity was lowest in September; diversity in February and May were not different from each other. There was no significant difference among stations for evenness or dominance but richness was significantly higher at station 3 that at stations 4, 5, 7, and 8. Evenness was significantly higher in May and February than in September, richness was significantly higher in February than in September (but not different from that in May), and dominance was significantly higher in September than in either February or May. The Hilsenhoff biotic index indicated that the stations sampled in this study fell within the "fair water quality" range. There was no significant difference among stations but the index for May was significantly lower than that for September and February.

The indices reflected a seasonal shift from high dominance, low evenness, richness, and diversity in September to low dominance, high evenness, richness, and diversity in February and May. This is likely to be the result of recruitment during the latter months. The majority of benthic macroinvertebrates collected in this study have a wide range of tolerance to organic pollution and the Hilsenhoff index indicated only fair water quality. Those organisms collected that were relatively intolerant of organic pollution (*Amnicola*, *Alasmidonta*) were found in low abundance.

The Shannon-Weaver mean diversity index and the Shannon diversity index both indicated that there was no significant difference in benthos among stations which would be expected if similarly tolerant organisms were present at upstream and downstream stations. The significant difference by month was attributed to seasonal changes with recruitment occurring in February and May. The common taxa index did show a decline in the number of taxa going downstream toward the discharge and a recovery at the lowermost station. However, these indices do not take into account any biological differences in microhabitat and, in addition, there may be unmeasured factors that influence the macroinvertebrate community.

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Introduction

Recent changes in environmental monitoring procedures of industrial activities suggest that future environmental assessments will be made using *biocriteria* methodology. The term biocriteria refers to using the expected assemblage of organisms characteristic of a unstressed environment to evaluate the present condition of a water body. The biocriteria for North Carolina coastal streams are presently being developed. Benthic macroinvertebrates have been the most often used group of organisms in assessing water quality (Rosenberg and Resh 1993) and will be major contributors to the establishment of biocriteria.

Little information is available on the benthic macroinvertebrates of the lower Roanoke River system of North Carolina, particularly seasonal changes and locational differences in community structure. Kirby-Smith and Van Dover (1979) examined the benthic macroinvertebrate community of the Roanoke River near Plymouth, NC, for Weyerhaeuser Paper Company but since then no comprehensive studies have been conducted. Beginning in 1983, the North Carolina Division of Environmental Management (NCDEM) has monitored the Roanoke River benthic community by sampling one location near the State Highway 45 bridge in July (NCDEM 1991), but this sampling scheme was not designed to assess seasonal changes in the macroinvertebrate community or differences in community structure. The present study was designed to use biocriteria methodology to determine if the Plymouth Pulp and Paper Mill discharge had detectable effects on the downstream macroinvertebrate community, and to contribute to our understanding of the macroinvertebrate community in the lower Roanoke River.

Methods

Station selection. Ten stations within the lower Roanoke River delta were sampled beginning 11 river miles from the river mouth (Figure 1). Stations were paired:

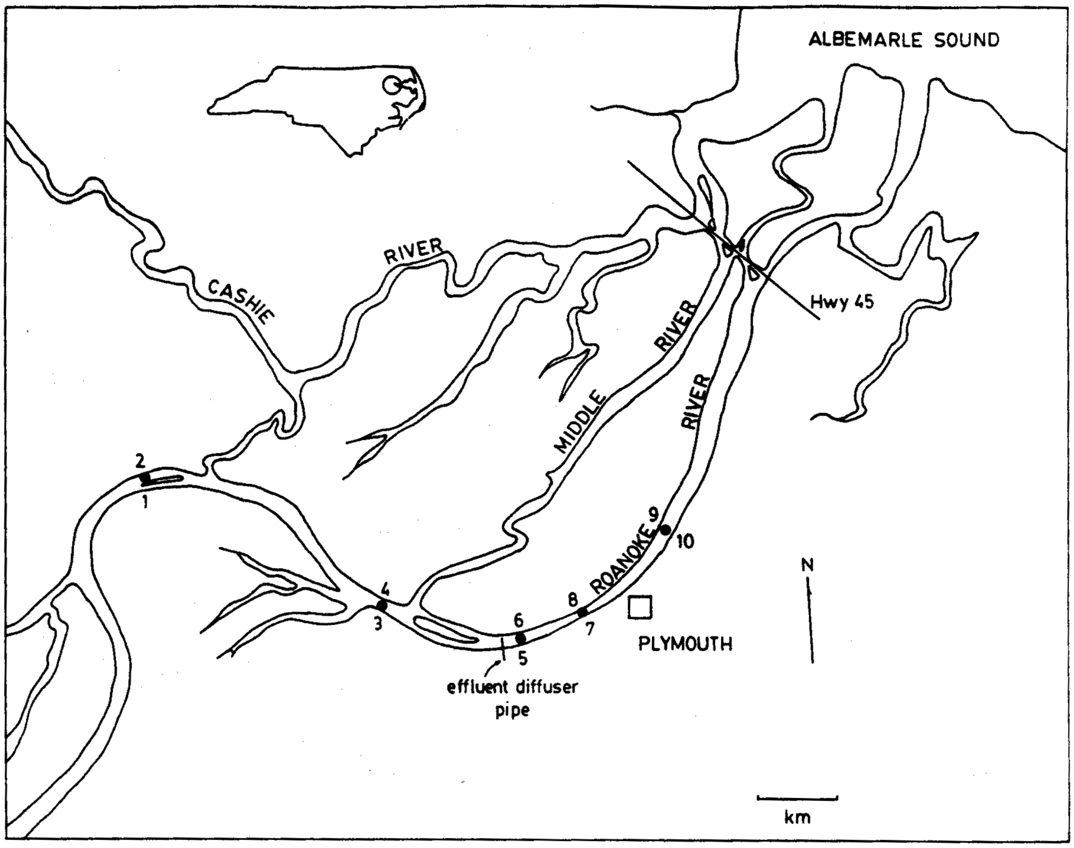


Figure 1. Location of benthic sampling stations in the lower Roanoke River. Each closed circle represents a pair of stations: odd numbers are shallow stations, even numbers are deep stations.

one location in relatively shallow water (0.9 to 3.0 m) and the other in deeper water (4.6 to 12.2 m). Four of the stations were upstream of the Plymouth mill effluent diffuser pipe and the remainder were downstream of the pipe. Stations were selected to minimize differences in substrate material to minimize confounding effects in data analysis.

Water quality measurements. At each station, dissolved oxygen (YSI oxygen probe), temperature, salinity, and conductivity (Beckman salinometer) were measured at the surface, mid-depth, and bottom. Surface water was measured for pH using a hand-held digital meter.

Sediment characterization. Three replicate 120-ml samples were taken at each station for grain size and organic content determination. Samples were stored at 38^{o} F until the analyses were performed. Techniques to determine sediment grain size followed the procedure of Werme (1985). Briefly, a 10-g homogenized subsample was dried at 75^{o} C for 24 hr, weighed, then passed through a 62.5-µm mesh screen with agitation using sodium oxalate as a dispersant. Dispersant was added to the sample until no visible particles passed through the sieve. The sieved material was collected in a graduated cylinder and the total volume increased to 100 ml by adding dispersant. The remaining sand was washed with deionized water to remove the dispersant, dried at 75^{o} C for 24 hr and weighed. The contents of the graduated cylinder were agitated with a stirring paddle until the mixture was homogenous. After allowing the mixture to stand for 15 s, a 10-ml sample was pipetted from the 25 ml mark in the graduated cylinder. This was emptied into a microbeaker and constituted the silt fraction. The mixture in the cylinder was again agitated and, after 22 min, a second 10-ml sample was pipetted from 1 cm below the surface. This sample, representing the clay fraction, was placed in another microbeaker.

A 10-ml sample of the dispersant was pipetted into a microbeaker and all microbeakers were dried at 75^{o} C for 24 hr, cooled, and then weighed. Weights of the silt and clay fractions were corrected by subtracting the dispersant dry weight from them, then calculated as percent dry weight of the original sample.

Organic content. A sample of sediment (7-17 g) was added to pre-weighed aluminum pans, weighed, dried at 75^{o} C for 24 hr, weighed again, then ashed in a muffle furnace at 480^{o} C for 8 hrs, cooled in the muffle furnace, and weighed a third time. The loss in weight from the dry weight to the ashed weight was considered to be the total weight of the organic material and was expressed as a percentage of the dry weight.

Macroinvertebrates. Five replicate samples were taken at each of the ten stations in September 1992, and February and May 1993, using a 15-cm square (0.02m^{2}) Ponar dredge with a maximum volume of 2000 cm^{3}. One replicate from May (Station 8) was improperly preserved and was therefore not used. Each replicate was emptied into a 4000 cm^{3} graduated bucket to determine sediment volume and then washed through a 500-µm mesh screen. The remaining material was preserved with 10% buffered formalin containing rose bengal dye. In the laboratory, each sample was washed through a 250-µm mesh screen to remove the formalin and then sorted twice to remove all organisms, which were placed in 70% isopropyl alcohol. The effectiveness of this sorting procedure was tested with 15 samples containing a large amount of detritus. Each sample was sorted three times, recording the number of organisms found in each sort. No additional organisms were found after the second sorting. An average of 4.9% (range: 0 to 10.7) of the organisms were missed during the first sorting (Table 1; appendix).

All organisms were identified to the lowest practical taxon and counted. Clams were measured for length (0.1 mm) using a dial caliper. Chironomidae identification was made from permanent or temporary glass slide mounts viewed under an inverted microscope at 400X. The primary identification references were Mason (1973), Merritt and Cummins (1984), and Pennak (1978).

Statistical Analysis. Statistical comparisons of our data with that of Kirby-Smith and VanDover (1979) were performed using the following station groupings: R45 versus stations 3 and 4 of the present study; R48 and R49 versus stations 5 and 6; R41 and R42 with stations 7 and 8; and R39 with stations 9 and 10. There were no corresponding stations in Kirby-Smith and VanDover for our stations 1 and 2. Sediment composition by station, mean diversity by station and month, and mean total density ($\log_{10}$-transformed to normalize data distribution) by station and month were analyzed using PROC GLM (SAS version 6.03, 1990). Multiple comparisons of stations and months were made using the Tukey and Duncan procedures. Analysis of community indices was performed using PROC GLM.

Community indices. The following eight indices were used to analyze the benthos data: Simpson's dominance, richness, evenness, Shannon diversity, Shannon-Weaver mean diversity, Hilsenhoff taxa index of organic tolerance, common dominants, and common taxa. A discussion of these indices is given in the appendix.

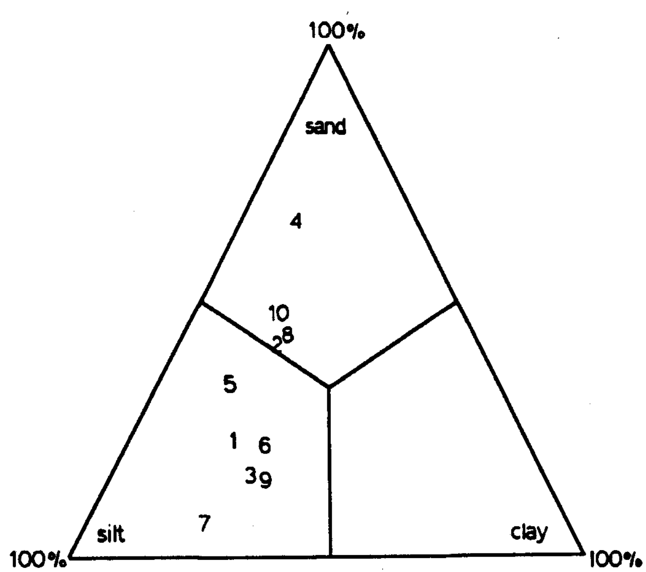
Results

Sediment characterization. The dominant sediment components of the ten stations were sand and silt. Stations 4 and 7 exhibited extreme values: sand ranged from 7.6% at station 7 to 67.8% at station 4 and correspondingly, silt ranged from 21.1% at station 4 to 70.4% at station 7. The other stations averaged 31.1% sand, 46.8% silt, and 22.0% clay. Percent clay was less than 30% at all stations (Table 1). The values for the individual stations are summarized in Figure 2.

Table 1. Sediment characterization of the stations sampled and percent organic content. Values are the means of three replicate samples for each station.

	Constituent percent			
Station	**Sand**	**Silt**	**Clay**	**Organic**
1	23.6	56.1	20.2	7.7
2	42.1	37.3	20.5	5.9
3	14.4	56.3	29.3	6.0
4	67.8	21.1	11.1	7.1
5	33.9	51.6	14.4	7.1
6	23.2	50.0	26.8	6.4
7	7.6	70.4	21.9	8.1
8	46.3	34.0	19.7	5.4
9	16.6	54.6	28.7	6.9
10	48.4	34.8	16.8	7.3

Figure 2. Schematic representation of sand, silt, and clay fractions of the Roanoke River sediments. Numbers refer to stations.



Organic content. Organic content ranged from 5.4% to 8.1% and averaged 6.8% (Table 1). The shallow water station sediments contained slightly more organic matter than the deeper stations but the difference was not significant (One-way ANOVA, $F = 2.1$, $P = 0.18$). There was no significant difference between the organic values found by Kirby-Smith and VanDover (1979) and those in the present study (One-way ANOVA, $F = 2.56$, $P = 0.15$) .

Water Quality. Monthly mean water temperature during the study ranged from a low in February of 5.5^{o}C to a high in September of 27.4^{o}C. There was no evidence of water mass stratification during any of the sampling months. Bottom water temperature was <2^{o}C lower than the surface in September and May. Water temperature was homogeneous at all depths within each station during February. Dissolved oxygen (as percent saturation) was lowest in September (43.0 to 54.5%) and highest in February (88.8 to 92.9%). pH ranged from 6.6 to 7.8 and was slightly higher in February than in the other two months. Salinity and conductivity were below the detection limit of the instrument used (limits: 0.1 ppt and 500 umhos, respectively). Mean conductivity, as recorded by NCDEM (Highway 45 bidge) averaged 171 umhos/cm (271 observations) from 1981 to 1990. The highest recorded conductivity during this period was 2,135 umhos/cm in July 1985 (NCDEM 1991). A summary of water quality measurements is given in Table 2 of the appendix.

Daily river flows peaked at about 20,000 cubic feet per second (cfs) for short periods during January, May and June, 1992 (mean: 7,735 cfs) but were generally stable during September (mean: 3,458 cfs). Flow rates increased from over 4,000 cfs in October to 16,658 cfs in January 1993. This high flow rate precluded any sample collection in January. Flow rates decreased to 9,010 cfs for a ten-day period in February before increasing again through April (mean: 32,762 cfs). River discharge decreased to an

Table 2. Summary statistics of replicate samples by month and station for five common taxa. Values given are the mean number of organisms collected, one standard deviation in parentheses, and the coefficient of variation. Dashed lines indicate that fewer than five organisms were collected.

Station	Month	*Gammarus fasciatus*	Oligochaeta	*Corbicula fluminea*	*Coleotanypus*	*Polypedilum*
1	Sept	---	50.2(5.1), 0.10	1.2(0.4), 0.33	---	---
	Feb	2.2(1.8), 0.83	58.8(29.3), 0.50	---	6.8(1.6), 0.23	---
	May	14.2(5.5), 0.39	57.6(8.9), 0.15	4.8(4.7), 0.98	10.6(2.9), 0.27	5.6(3.5), 0.6
2	Sept	3.2(2.3), 0.73	23.8(18.0), 0.75	10.8(2.5), 0.23	---	---
	Feb	2.0(2.2), 1.10	17.8(4.3), 0.24	6.8(5.0), 0.74	5.8(3.5), 0.61	---
	May	11.0(9.9), 0.90	14.8(4.4), 0.30	40.8(21.4), 0.52	---	---
3	Sept	---	30.0(15.1), 0.50	4.4(3.5), 0.81	1.8(1.1), 0.60	---
	Feb	3.4(2.6), 0.76	40.0(4.0), 0.10	---	7.2(3.3), 0.46	2.6(2.3), 0.9
	May	11.2(3.6), 0.32	29.0(16.9), 0.58	15.4(17.0), 1.11	3.4(2.6), 0.76	6.2(5.4), 0.8
4	Sept	1.4(0.5), 0.35	36.0(4.2), 0.12	33.2(10.7), 0.32	---	---
	Feb	4.6(3.3), 0.71	18.4(5.9), 0.32	0.6(0.5), 0.82	19.2(7.1), 0.37	---
	May	---	8.8(5.3), 0.60	20.0(16.2), 0.81	---	---
5	Sept	---	51.2(14.5), 0.28	---	2.2(2.5), 1.13	---
	Feb	1.0(0.5), 0.47	31.8(4.5), 0.60	---	17.0(2.2), 0.13	---
	May	2.8(1.9), 0.69	23.4(8.5), 0.36	2.8(3.8), 1.35	8.4(1.8), 0.22	1.2(0.9), 0.7
6	Sept	3.0(5.6), 1.88	80.2(24.3),0.30	7.2(7.1), 0.99	5.0(1.8), 0.36	---
	Feb	1.8(3.5), 1.94	28.4(11.8), 0.41	7.8(9.4), 1.21	22.0(11.4), 0.52	1.2(0.8), 0.6
	May	4.2(2.6), 0.63	27.8(5.3), 0.19	4.2(4.1), 0.97	11.6(5.4), 0.47	7.6(7.9), 1.0
7	Sept	---	52.8(11.6), 0.22	---	2.4(0.8), 0.34	---
	Feb	---	25.6(8.0), 0.31	---	12.2(4.1), 0.34	---
	May	2.6(1.8), 0.69	20.6(10.3), 0.50	1.4(0.8), 0.59	6.4(2.4),0.38	---
8	Sept	---	106(8.3), 0.08	42.8(3.5), 0.08	5.0(1.4), 0.28	---
	Feb	4.6(4.9), 1.07	52.6(6.5), 0.12	26.4(3.7), 0.14	20.6(8.7), 0.42	---
	May	13.0(9.3), 0.71	28.7(4.4), 0.15	31.5(6.7), 0.21	2.2(1.6), 0.72	1.2(0.9), 0.7
9	Sept	---	38.6(13.1), 0.34	50.0(6.8), 0.14	1.0(0.5), 0.47	1.4(1.3), 0.9
	Feb	0.8(0.5), 0.59	27.8(7.2), 0.26	17.0(12.5), 0.73	14.8(5.1), 0.35	---
	May	21.0(9.1), 0.43	22.8(5.7), 0.25	13.4(4.2), 0.31	10.4(2.1), 0.20	6.6(3.2), 0.4
10	Sept	3.2(3.5), 1.10	77.2(40.1), 0.52	16.2(17.8), 1.10	6.4(4.1), 0.64	---
	Feb	6.4(3.3), 0.51	50.8(10.4), 0.20	12.4(4.4), 0.35	33.4(12.7), 0.38	1.8(1.4), 0.7
	May	9.2(4.7), 0.50	11.6(6.0), 0.52	5.6(2.6), 0.46	7.6(3.3), 0.43	2.6(1.8), 0.6

Table 3. Summary of organisms collected by station (all months combined) and their taxonomic relationships.

Taxa		Station 1	2	3	4	5	6	7	8	9	10	Total	% of total
Turbellaria									1			1	0.01
Nematoda			1	3	1	1	1	7		1	2	17	0.16
Annelida													
	Oligochaeta	833	282	495	316	532	682	495	908	446	698	5687	53.56
	Peloscolex	10	1	1			1	15	1		4	33	0.31
	Piscicolidae		2									2	0.02
	Glossiphoniidae		1									1	0.01
	Manyunkia speciosa			1								1	0.01
Crustacea													
	Gammarus fasciatus	84	81	74	30	19	45	13	78	110	94	628	5.91
	Hyallela azteca									1		1	0.01
	Cyathura polita		7	51	15	2	2		1	2		80	0.75
	Asellus		1									1	0.01
Ephemeroptera													
	Stenonema		1									1	0.01
	Hexagenia	2		3		4					1	10	0.09
Odonata													
	Dromogomphus	3	1	4	4	1	1		1	3	1	19	0.18
	Somatochlora		1									1	0.01
Megaloptera													
	Sialis	1								1	2	4	0.04
Trichoptera													
	Cymellus			2	1							3	0.03
	Hydropsyche			2								2	0.02
	Lepidostoma						1					1	0.01
	Nectopsyche	1										1	0.01
	Oecetis	4					2		6	11	2	25	0.24
	Oecetis pupa							1				1	0.01
	Phylocentropus	5	1	2			1	1		1	1	12	0.11
Coleoptera													
	Ancyronyx		1									1	0.01
	Hydroporus		1		1							2	0.02
	unid. beetle larva									1		1	0.01
Neuroptera													
	Sisyra		1									1	0.01
Hemiptera													
	Corixidae									2		2	0.02
Diptera													
	Chaoborus	5	2	33	2		3	30	1	5		81	0.76
	Palpomyia		1				1				4	6	0.06
	Ablabesmyia	1					1				1	3	0.03
	Chironomus	75	4	6		9	11	3	1	4	4	117	1.10
	Cladotanytarsus	5		1		1	2					9	0.08
	Coleotanypus	68	31	62	102	138	193	105	137	131	237	1204	11.34
	Cryptochironomus	1				5	31	6	34	10		87	0.82
	Dicrotendipes						1		2	1		4	0.04
	Endochironomus		2		1	2	16	1			3	25	0.24
	Glyptotendipes	11		2	4			2				19	0.18
	Nanocladius	10	9	9	3	1	5	1	1		1	40	0.38
	Pagastiella							1				1	0.01
	Parachironomus						9	1		9		19	0.18
	Parachironomus pupa	1				1					1	3	0.03
	Paracladopelma			1								1	0.01
	Paralauterborniella			3								3	0.03
	Phaenospectra		1							2		3	0.03
	Polypedilum	31	5	45	1	7	51	1	5	40	22	208	1.96
	Procladius	6		12	2		1	5	4	9	3	42	0.40
	Tanytarsus			2								2	0.02
	Xenochironomus			1								1	0.01
	unid. Orthocladinae										1	1	0.01
	unid. chironomidae			1	1							2	0.02
	diptera pupa								1	2	2	5	0.05
	Syrphidae								1			1	0.01

Table 3. continued.

Taxa		Station 1	2	3	4	5	6	7	8	9	10	Total	% of total
	Hydrolimax grisea	5		1		1	5			5	5	22	0.21
Mollusca													
	Corbicula fluminea	32	292	101	269	15	117	12	473	405	171	1887	17.77
	Pisidium	20	2	2	1	28	16	40		29		138	1.30
	Rangia cuneata										2	2	0.02
	Sphaerium	5	6	1	5	20	7	47	1	11	8	111	1.05
	Alasmidonta	1	1									2	0.02
	Amnicola						1				3	4	0.04
	Heliosoma		1									1	0.01
	Laevapex		4						2	1		7	0.07
	Physa		13	1					3	1		18	0.17
Total		1220	757	922	759	787	1207	787	1662	1244	1273	10618	100
Number of taxa		25	30	29	18	18	27	20	21	27	25	62	

average of 13,183 cfs in May. The average flow rates during each sampling period were: 5,865 cfs (September), 9,010 cfs (February), and 20,000 cfs (May).

Macroinvertebrates. Variability among station replicates was examined for the five most abundant taxa (see Table 4, appendix, for a list of common names) (*Gammarus fasciatus*, Oligochaeta, *Corbicula fluminea*, *Coleotanypus* sp., and *Polypedilum* sp.) to determine if the sampling procedure provided reliable estimates of individuals in each replicate (Table 2). If the coefficient of variation (CV) was less than one (standard deviation < the mean), the replicates were considered to be adequate. All replicates for Oligochaeta were adequate, the highest CV being 0.75. The percentage of cases in which the standard deviation was less than the mean for the other taxa were: *Coleotanypus* (96%), *Corbicula* (92%), *Polypedilum* (91%), and *Gammarus* (77%). There was no difference between month of collection and the value of the CV. The densities of the remaining taxa collected were low and were not adequately represented between sample replicates with the present study design.

Macroinvertebrates were dominated by three groups: Oligochaeta (53.6%), Mollusca (20.4%), and Chironomidae (16.9%), which together accounted for 90.9% of the total organisms collected. The remaining 9.1% was composed of 31 other taxa (Table 3). Oligochaetes were not identified beyond the phylum level except for *Peloscolex* sp. which was distinctive.

The phylum Mollusca was composed of nine genera, five of which were bivalves. Bivalves were dominated by *Corbicula fluminea* (86.9%) which was found at all stations. There was no significant difference in the number of *Corbicula* collected in shallow water versus deeper water ($F = 2.46$; $P = 0.15$) nor was there any significant difference between stations upstream of the discharge or downstream of it ($F = 0.5$; $P = 0.35$). The majority of *Corbicula* ranged in size from 19 to 34 mm (Figure 3). Recruitment occurred in the

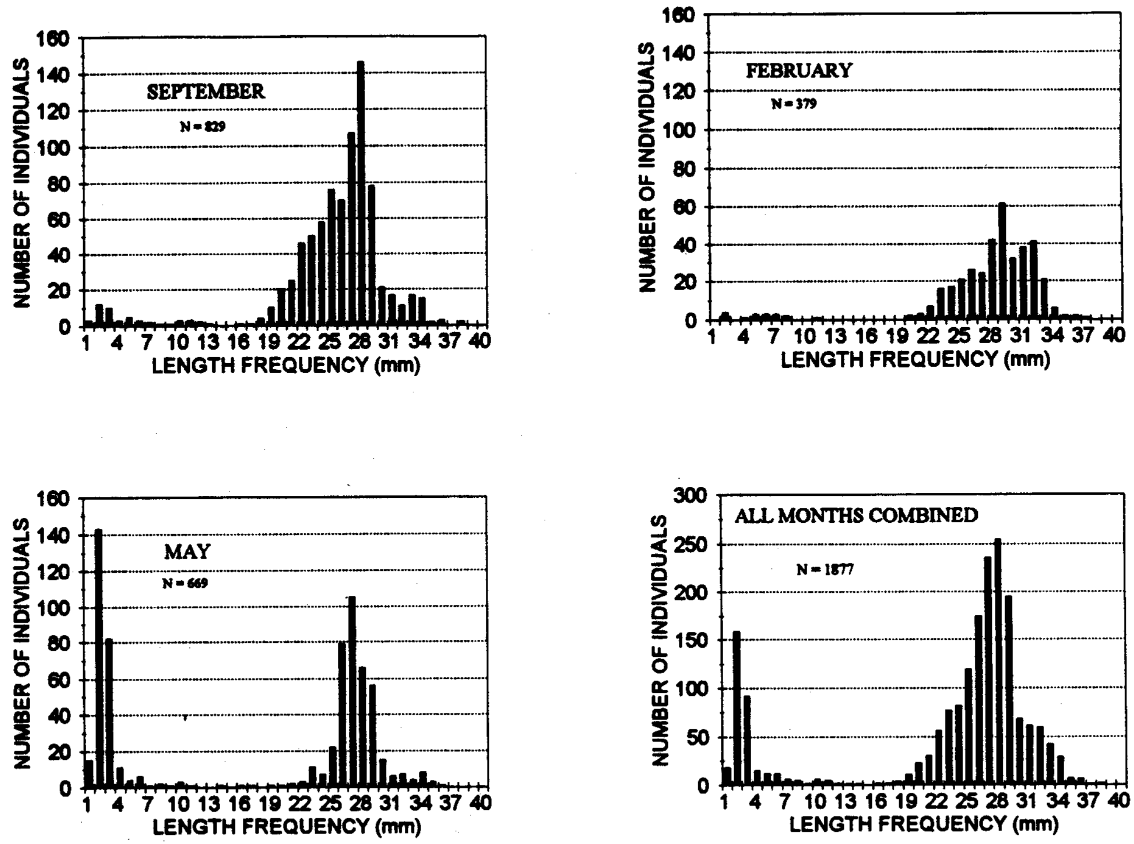


Figure 3. Length frequency by month, and all months combined, of *Corbicula fluminea* collected in the lower Roanoke River.

spring months; a large increase in the number of individuals collected in the 1 to 5 mm size was observed in May.

Only two *Rangia cuneata* clams were collected (September and May) and both were taken at station 10. This would appear to be the furthest upstream range of this clam within the study area. Two specimens of the unionid mussel genus *Alasmidonta* were collected, one at station 1 and the other at station 2 (identified by Arthur Bogan, Freshwater Molluscan Research, Sewell, NJ). The small size of these mussels prevented any determination of species.

The family Chironomidae was composed of 19 genera but was dominated by *Coleotanypus* (11.3% of the total organisms collected) and *Polypedilum* (approximately 2%). Each of the remaining chironomid genera accounted for < 1% of the total organisms collected.

Mean total density (log_{10}-transformed data) was not significantly different among stations (F = 1.94, P = 0.11) or months (F = 1.01, P = 0.38) and there was no significant difference between stations above the discharge and those below it.

Differences in the species composition of stations were evaluated using the Shannon-Weaver mean diversity index (Lloyd et al. 1968) and the Shannon diversity index (Ludwig and Reynolds 1988). Both calculations use the number of individuals and are affected by both the number of species (richness) and the spatial distribution of species in the sample area (composition) (Figure 4). Both indices indicated a significant difference in diversity among months (F = 24.9, P = 0.0001; F = 23.47, P = 0.0001, respectively) but not among stations (F = 1.33, P = 0.29; F = 1.36, P = 0.27, respectively). Both indices of diversity were significantly lower in September but those from February and May were not statistically different from each other.

There was no significant difference among stations for evenness or dominance but richness was significantly higher at station 3 than at stations 4, 5, 7, and 8 (Table 4).

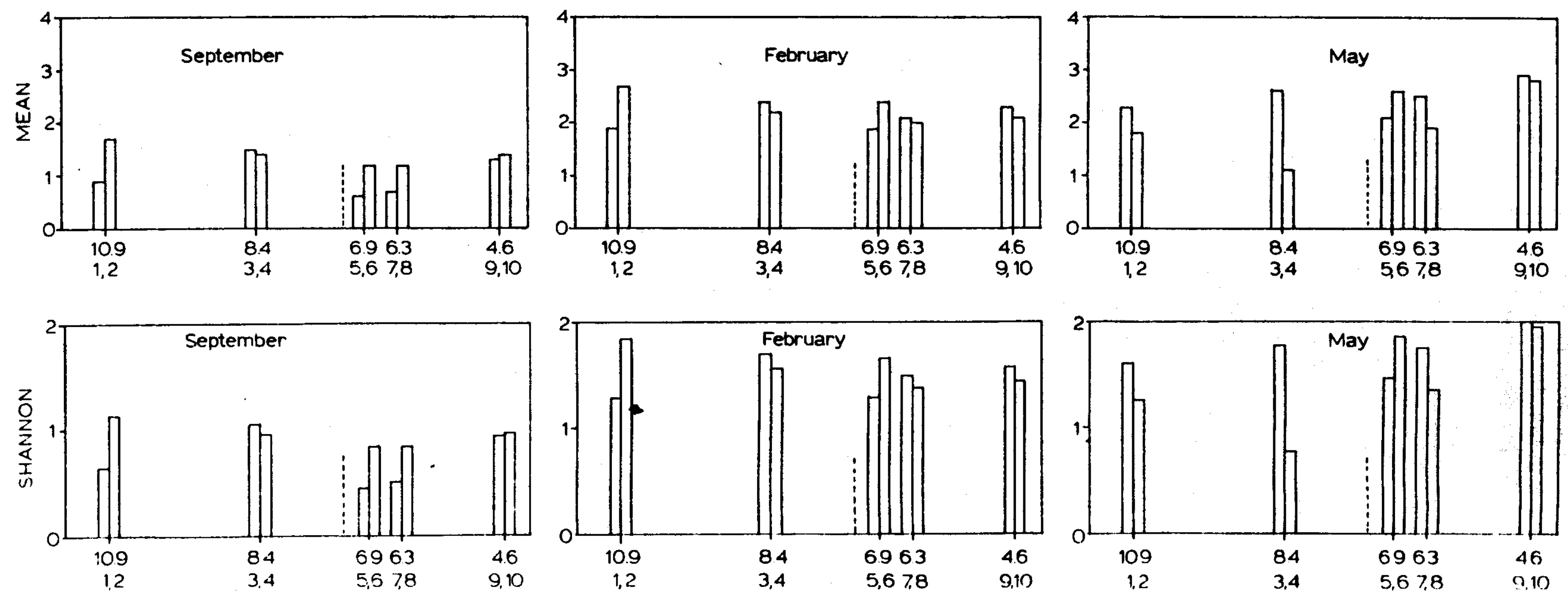


Figure 4. Graphical presentation of the Shannon-Weaver mean diversity index and the Shannon diversity index by month. The numbers on the x-axis indicate river mile (top row) and the station number (bottom row). The dashed line indicates the location of the diffuser pipe.

Table 4. Statistical analysis of the indices evenness, richness, and dominance by month and station. F values with an asterisk are significant at the 0.05 level. Months and station numbers with a common underline are not significantly different.

Index	Month			Station
Evenness		37.88*		0.95
	May	Feb	Sept	
Richness		8.05*		2.50*
	Feb	May	Sept	3 9 2 1 10 6 7 5 4 8
Dominance		24.76*		1.39
	Sept	Feb	May	

This apparent contradiction with the diversity indices is the result of the interaction of richness and composition in the diversity indices. Evenness was significantly higher in May and February than in September; richness was significantly higher in February than in September but not significantly different than in May; and dominance was significantly higher in September than in February or May (Figure 5).

The same observed values are used in the calculation of these indices and in the Shannon diversity index and are thus correlated. The degree of correlation of richness and evenness with diversity will indicate which variable was more important in the resulting diversity index value for that month. Results of the correlation analysis (Table 5) shows that evenness was more important in September than richness, nearly equal in February and less important in May.

Table 5. Pearson correlation coefficients of Shannon diversity correlated with evenness and richness and, in parentheses, the probability value for the null hypothesis of Rho = 0.

Month	Evenness	Richness
Sept	0.94 (0.0001)	0.62 (0.05)
Feb	0.54 (0.10)	0.69 (0.03)
May	0.76 (0.01)	0.90 (0.004)

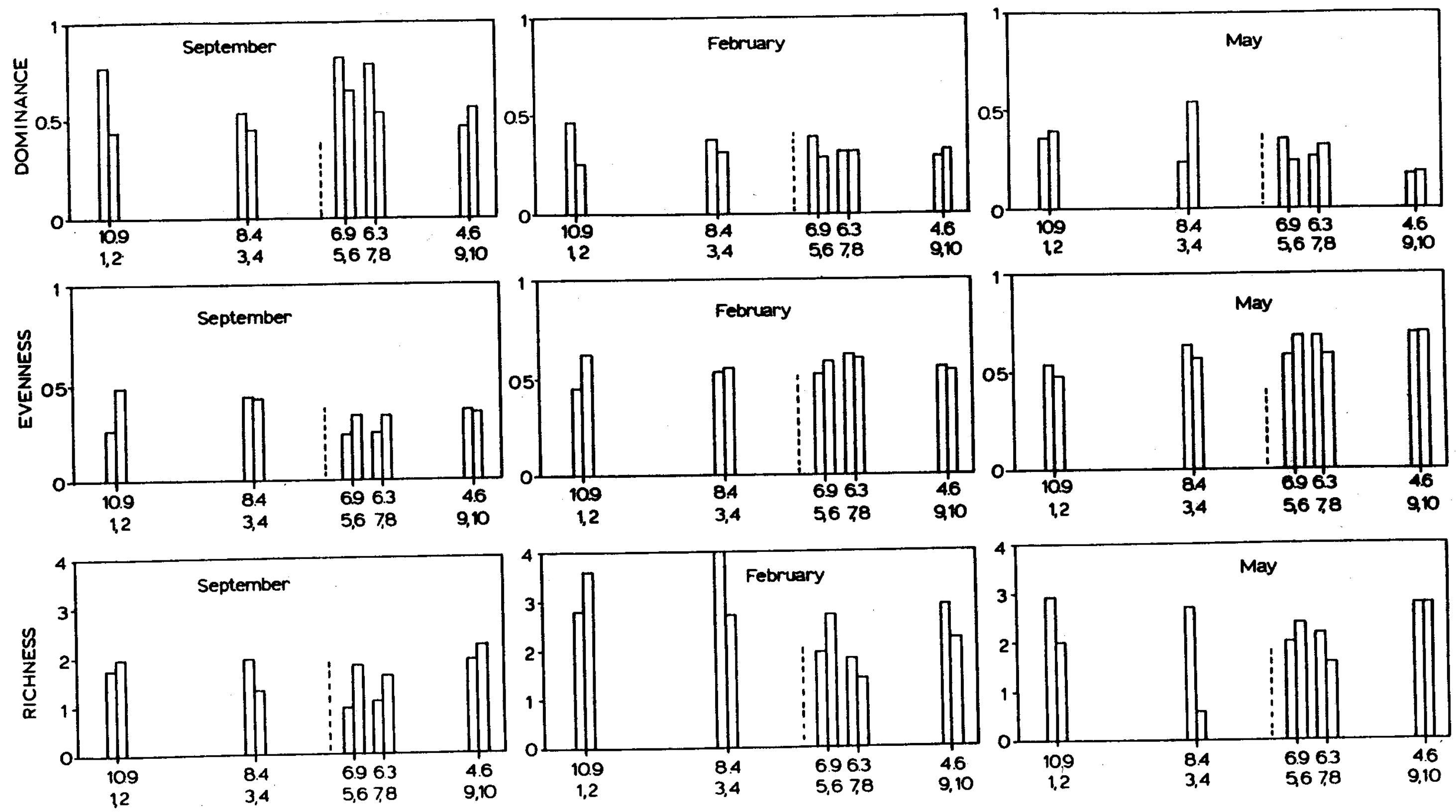


Figure 5. Graphical presentation of the indices Simpson dominance, evenness, and richness by month. The numbers on the x-axis indicate river mile (top row) and the station number (bottom row). The dashed line indicates the location of the diffuser pipe.

The Hilsenhoff (1977) biotic index is designed to detect changes in community structure based on the tolerance of various benthic organisms to organic pollution. Each taxa collected is given a score (Klemm et al. 1990) and an index is calculated that ranges from zero (excellent water quality) to four (severe pollution). The index for the stations sampled in this study fell within the range of fair water quality (2.51 to 3.75). There was no significant difference among stations (F = 1.20; P = 0.28) but the mean index for May was significantly lower than that for September and February (F = 13.85; P = 0.0001). The index for the latter two months were not significantly different (Table 6).

Table 6. Values for the Hilsenhoff organic pollution index by month for the lower Roanoke River. The diffuser pipe is located between stations 4 and 5.

Station	September	February	May
1	2.97	2.94	2.84
2	2.90	2.88	2.81
3	2.96	2.86	2.77
4	2.97	2.87	3.00
5	2.99	2.96	2.92
6	2.95	2.96	2.93
7	2.99	2.97	2.81
8	2.99	2.95	2.82
9	2.99	2.94	2.73
10	2.95	2.93	2.76

The dominants in common index (common dominants) is used for comparing upstream sites to downstream sites. In this study, results from the three sampling months were combined to minimize seasonal effects and each pair of stations were combined to minimize sample depth differences. The eight most abundant taxa were used and the index was calculated as the number of abundant taxa in common divided by the number of abundant taxa at the upstream pair of stations. Since each of the eight abundant taxa, with the exception of Chironomus at station 4 and Pisidium at stations 8 and 10, were found at each station during the sampling period, the index value was always above 87%, which indicated no impact.

The common taxa index (similar but not identical to common dominants index) uses the number of taxa in common at two sites as a percentage of the maximum number of taxa at either site. Each pair of stations was combined and summed over the three sampling months. The evaluation of the collected data followed the premise that if an impact was present, the index value should decrease going downstream to the discharge point and then recover as distance downstream increased. Stations 1 and 2 were used as controls and were compared with each succeeding pair of stations with the following results: 53.6% (sta. 3 and 4); 48.8% (sta. 5 and 6); 48.8% (sta. 7 and 8); and 65.8% (sta. 9 and 10). These values indicated a slight to moderate impact from the mill discharge on the composition of the downstream macroinvertebrate community. The same procedure was repeated using station 3 and 4 as controls: 64.5% (sta. 5 and 6); 51.6% (sta. 7 and 8); and 54.0% (sta. 9 and 10). These values would indicate a slight impact.

Discussion

The macrobenthos of the lower Roanoke River is composed of predominantly freshwater organisms with the exception of the euryhaline organisms *Cyathura polita* and *Rangia cuneata*. The freshwater organisms that live successfully in the lower Roanoke River must have some tolerance for salinity, at least at the stations nearest the river mouth. Although no salinity was found in this study, salinity levels of 0.39 ppt have been documented (Rulifson et al. 1992) upriver to river mile 7, just upstream from stations 5 and 6 in the present study. These periods of salinity intrusion were associated with the presence of saline water in western Albemarle Sound.

There were seasonal shifts from high dominance, low evenness, richness, and diversity in September to low dominance, high evenness, richness, and diversity in February and May. This is likely to be the result of recruitment during the latter months, similar to that found in subtributaries of the Pamlico River (West 1985) but may have been affected by increasing river flow during February, March, and April transporting organisms from upstream areas to the sampling stations. The only index which showed a statistical difference among stations was richness. The differences can be partly explained by the differences in sediment type for stations 4 (sandy) and 7 (silty) but there is no clear explanation for the differences between station 3 and stations 5 and 8.

Oligochaetes and *Corbicula* were the dominant taxa in the present study and that of Kirby-Smith and VanDover (1979). Among the Chironomidae, both studies found that *Coleotanypus*, *Polypedilum*, and *Chironomus* were the most abundant genera. Nine genera of Chironomidae were collected in the present study that were not reported by Kirby-Smith and VanDover (1979): *Cladotanytarsus*, *Dicrotendipes*, *Endochironomus*, *Nanocladius*, *Pagastiella*, *Parachironomus*, *Paralauterborniella*, *Phaenospectra*, and *Xenochironomus*. Kirby-Smith and VanDover sampled only during August and September. Of the nine additional genera, only *Nanocladius* was collected in September in the present study; thus these differences may reflect seasonal abundances. All of these genera have been reported previously from the lower Roanoke River (NCDEM 1991). There are further differences between Kirby-Smith and VanDover (1979) and the present study: *Cyathura polita* was collected three river miles further upstream in the present study in all months sampled; unionid clams and mayflies, which were abundant in 1978, were not abundant in the present study.

Many of the taxa collected during the present study were low in abundance and therefore estimates of their abundance could not be adequately represented within the current budgetary constraints. These taxa comprised only a small precentage of the total benthic macroinvertebrate fauna: the abundant taxa were adequately represented in the samples and therefore would present a reliable view of the benthic macroinvertebrate community.

Only two juvenile *Alasmidonta* and no adults were collected in the present study. The genus *Alasmidonta* is represented by six species in North Carolina, *A. heterodon*, *A. raveneliana*, *A. robusta* (all endangered), *A. varicosa* (threatened), *A. undulata* (special concern), and *A. viridis* (special concern) (Williams et al. 1993). Clarke (1983) did not find any unionid clams from six locations on the Roanoke and Cooper (1992) found only one living unionid specimen in the lower river, *Elliptio roanokensis*. The asian clam, *Corbicula fluminea*, has been reported as abundant in certain areas of the Roanoke River (Kirby-Smith and VanDover 1979; Clarke 1983; NCDEM 1991). The size range (up to 38 mm) and mode (27 mm) of *Corbicula* was much greater in the present study than in Kirby-Smith and VanDover (1979: up to 24 mm; mode of 2 mm).

The majority of benthic organisms collected in this study have a wide range of tolerance to organic pollution (Klemm et al. 1990) and the resulting Hilsenhoff index indicated only fair water quality. Those organisms collected that were relatively intolerant of organic pollution (*Amnicola*, *Alasmidonta*) were found in low abundance. Mayflies were also rare in the collections but not all habitats were sampled.

The answer to the question of the Plymouth mill's effluent having a demonstrable effect upon the benthic fauna in the lower river must take into account that the upstream sampling stations may be affected by upstream discharges. There are 14 NPDES permitted discharges to the river and 41 within the watershed (Briggs 1991). These discharges, as well as non-point sources such as agricultural and municipal runoff, could affect the "control" stations used in this study. Thus, the indices used to predict changes from upstream to downstream of the discharge could be comparing only those organisms that have a similar tolerance.

The Shannon-Weaver mean diversity index and the Shannon diversity index both indicated that there was no significant difference in benthos among stations, which would be expected if similarly tolerant organisms were present at upstream and downstream stations. The significant difference by month was attributable to seasonal changes with increasing recruitment occurring in February and May. The common taxa index indicated a decline in the number of taxa between the control stations continuing downstream to an apparent recovery at the most downstream pair of stations. These indices do not take into account any biological differences in microhabitat, and although the sediment types were similar, there may be unmeasured factors that influence the macroinvertebrate community.

Acknowledgments

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APPENDIX

Table 1. Results of repetitive sorting of February samples with abundant detritus. Number of organisms does not include molluscs. Totals may not agree with taxa lists due to differences in counting oligochaetes.

Sample	Number of sort 1	2	3	Percent missed	Comments
1-1	89	5	0	5.3	Small oligochaetes
1-2	67	8	0	10.7	Small oligochaetes and one chironomid
1-3	81	3	0	3.5	Small oligochaetes and one chironomid
1-4	136	4	0	2.8	Small oligochaetes
1-5	162	10	0	5.8	Small oligochaetes
Total	565	30	0	5.3	
6-1	112	10	0	8.9	Chironomids
6-2	56	0	0	0	
6-3	70	5	0	6.7	Chironomids
6-4	65	6	0	8.4	Chironomids
6-5	52	2	0	3.7	Chironomids
Total	355	23	0	6.1	
8-1	67	4	0	5.6	Chironomids
8-2	97	2	0	2.0	Chironomids
8-3	88	3	0	3.3	Chironomids
8-4	56	3	0	5.1	Chironomids
8-5	62	1	0	1.6	Chironomids
Total	370	13	0	3.4	
			Overall	4.9	

Table 2. Summary of water quality measurements from the Roanoke River, 1992-93. Temperature and dissolved oxygen values represent the mean of surface, mid-depth and bottom measurements at each station. Conductivity was below the detection limit (500 umhos) of the instrument used. Salinity, if present, was less than 0.1 ppt.

Date	Station	Temp.	D.O.	% satur.	pH
7 Sept	1	26.3	4.4	54.5	6.6
	2	26.3	4.2	52.0	7.1
	3	26.4	4.1	50.9	7.3
	4	26.4	4.0	49.7	7.3
	5	27.1	3.9	49.0	7.3
	6	26.9	3.7	46.3	7.3
8 Sept	7	26.5	4.1	51.0	7.0
	8	27.0	3.8	47.7	7.3
	9	27.4	3.4	43.0	7.1
	10	27.1	3.6	45.2	7.2
8 Feb	1	5.9	11.4	91.3	—
	2	5.9	11.6	92.9	—
	3	5.8	11.2	90.4	—
	4	5.8	11.2	90.4	—
9 Feb	5	5.8	11.2	90.4	7.2
	6	5.5	11.2	88.8	7.2
	7	5.5	11.4	90.4	7.6
	8	5.5	11.3	89.6	7.8
	9	5.8	11.3	90.3	7.8
	10	5.8	11.2	90.4	7.8
12 May	1	18.7	5.9	63.2	7.4
	2	18.7	5.5	58.9	6.7
	3	19.0	5.0	53.9	7.0
	4	18.0	5.5	58.1	7.0
13 May	5	18.3	5.5	58.4	6.9
	6	18.2	5.8	61.5	7.1
	7	18.2	5.8	61.5	7.2
	8	18.2	5.8	61.5	7.4
14 May	9	17.0	5.4	55.8	7.0
	10	17.0	5.4	55.8	7.1

Figure 1. Confidence curves for determination of the approximate number of samples required. Source: Methods for the Examination of Waters and Associated Materials; General Principles of Sampling and Accuracy of results. 1980. Her Majesty's Stationery Office, London, England.

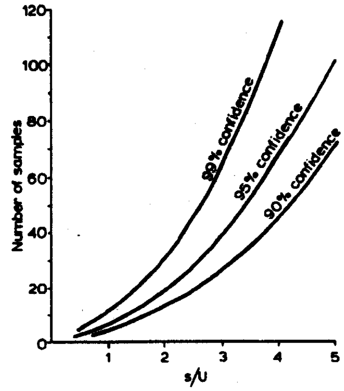

Table 3. Determination of the number of sample units required to be within 50% and 80% of the mean for five common taxa, based on the collections made in September, 1992. Calculations were made from the graph in Figure 1 where s is the standard deviation and U is the level of uncertainty (50% or 20% of the mean).

DATE	STA	TAXA	REPLICATE 1	2	3	4	5	Standard deviation (mean)	s/U	Uncertainty level 50% Samples required	20%
Sept	8	Coleotanypus sp.	3	5	7	6	4	2.92965	2.93/1.7	10	
Sept	3	Coleotanypus sp.	2	0	4	2	1	(3.4)	2.93/0.68		63
Sept	7	Coleotanypus sp.	3	0	4	5	0				
Sept	6	Coleotanypus sp.	4	6	7	2	6				
Sept	10	Coleotanypus sp.	7	14	4	5	2				
Sept	5	Coleotanypus sp.	1	7	1	0	2				
Sept	9	Coleotanypus sp.	0	1	0	2	2				
Sept	6	Corbicula fluminea	8	22	6	0	0	19.4499	19.45/10.	18	
Sept	10	Corbicula fluminea	2	8	18	50	3	(20.7)	19.45/4.1		92
Sept	9	Corbicula fluminea	47	62	53	44	44				
Sept	8	Corbicula fluminea	42	48	44	43	37				
Sept	4	Corbicula fluminea	13	44	40	36	33				
Sept	3	Corbicula fluminea	2	1	11	5	3				
Sept	2	Corbicula fluminea	11	13	14	8	8				
Sept	1	Corbicula fluminea	1	1	2	1	1				
Sept	2	Gammarus fasciatus	3	2	8	3	0	2.87423	2.87/0.85	38	
Sept	8	Gammarus fasciatus	2	0	1	0	0	(1.7)	2.87/0.34		>280
Sept	10	Gammarus fasciatus	0	2	10	3	1				
Sept	9	Gammarus fasciatus	0	1	0	0	0				
Sept	1	Gammarus fasciatus	0	0	0	2	0				
Sept	4	Gammarus fasciatus	1	2	1	1	2				
Sept	6	Gammarus fasciatus	13	1	1	0	0				
Sept	5	Oligochaeta	67	54	66	31	38	30.6157	30.62/27.	6	
Sept	1	Oligochaeta	45	51	51	45	59	(54.6)	30.62/10.9		35
Sept	10	Oligochaeta	58	149	92	41	46				
Sept	9	Oligochaeta	57	34	17	43	42				
Sept	3	Oligochaeta	20	29	25	59	17				
Sept	7	Oligochaeta	35	70	51	59	49				
Sept	6	Oligochaeta	88	38	70	104	101				
Sept	8	Oligochaeta	115	109	111	104	91				
Sept	2	Oligochaeta	6	18	23	14	58				
Sept	4	Oligochaeta	36	43	37	34	30				

Table 4. List of benthic organisms collected in the Roanoke River with common names.

Taxa	Common name	Referenced as:
Turbellaria	Flatworms	
Nematoda	Roundworms	
Annelida	Aquatic earthworms	
		Oligochaeta
		Peloscolex
	Leeches	Piscicolidae
		Glossiphoniidae
	Freshwater polychaete	*Manyunkia speciosa*
Crustacea		
	Amphipods	*Gammarus fasciatus*
		Hyallela azteca
	Isopods	*Cyathura polita*
		Asellus
Ephemeroptera	Mayflies	
		Stenonema
		Hexagenia
Odonata	Dragonflies	
		Dromogomphus
		Somatochlora
Megaloptera	Alderflies	
		Sialis
Trichoptera	Stoneflies	
		Cymellus
		Hydropsyche
		Lepidostoma
		Nectopsyche
		Oecetis
		Oecetis pupa
		Phylocentropus
Coleoptera	Beetles	
		Ancyronyx
		Hydroporus
		unid. beetle larva
Neuroptera	Spongillaflies	
		Sisyra
Hemiptera	True bugs	
		Corixidae
Diptera	Midges	
		Chaoborus
		Palpomyia
		Ablabesmyia
		Chironomus
		Cladotanytarsus
		Coleotanypus
		Cryptochironomus
		Dicrotendipes
		Endochironomus
		Glyptotendipes
		Nanocladius
		Pagastiella
		Parachironomus
		Parachironomus pupa
		Paracladopelma
		Paralauterborniella
		Phaenospectra
		Polypedilum
		Procladius
		Tanytarsus
		Xenochironomus
		unid. Orthocladinae
		unid. chironomidae
		diptera pupa
	Flower fly	Syrphidae

Table 4. continued.

Taxa	Common name	Referenced as:
Planaria	Hydrolimax grisea	Hydrolimax grisea
Mollusca		
Pelecypods	**Asian freshwater clam**	***Corbicula fluminea***
	Peaclam	***Pisidium***
	Atlantic rangia	***Rangia cuneata***
	Fingernail clam	***Sphaerium***
	Unionid mussel	***Alasmidonta sp.***
Gastropods		
	Duskysnail	***Amnicola***
	Rams-horn	***Heliosoma***
	Ancylid	***Laevapex***
	Physa	***Physa***

Table 5. Benthic organisms collected by petite ponar dredge in the Roanoke River. Volumes are the amount of sediment collected per sample.

DATE	STA	TAXA	REPLICATE 1	REPLICATE 2	REPLICATE 3	REPLICATE 4	REPLICATE 5	sum TOTAL	volume Density (cm3)	No./m2 area 0.0235	% of total
		VOL* (cm3)	2000	2000	1800	2000	1900	9700			
Sept	1	Gammarus fasciatus				2		2	0.0002	17.0	0.7
Sept	1	Oligochaeta	45	51	51	45	59	251	0.0259	2136.2	86.9
Sept	1	Pisidium sp.	1		1	2	1	5	0.0005	42.6	1.7
Sept	1	Corbicula fluminea	1	1	2	1	1	6	0.0006	51.1	2.1
Sept	1	Alasmidonta sp.				1		1	0.0001	8.5	0.3
Sept	1	Chaoborus sp.					1	1	0.0001	8.5	0.3
Sept	1	Coleotanypus sp.	3	3	3	3	3	15	0.0015	127.7	5.2
Sept	1	Ablabesmyia sp.					1	1	0.0001	8.5	0.3
Sept	1	Nanocladius sp.	1	1	1			3	0.0003	25.5	1.0
Sept	1	Polypedilum sp.		1		1	1	3	0.0003	25.5	1.0
Sept	1	Peloscolex sp.				1		1	0.0001	8.5	0.3
		Total	51	57	58	56	67	289	0.0298	2459.6	100
		Density by volume	0.026	0.029	0.032	0.028	0.035	0.0298			
		Density by area	2170	2426	2468	2383	2851	2459.6			

DATE	STA	TAXA	REPLICATE 1	REPLICATE 2	REPLICATE 3	REPLICATE 4	REPLICATE 5	sum TOTAL	volume Density (cm3)	No./m2 area 0.0235	% of total
		VOL* (cm3)	500	400	500	500	1000	2900			
Sept	2	Gammarus fasciatus	3	2	8	3		16	0.0055	136.2	8.0
Sept	2	Oligochaeta	6	18	23	14	58	119	0.0410	1012.8	59.2
Sept	2	Corbicula fluminea	11	13	14	8	8	54	0.0186	459.6	26.9
Sept	2	Alasmidonta sp.			1			1	0.0003	8.5	0.5
Sept	2	Chaoborus sp.	1					1	0.0003	8.5	0.5
Sept	2	Cyathura polita	1	1		1		3	0.0010	25.5	1.5
Sept	2	Laevapex sp.		1				1	0.0003	8.5	0.5
Sept	2	Ancyronyx sp.	1					1	0.0003	8.5	0.5
Sept	2	Coleotanypus sp.			1		1	2	0.0007	17.0	1.0
Sept	2	Nanocladius sp.			1			1	0.0003	8.5	0.5
Sept	2	Polypedilum sp.	1	1				2	0.0007	17.0	1.0
		Total	24	36	48	26	67	201	0.0693	1710.6	100
		Density by volume	0.048	0.09	0.096	0.052	0.067	0.0693			
		Density by area	1021	1532	2043	1106	2851	1710.6			

DATE	STA	TAXA	REPLICATE 1	REPLICATE 2	REPLICATE 3	REPLICATE 4	REPLICATE 5	sum TOTAL	volume Density (cm3)	No./m2 area 0.0235	% of total
		VOL* (cm3)	1100	1000	1500	1500	1500	6600			
Sept	3	Gammarus fasciatus		1				1	0.0002	8.5	0.5
Sept	3	Oligochaeta	20	29	25	59	17	150	0.0227	1276.6	72.1
Sept	3	Corbicula fluminea	2	1	11	5	3	22	0.0033	187.2	10.6
Sept	3	Dromogomphus sp.	1					1	0.0002	8.5	0.5
Sept	3	Nematoda			1			1	0.0002	8.5	0.5
Sept	3	Chaoborus sp.	2		1			3	0.0005	25.5	1.4
Sept	3	Cyathura polita	3	2	4	1	7	17	0.0026	144.7	8.2
Sept	3	Coleotanypus sp.	2		4	2	1	9	0.0014	76.6	4.3
Sept	3	Procladius sp.		1				1	0.0002	8.5	0.5
Sept	3	Nanocladius sp.		1		1		2	0.0003	17.0	1.0
Sept	3	Polypedilum sp.				1		1	0.0002	8.5	0.5
		Total	30	35	46	69	28	208	0.0315	1770.2	100
		Density by volume	0.027	0.035	0.031	0.046	0.019	0.0315			
		Density by area	1277	1489	1957	2936	1191	1770.2			

Table 5. continued.

					REPLICATE			sum	volume	No./m2	%
		VOL* (cm3)	1500	1300	1000	1000	1200	6000	Density	area	of
DATE	STA	TAXA	1	2	3	4	5	TOTAL	(cm3)	0.0235	total
Sept	4	Gammarus fasciatus	1	2	1	1	2	7	0.0012	59.6	1.9
Sept	4	Oligochaeta	36	43	37	34	30	180	0.0300	1531.9	49.2
Sept	4	Corbicula fluminea	13	44	40	36	33	166	0.0277	1412.8	45.4
Sept	4	Dromogomphus sp.			1			1	0.0002	8.5	0.3
Sept	4	Chaoborus sp.	1					1	0.0002	8.5	0.3
Sept	4	Cyathura polita				2	1	3	0.0005	25.5	0.8
Sept	4	Coleotanypus sp.		3	2	1		6	0.0010	51.1	1.6
Sept	4	Nanocladius sp.			1			1	0.0002	8.5	0.3
Sept	4	Polypedilum sp.			1			1	0.0002	8.5	0.3
		Total	51	92	83	74	66	366	0.0610	3114.9	100
		Density by volume	0.034	0.071	0.083	0.074	0.055	0.061			
		Density by area	2170	3915	3532	3149	2809	3114.9			

					REPLICATE			sum	volume	No./m2	%
		VOL* (cm3)	1500	1800	1800	1800	1900	8800	Density	area	of
DATE	STA	TAXA	1	2	3	4	5	TOTAL	(cm3)	0.0235	total
Sept	5	Oligochaeta	67	54	66	31	38	256	0.0291	2178.7	90.1
Sept	5	Pisidium sp.	1	5	5	1	2	14	0.0016	119.1	4.9
Sept	5	Dromogomphus sp.					1	1	0.0001	8.5	0.4
Sept	5	Nematoda			1			1	0.0001	8.5	0.4
Sept	5	Coleotanypus sp.	1	7	1		2	11	0.0013	93.6	3.9
Sept	5	Nanocladius sp.				1		1	0.0001	8.5	0.4
		Total	69	66	73	33	43	284	0.0323	2417.0	100
		Density by volume	0.046	0.037	0.041	0.018	0.023	0.0323			
		Density by area	2936	2809	3106	1404	1830	2417			

					REPLICATE			sum	volume	No./m2	%
		VOL* (cm3)	500	1300	1600	1500	1400	6300	Density	area	of
DATE	STA	TAXA	1	2	3	4	5	TOTAL	(cm3)	0.0235	total
Sept	6	Gammarus fasciatus	13	1	1			15	0.0024	127.7	3.0
Sept	6	Oligochaeta	88	38	70	104	101	401	0.0637	3412.8	80.2
Sept	6	Pisidium sp.			1			1	0.0002	8.5	0.2
Sept	6	Corbicula fluminea	8	22	6			36	0.0057	306.4	7.2
Sept	6	Sphaerium sp.			1			1	0.0002	8.5	0.2
Sept	6	Chaoborus sp.				1	2	3	0.0005	25.5	0.6
Sept	6	Hydrolimax grisea	3					3	0.0005	25.5	0.6
Sept	6	Oecetis sp.			2			2	0.0003	17.0	0.4
Sept	6	Coleotanypus sp.	4	6	7	2	6	25	0.0040	212.8	5.0
Sept	6	Nanocladius sp.	2	2		1		5	0.0008	42.6	1.0
Sept	6	Polypedilum sp.	6		1			7	0.0011	59.6	1.4
Sept	6	Ablabesmyia sp.	1					1	0.0002	8.5	0.2
		Total	125	69	89	108	109	500	0.0794	4255.3	100
		Density by volume	0.25	0.053	0.056	0.072	0.078	0.0794			
		Density by area	5319	2936	3787	4596	4638	4255.3			

					REPLICATE			sum	volume	No./m2	%
		VOL* (cm3)	1600	1800	1700	1700	2000	8800	Density	area	of
DATE	STA	TAXA	1	2	3	4	5	TOTAL	(cm3)	0.0235	total
Sept	7	Oligochaeta	35	70	51	59	49	264	0.0300	2246.8	88.6
Sept	7	Pisidium sp.	2		5	7	2	16	0.0018	136.2	5.4
Sept	7	Nematoda		1	1	1		3	0.0003	25.5	1.0
Sept	7	Chaoborus sp.					1	1	0.0001	8.5	0.3
Sept	7	Oecetis pupa				1		1	0.0001	8.5	0.3
Sept	7	Coleotanypus sp.	3		4	5		12	0.0014	102.1	4.0
Sept	7	Nanocladius sp.			1			1	0.0001	8.5	0.3
		Total	40	71	62	73	52	298	0.0339	2536.2	100
		Density by volume	0.025	0.039	0.036	0.043	0.026	0.0339			
		Density by area	1702	3021	2638	3106	2213	2536.2			

Table 5. continued.

DATE	STA	VOL* (cm3) TAXA	REPLICATE 1700 1	1900 2	1800 3	1900 4	1500 5	sum 8800 TOTAL	volume Density (cm3)	No./m2 area 0.0235	% of total
Sept	8	**Gammarus fasciatus**	2		1			3	0.0003	25.5	0.4
Sept	8	**Oligochaeta**	115	109	111	104	91	530	0.0602	4510.6	67.7
Sept	8	**Corbicula fluminea**	42	48	44	43	37	214	0.0243	1821.3	27.3
Sept	8	**Sphaerium sp.**					1	1	0.0001	8.5	0.1
Sept	8	**Dromogomphus sp.**				1		1	0.0001	8.5	0.1
Sept	8	**Chaoborus sp.**		1				1	0.0001	8.5	0.1
Sept	8	**Cyathura polita**		1				1	0.0001	8.5	0.1
Sept	8	**Oecetis sp.**		2			2	4	0.0005	34.0	0.5
Sept	8	**Diptera pupa**		1				1	0.0001	8.5	0.1
Sept	8	**Coleotanypus sp.**	3	5	7	6	4	25	0.0028	212.8	3.2
Sept	8	**Nanocladius sp.**			1			1	0.0001	8.5	0.1
Sept	8	**Procladius sp.**		1				1	0.0001	8.5	0.1
		Total	162	168	164	154	135	783	0.0890	6663.8	100
		Density by volume	0.095	0.088	0.091	0.081	0.09	0.0890			
		Density by area	6894	7149	6979	6553	5745	6663.8			

DATE	STA	VOL* (cm3) TAXA	REPLICATE 1500 1	1600 2	1400 3	1800 4	1500 5	sum 7800 TOTAL	volume Density (cm3)	No./m2 area 0.0235	% of total
Sept	9	**Gammarus fasciatus**		1				1	0.0001	8.5	0.2
Sept	9	**Oligochaeta**	57	34	17	43	42	193	0.0247	1642.6	41.6
Sept	9	**Corbicula fluminea**	47	62	53	44	44	250	0.0321	2127.7	53.9
Sept	9	**Nematoda**			1			1	0.0001	8.5	0.2
Sept	9	**Chaoborus sp.**		1				1	0.0001	8.5	0.2
Sept	9	Hydrolimax grisea					1	1	0.0001	8.5	0.2
Sept	9	**Cyathura polita**			1			1	0.0001	8.5	0.2
Sept	9	**Oecetis sp.**			1			1	0.0001	8.5	0.2
Sept	9	**Sialis sp.**	1					1	0.0001	8.5	0.2
Sept	9	**Laevapex sp.**			1			1	0.0001	8.5	0.2
Sept	9	**Coleotanypus sp.**		1		2	2	5	0.0006	42.6	1.1
Sept	9	**Polypedilum sp.**	1		1	4	1	7	0.0009	59.6	1.5
Sept	9	**Procladius sp.**			1			1	0.0001	8.5	0.2
		Total	106	99	76	93	90	464	0.0595	3948.9	100
		Density by volume	0.071	0.062	0.054	0.052	0.06	0.0595			
		Density by area	4511	4213	3234	3957	3830	3948.9			

DATE	STA	VOL* (cm3) TAXA	REPLICATE 1800 1	1800 2	1100 3	1500 4	1800 5	sum 8000 TOTAL	volume Density (cm3)	No./m2 area 0.0235	% of total
Sept	10	**Gammarus fasciatus**		2	10	3	1	16	0.0020	136.2	3.0
Sept	10	**Oligochaeta**	58	149	92	41	46	386	0.0483	3285.1	72.7
Sept	10	**Corbicula fluminea**	2	8	18	50	3	81	0.0101	689.4	15.3
Sept	10	**Rangia cuneata**			1			1	0.0001	8.5	0.2
Sept	10	**Dromogomphus sp.**	1					1	0.0001	8.5	0.2
Sept	10	**Chaoborus sp.**	1					1	0.0001	8.5	0.2
Sept	10	Hydrolimax grisea		2		1		3	0.0004	25.5	0.6
Sept	10	**Oecetis pupa**				1		1	0.0001	8.5	0.2
Sept	10	**Diptera pupa**				1		1	0.0001	8.5	0.2
Sept	10	**Sialis sp.**					1	1	0.0001	8.5	0.2
Sept	10	**Palpomyia sp.**	1					1	0.0001	8.5	0.2
Sept	10	**Amnicola sp.**				1		1	0.0001	8.5	0.2
Sept	10	**Coleotanypus sp.**	7	14	4	5	2	32	0.0040	272.3	6.0
Sept	10	**Nanocladius sp.**	1	2			1	4	0.0005	34.0	0.8
Sept	10	**Ablabesmyia sp.**	1					1	0.0001	8.5	0.2
		Total	72	177	125	103	54	531	0.0664	4519.1	100
		Density by volume	0.04	0.098	0.114	0.069	0.03	0.0664			
		Density by area	3064	7532	5319	4383	2298	4519.1			

Table 5. continued.

DATE	STA	TAXA	1	2	3	4	5	Total	volume Density (cm3)	No./m2 area 0.0235m	% of total
		VOL*(cm3)	1600	2000	1700	1800	1800	8900			
					REPLICATE						
Feb	1	Gammarus fasciatus			4	3	4	11	0.0012	93.62	2.5
Feb	1	Oligochaeta	40	34	31	92	97	294	0.0330	2502.13	65.8
Feb	1	Pisidium sp.	1		1			2	0.0002	17.02	0.4
Feb	1	Corbicula fluminea					2	2	0.0002	17.02	0.4
Feb	1	Sphaerium sp.			1	1	1	3	0.0003	25.53	0.7
Feb	1	Dromogomphus sp.	1	1				2	0.0002	17.02	0.4
Feb	1	Chaoborus sp.					2	2	0.0002	17.02	0.4
Feb	1	Hydrolimax grisea				3	1	4	0.0004	34.04	0.9
Feb	1	Phylocentropus sp.	2		1	2		5	0.0006	42.55	1.1
Feb	1	Nectopsyche sp.			1			1	0.0001	8.51	0.2
Feb	1	Sialis sp.					1	1	0.0001	8.51	0.2
Feb	1	Coleotanypus sp.	4	8	8	8	6	34	0.0038	289.36	7.6
Feb	1	Procladius sp.	2			1	2	5	0.0006	42.55	1.1
Feb	1	Chironomus sp.	16	13	10	14	13	66	0.0074	561.70	14.8
Feb	1	Nanocladius sp.			2			2	0.0002	17.02	0.4
Feb	1	Glyptotendipes sp.				7	1	8	0.0009	68.09	1.8
Feb	1	Cryptochironomus sp.					1	1	0.0001	8.51	0.2
Feb	1	Peloscolex sp.			3	1	1	5	0.0006	42.55	1.1
		Total	66	56	62	132	132	448	0.0503	3812.77	100
		Density by volume	0.041	0.028	0.0365	0.0733	0.073	0.0503			
		Density by area	2809	2383	2638.3	5617	5617	3812.8			

DATE	STA	TAXA	1	2	3	4	5	Total	volume Density (cm3)	No./m2 area 0.0235m	% of total
		VOL*(cm3)	600	500	1200	600	500	3400			
					REPLICATE						
Feb	2	Gammarus fasciatus	6	2			2	10	0.0029	85.11	5.0
Feb	2	Oligochaeta	25	16	15	20	13	89	0.0262	757.45	44.5
Feb	2	Pisidium sp.		1			1	2	0.0006	17.02	1.0
Feb	2	Corbicula fluminea	1		15	10	8	34	0.0100	289.36	17.0
Feb	2	Sphaerium sp.		1			5	6	0.0018	51.06	3.0
Feb	2	Dromogomphus sp.					1	1	0.0003	8.51	0.5
Feb	2	Nematoda		1				1	0.0003	8.51	0.5
Feb	2	Chaoborus sp.				1		1	0.0003	8.51	0.5
Feb	2	Cyathura polita			3		1	4	0.0012	34.04	2.0
Feb	2	Palpomyia sp.	1					1	0.0003	8.51	0.5
Feb	2	Coleotanypus sp.	8	3	6	11	1	29	0.0085	246.81	14.5
Feb	2	Chironomus sp.		2	2			4	0.0012	34.04	2.0
Feb	2	Nanocladius sp.	3	3	2	2		10	0.0029	85.11	5.0
Feb	2	Polypedilum sp.					1	1	0.0003	8.51	0.5
Feb	2	Somatochlora sp.	1					1	0.0003	8.51	0.5
Feb	2	Piscicolidae	1					1	0.0003	8.51	0.5
Feb	2	Endochironomus sp.			2			2	0.0006	17.02	1.0
Feb	2	Phaenospectra sp.					1	1	0.0003	8.51	0.5
Feb	2	Stenonema sp.					1	1	0.0003	8.51	0.5
Feb	2	Peloscolex sp.					1	1	0.0003	8.51	0.5
		Total	46	29	45	44	36	200	0.0588	1702.13	100
		Density by volume	0.08	0.06	0.04	0.07	0.07	0.06			
		Density by area	1957	1234	1914.9	1872.3	1532	1702.1			

Table 5. continued.

DATE	STA	TAXA	VOL* (cm3) 1000 REPLICATE 1	1000 2	1000 3	500 4	1000 5	4500 Total	volume Density (cm3)	No./m2 area 0.0235m	% of total
Feb	3	Gammarus fasciatus	1	4	1	3	8	17	0.0038	144.68	5.0
Feb	3	Oligochaeta	38	45	34	39	44	200	0.0444	1702.13	58.8
Feb	3	Pisidium sp.					1	1	0.0002	8.51	0.3
Feb	3	Corbicula fluminea			1	1		2	0.0004	17.02	0.6
Feb	3	Sphaerium sp.			1			1	0.0002	8.51	0.3
Feb	3	Dromogomphus sp.				1	1	2	0.0004	17.02	0.6
Feb	3	Nematoda				1		1	0.0002	8.51	0.3
Feb	3	Chaoborus sp.		1	1		3	5	0.0011	42.55	1.5
Feb	3	Hydrolimax grisea	1					1	0.0002	8.51	0.3
Feb	3	Phylocentropus sp.					1	1	0.0002	8.51	0.3
Feb	3	Cyathura polita	2	2	7	8	2	21	0.0047	178.72	6.2
Feb	3	Coleotanypus sp.	10	3	6	5	12	36	0.0080	306.38	10.6
Feb	3	Procladius sp.	7		2	1	1	11	0.0024	93.62	3.2
Feb	3	Chironomus sp.	4				1	5	0.0011	42.55	1.5
Feb	3	Nanocladius sp.				6		6	0.0013	51.06	1.8
Feb	3	Polypedilum sp.		3	6		4	13	0.0029	110.64	3.8
Feb	3	Glyptotendipes sp.	1	1				2	0.0004	17.02	0.6
Feb	3	Paralauterborniella sp	1			2		3	0.0007	25.53	0.9
Feb	3	Hydropsyche sp.		2				2	0.0004	17.02	0.6
Feb	3	Tanytarsus sp.	2					2	0.0004	17.02	0.6
Feb	3	Hexagenia sp.			1	1	1	3	0.0007	25.53	0.9
Feb	3	Cyrnellus sp.			2			2	0.0004	17.02	0.6
Feb	3	unid. chironomidae-1			1			1	0.0002	8.51	0.3
Feb	3	Peloscolex sp.			1			1	0.0002	8.51	0.3
Feb	3	Xenochironomus sp.	1					1	0.0002	8.51	0.3
		Total	68	61	64	68	79	340	0.0756	2893.62	100
		Density by volume	0.068	0.061	0.064	0.136	0.079	0.0756			
		Density by area	2894	2596	2723	2893.6	3362	2893.6			

DATE	STA	TAXA	VOL* (cm3) 1100 REPLICATE 1	500 2	500 3	700 4	800 5	3600 Total	volume Density (cm3)	No./m2 area 0.0235m	% of total
Feb	4	Gammarus fasciatus	3	11	4	3	2	23	0.0064	195.74	9.5
Feb	4	Oligochaeta	26	18	9	16	23	92	0.0256	782.98	37.9
Feb	4	Pisidium sp.			1			1	0.0003	8.51	0.4
Feb	4	Corbicula fluminea		1	1	1		3	0.0008	25.53	1.2
Feb	4	Sphaerium sp.		5				5	0.0014	42.55	2.1
Feb	4	Dromogomphus sp.		2		1		3	0.0008	25.53	1.2
Feb	4	Nematoda	1					1	0.0003	8.51	0.4
Feb	4	Chaoborus sp.		1				1	0.0003	8.51	0.4
Feb	4	Cyathura polita	1	3	2	1		7	0.0019	59.57	2.9
Feb	4	Coleotanypus sp.	23	30	20	11	12	96	0.0267	817.02	39.5
Feb	4	Procladius sp.	1	1				2	0.0006	17.02	0.8
Feb	4	Nanocladius sp.			1		1	2	0.0006	17.02	0.8
Feb	4	Endochironomus sp.					1	1	0.0003	8.51	0.4
Feb	4	Cyrnellus sp.				1		1	0.0003	8.51	0.4
Feb	4	Glyptotendipes sp.		2	2			4	0.0011	34.04	1.6
Feb	4	unid. chironomidae-1					1	1	0.0003	8.51	0.4
		Total	55	74	40	34	40	243	0.0675	2068.09	100
		Density by volume	0.05	0.15	0.08	0.05	0.05	0.07			
		Density by area	2340	3149	1702	1446.8	1702	2068.1			

Table 5. continued.

DATE	STA	TAXA	REPLICATE						volume	No./m2	%
		VOL* (cm3)	1800	1800	1800	1800	1800	9000	Density	area	of
			1	2	3	4	5	Total	(cm3)	0.0235m	total
Feb	5	Gammarus fasciatus	2	2		1		5	0.0006	42.55	1.7
Feb	5	Oligochaeta	32	39	34	27	27	159	0.0177	1353.19	54.1
Feb	5	Pisidium sp.			1			1	0.0001	8.51	0.3
Feb	5	Corbicula fluminea		1				1	0.0001	8.51	0.3
Feb	5	Sphaerium sp.	4	1	1	8	6	20	0.0022	170.21	6.8
Feb	5	Coleotanypus sp.	14	20	15	18	18	85	0.0094	723.40	28.9
Feb	5	Procladius sp.	3		1	1		5	0.0006	42.55	1.7
Feb	5	Chironomus sp.	5		2		2	9	0.0010	76.60	3.1
Feb	5	Polypedilum sp.	1					1	0.0001	8.51	0.3
Feb	5	Cryptochironomus sp	1	3	1			5	0.0006	42.55	1.7
Feb	5	Endochironomus sp.			1			1	0.0001	8.51	0.3
Feb	5	Hexagenia sp.			1	1		2	0.0002	17.02	0.7
		Total	62	66	57	56	53	294	0.0327	2502.13	100
		Density by volume	0.03	0.04	0.03	0.03	0.03	0.03			
		Density by area	2638	2809	2426	2383	2255	2502.1			

DATE	STA	TAXA	REPLICATE						volume	No./m2	%
		VOL* (cm3)	1000	1000	800	1000	800	4600	Density	area	of
			1	2	3	4	5	Total	(cm3)	0.0235m	total
Feb	6	Gammarus fasciatus		1			8	9	0.0020	76.6	2.5
Feb	6	Oligochaeta	40	22	45	19	16	142	0.0309	1208.5	39.4
Feb	6	Corbicula fluminea		12	26	2	18	58	0.0126	493.6	16.1
Feb	6	Sphaerium sp.				4		4	0.0009	34.0	1.1
Feb	6	Dromogomphus sp.		1				1	0.0002	8.5	0.3
Feb	6	Nematoda					1	1	0.0002	8.5	0.3
Feb	6	Cyathura polita	2					2	0.0004	17.0	0.6
Feb	6	Coleotanypus sp.	42	15	16	27	10	110	0.0239	936.2	30.6
Feb	6	Procladius sp.				1		1	0.0002	8.5	0.3
Feb	6	Chironomus sp.	1	2	4	2		9	0.0020	76.6	2.5
Feb	6	Peloscolex sp.			1			1	0.0002	8.5	0.3
Feb	6	Polypedilum sp.	2	3	1			6	0.0013	51.1	1.7
Feb	6	Cryptochironomus sp	5	6	9	4	6	30	0.0065	255.3	8.3
Feb	6	Endochironomus sp.				1	1	2	0.0004	17.0	0.6
Feb	6	Dicrotendipes sp.			1			1	0.0002	8.5	0.3
Feb	6	Amnicola sp.			1			1	0.0002	8.5	0.3
Feb	6	Lepidostoma sp.					1	1	0.0002	8.5	0.3
		Total	92	62	104	60	61	379	0.0824	3225.5	100
		Density by volume	0.09	0.06	0.13	0.06	0.08	0.0824			
		Density by area	3915	2638	4426	2553.2	2596	3225.5			

DATE	STA	TAXA	REPLICATE						volume	No./m2	%
		VOL* (cm3)	2000	2000	2100	2000	2000	*****	Density	area	of
			1	2	3	4	5	Total	(cm3)	0.0235m	total
Feb	7	Oligochaeta	26	24	38	27	13	128	0.0127	1089.4	47.9
Feb	7	Pisidium sp.		3	2	1	1	7	0.0007	59.6	2.6
Feb	7	Corbicula fluminea		1	3	1		5	0.0005	42.6	1.9
Feb	7	Sphaerium sp.	2		13	8	22	45	0.0045	383.0	16.9
Feb	7	Nematoda			3		1	4	0.0004	34.0	1.5
Feb	7	Chaoborus sp.				2		2	0.0002	17.0	0.7
Feb	7	Coleotanypus sp.	9	7	17	17	11	61	0.0060	519.1	22.8
Feb	7	Procladius sp.		4			1	5	0.0005	42.6	1.9
Feb	7	Chironomus sp.			2	1		3	0.0003	25.5	1.1
Feb	7	Polypedilum sp.		1				1	0.0001	8.5	0.4
Feb	7	Cryptochironomus sp	3		3			6	0.0006	51.1	2.2
		Total	40	40	81	57	49	267	0.0264	2272.3	100
		Density by volume	0.02	0.02	0.039	0.0285	0.025	0.0264			
		Density by area	1702	1702	3447	2425.5	2085	2272.3			

Table 5. continued.

DATE	STA	TAXA	1	2	3	4	5	Total	volume Density (cm3)	No./m2 area 0.0235m	% of total
					REPLICATE						
		VOL* (cm3)	500	500	500	500	1000	3000.0			
Feb	8	Gammarus fasciatus	2	5	14	2		23	0.0077	195.7	4.1
Feb	8	Oligochaeta	41	58	56	50	58	263	0.0877	2238.3	46.7
Feb	8	Corbicula fluminea	20	29	26	31	26	132	0.0440	1123.4	23.4
Feb	8	Oecetis sp.		1		1		2	0.0007	17.0	0.4
Feb	8	Coleotanypus sp.	24	36	13	13	17	103	0.0343	876.6	18.3
Feb	8	Procladius sp.	2		1			3	0.0010	25.5	0.5
Feb	8	Chironomus sp.	1					1	0.0003	8.5	0.2
Feb	8	Cryptochironomus sp	11	4	9	4	5	33	0.0110	280.9	5.9
Feb	8	Dicrotendipes sp.		2				2	0.0007	17.0	0.4
Feb	8	Peloscolex sp.	1					1	0.0003	8.5	0.2
		Total	102	135	119	101	106	563	0.1877	4791.5	100
		Density by volume	0.204	0.27	0.238	0.202	0.106	0.1877			
		Density by area	4340	5745	5064	4297.9	4511	4791.5			

DATE	STA	TAXA	1	2	3	4	5	Total	volume Density (cm3)	No./m2 area 0.0235m	% of total
					REPLICATE						
		VOL* (cm3)	1800	1500	1500	1500	1500	7800.0			
Feb	9	Gammarus fasciatus		2	1		1	4	0.0005	34.04	1.2
Feb	9	Oligochaeta	30	41	23	23	22	139	0.0178	1182.98	41.1
Feb	9	Pisidium sp.					1	1	0.0001	8.51	0.3
Feb	9	Corbicula fluminea		3	38	24	20	85	0.0109	723.40	25.1
Feb	9	Sphaerium sp.		2				2	0.0003	17.02	0.6
Feb	9	Dromogomphus sp.	1		1			2	0.0003	17.02	0.6
Feb	9	Hydrolimax grisea	1	2				3	0.0004	25.53	0.9
Feb	9	Cyathura polita		1				1	0.0001	8.51	0.3
Feb	9	Oecetis sp.	2		1			3	0.0004	25.53	0.9
Feb	9	diptera pupa		1				1	0.0001	8.51	0.3
Feb	9	Coleotanypus sp.	21	21	9	11	12	74	0.0095	629.79	21.9
Feb	9	Procladius sp.	4	4				8	0.0010	68.09	2.4
Feb	9	Chironomus sp.		2				2	0.0003	17.02	0.6
Feb	9	Hyalella azteca		1				1	0.0001	8.51	0.3
Feb	9	Cryptochironomus sp.		2	1	4	1	8	0.0010	68.09	2.4
Feb	9	Phaenospectra sp.		2				2	0.0003	17.02	0.6
Feb	9	unid. beetle larva			1			1	0.0001	8.51	0.3
Feb	9	Dicrotendipes sp.				1		1	0.0001	8.51	0.3
		Total	59	84	75	63	57	338	0.0433	2876.60	100
		Density by volume	0.033	0.056	0.05	0.042	0.038	0.0433			
		Density by area	2511	3574	3191	2680.9	2426	2876.6			

DATE	STA	TAXA	1	2	3	4	5	Total	volume Density (cm3)	No./m2 area 0.0235m	% of total
					REPLICATE						
		VOL* (cm3)	1800	2100	1500	1600	1500	8500.0			
Feb	10	Gammarus fasciatus	12	8	4	5	3	32	0.0038	272.3	5.8
Feb	10	Oligochaeta	59	65	42	51	37	254	0.0299	2161.7	45.9
Feb	10	Corbicula fluminea	17	13	14	14	4	62	0.0073	527.7	11.2
Feb	10	Sphaerium sp.	2			2	1	5	0.0006	42.6	0.9
Feb	10	Nematoda			2			2	0.0002	17.0	0.4
Feb	10	Phylocentropus sp.		1				1	0.0001	8.5	0.2
Feb	10	Oecetis sp.					1	1	0.0001	8.5	0.2
Feb	10	Sialis sp.				1		1	0.0001	8.5	0.2
Feb	10	Coleotanypus sp.	19	55	30	24	39	167	0.0196	1421.3	30.2
Feb	10	Procladius sp.			1		2	3	0.0004	25.5	0.5
Feb	10	Chironomus sp.	2	1			1	4	0.0005	34.0	0.7
Feb	10	Polypedilum sp.		5	2	2		9	0.0011	76.6	1.6
Feb	10	Orthocladinae		1				1	0.0001	8.5	0.2
Feb	10	Cryptochironomus sp	2	4		1	3	10	0.0012	85.1	1.8
Feb	10	Hexagenia sp.		1				1	0.0001	8.5	0.2
		Total	113	154	95	100	91	553	0.0651	4706.4	100
		Density by volume	0.063	0.073	0.063	0.0625	0.061	0.0651			
		Density by area	4809	6553	4043	4255.3	3872	4706.4			

Table 5. continued.

			REPLICATE						volume	No./m2	%
		VOL* (cm3)	1500	1700	2000	1500	1700	8400	Density	area	of
DATE	STA	TAXA	1	2	3	4	5	Total	(cm3)	0.0235m	total
May	1	Gammarus fasciatus	7	24	13	13	14	71	0.0085	604.26	13.7
May	1	Oligochaeta	49	57	72	62	48	288	0.0343	2451.06	55.7
May	1	Pisidium sp.	5	3		4	1	13	0.0015	110.64	2.5
May	1	Corbicula fluminea	1	4	14	3	2	24	0.0029	204.26	4.6
May	1	Sphaerium sp.	2					2	0.0002	17.02	0.4
May	1	Dromogomphus sp.				1		1	0.0001	8.51	0.2
May	1	Chaoborus sp.		1			1	2	0.0002	17.02	0.4
May	1	Hydrolimax grisea					1	1	0.0001	8.51	0.2
May	1	Oecetis sp.	1			3		4	0.0005	34.04	0.8
May	1	Parachironomus pupa	1					1	0.0001	8.51	0.2
May	1	Coleotanypus sp.	9	6	13	11	14	53	0.0063	451.06	10.3
May	1	Procladius sp.				1		1	0.0001	8.51	0.2
May	1	Chironomus sp.	2	1	3	3		9	0.0011	76.60	1.7
May	1	Nanocladius sp.		2		3		5	0.0006	42.55	1.0
May	1	Polypedilum sp.	8	1	5	11	3	28	0.0033	238.30	5.4
May	1	Cladotanytarsus sp.				5		5	0.0006	42.55	1.0
May	1	Glyptotendipes sp.				3		3	0.0004	25.53	0.6
May	1	Hexagenia sp.	1			1		2	0.0002	17.02	0.4
May	1	Peloscolex sp.	1				3	4	0.0005	34.04	0.8
		Total	87	99	120	124	87	517	0.0615	4400.00	100
		Density by volume	0.058	0.058	0.06	0.083	0.051	0.0615			
		Density by area	3702	4213	5106.4	5277	3702	4400			

			REPLICATE						volume	No./m2	%
		VOL* (cm3)	300	250	250	250	250	1300	Density	area	of
DATE	STA	TAXA	1	2	3	4	5	Total	(cm3)	0.0235m	total
May	2	Gammarus fasciatus	10	7	7	1	30	55	0.0423	468.09	15.4
May	2	Oligochaeta	21	18	11	9	15	74	0.0569	629.79	20.7
May	2	Corbicula fluminea	33	22	61	71	17	204	0.1569	1736.17	57.0
May	2	Phylocentropus sp.	1					1	0.0008	8.51	0.3
May	2	Laevapex sp.	2	1				3	0.0023	25.53	0.8
May	2	Physa sp.	2	3	2	2	4	13	0.0100	110.64	3.6
May	2	Heliosoma sp.		1				1	0.0008	8.51	0.3
May	2	Asellus sp.			1			1	0.0008	8.51	0.3
May	2	Hydroporus sp.					1	1	0.0008	8.51	0.3
May	2	Sisyra sp.					1	1	0.0008	8.51	0.3
May	2	Glossiphoniidae	1					1	0.0008	8.51	0.3
May	2	Polypedilum sp.		1		1		2	0.0015	17.02	0.6
May	2	Piscicolidae				1		1	0.0008	8.51	0.3
		Total	70	53	82	85	68	358	0.2754	3046.81	100
		Density by volume	0.23	0.21	0.33	0.34	0.27	0.28			
		Density by area	2979	2255	3489.4	3617	2894	3046.8			

Table 5. continued.

DATE	STA	TAXA (VOL* (cm3))	REPLICATE 1 (1700)	2 (1300)	3 (1400)	4 (1600)	5 (1500)	Total (7500)	volume Density (cm3)	No./m2 area 0.0235m	% of total
May	3	Gammarus fasciatus	15	9	16	7	9	56	0.0075	476.60	15.0
May	3	Oligochaeta	61	31	21	17	15	145	0.0193	1234.04	38.9
May	3	Pisidium sp.	1					1	0.0001	8.51	0.3
May	3	Corbicula fluminea	48		10	15	4	77	0.0103	655.32	20.6
May	3	Dromogomphus sp.	1					1	0.0001	8.51	0.3
May	3	Nematoda	1					1	0.0001	8.51	0.3
May	3	Chaoborus sp.	12	12				24	0.0032	204.26	6.4
May	3	Phylocentropus sp.			1			1	0.0001	8.51	0.3
May	3	Cyathura polita	7			5	1	13	0.0017	110.64	3.5
May	3	Coleotanypus sp.	2	7	6	1	1	17	0.0023	144.68	4.6
May	3	Chironomus sp.			1			1	0.0001	8.51	0.3
May	3	Nanocladius sp.	1					1	0.0001	8.51	0.3
May	3	Polypedilum sp.	16	8	4	1	2	31	0.0041	263.83	8.3
May	3	Cladotanytarsus sp.	1					1	0.0001	8.51	0.3
May	3	Paracladopelma sp.			1			1	0.0001	8.51	0.3
May	3	Physa sp.			1			1	0.0001	8.51	0.3
May	3	Manayunkia speciosa		1				1	0.0001	8.51	0.3
		Total	166	68	61	46	32	373	0.0497	3174.47	100
		Density by volume	0.098	0.052	0.0436	0.029	0.021	0.0497			
		Density by area	7064	2894	2595.7	1957	1362	3174.5			

DATE	STA	TAXA (VOL* (cm3))	REPLICATE 1 (400)	2 (250)	3 (300)	4 (300)	5 (250)	Total (1500)	volume Density (cm3)	No./m2 area 0.0235m	% of total
May	4	Oligochaeta	12	17	5	2	8	44	0.0293	374.47	29.3
May	4	Corbicula fluminea	9	14	52	10	15	100	0.0667	851.06	66.7
May	4	Cyathura polita	2	1	1		1	5	0.0033	42.55	3.3
May	4	Hydroporus sp.	1					1	0.0007	8.51	0.7
		Total	24	32	58	12	24	150	0.1000	1276.60	100
		Density by volume	0.06	0.13	0.19	0.04	0.10	0.10			
		Density by area	1021	1362	2468.1	510.6	1021	1276.6			

DATE	STA	TAXA (VOL* (cm3))	REPLICATE 1 (1800)	2 (1800)	3 (1600)	4 (1600)	5 (1800)	Total (8600)	volume Density (cm3)	No./m2 area 0.0235m	% of total
May	5	Gammarus fasciatus	4	1	1	2	6	14	0.0016	119.15	6.5
May	5	Oligochaeta	26	18	17	39	17	117	0.0136	995.74	54.7
May	5	Pisidium sp.	1	2	5	4	1	13	0.0015	110.64	6.1
May	5	Corbicula fluminea	2		10	1	1	14	0.0016	119.15	6.5
May	5	Hydrolimax grisea					1	1	0.0001	8.51	0.5
May	5	Cyathura polita	1			1		2	0.0002	17.02	0.9
May	5	Coleotanypus sp.	7	8	12	8	7	42	0.0049	357.45	19.6
May	5	Parachironomus pupa	1					1	0.0001	8.51	0.5
May	5	Polypedilum sp.	1		1	3	1	6	0.0007	51.06	2.8
May	5	Cladotanytarsus sp.				1		1	0.0001	8.51	0.5
May	5	Endochironomus sp.		1				1	0.0001	8.51	0.5
May	5	Hexagenia sp.				1	1	2	0.0002	17.02	0.9
		Total	43	30	46	60	35	214	0.0249	1821.28	100
		Density by volume	0.02	0.02	0.03	0.04	0.02	0.02			
		Density by area	1830	1277	1957.4	2553	1489	1821.3			

Table 5. continued.

			REPLICATE						volume	No./m2	%
		VOL*(cm3)	1800	1600	1700	1500	1500	8100	Density	area	of
DATE	STA	TAXA	1	2	3	4	5	Total	(cm3)	0.0235m	total
May	6	Gammarus fasciatus	2	9	2	5	3	21	0.0026	178.7	6.4
May	6	Oligochaeta	34	25	32	29	19	139	0.0172	1183.0	42.6
May	6	Pisidium sp.	2	3	2	8		15	0.0019	127.7	4.6
May	6	Corbicula fluminea	2	2	5	12	2	23	0.0028	195.7	7.1
May	6	Sphaerium sp.		2				2	0.0002	17.0	0.6
May	6	Hydrolimax grisea				2		2	0.0002	17.0	0.6
May	6	Phylocentropus sp.				1		1	0.0001	8.5	0.3
May	6	Palpomyia sp.		1				1	0.0001	8.5	0.3
May	6	Coleotanypus sp.	12	14	4	20	8	58	0.0072	493.6	17.8
May	6	Chironomus sp.		2				2	0.0002	17.0	0.6
May	6	Cryptochironomus sp.					1	1	0.0001	8.5	0.3
May	6	Polypedilum sp.	5	3	7	23		38	0.0047	323.4	11.7
May	6	Cladotanytarsus sp.	1			1		2	0.0002	17.0	0.6
May	6	Endochironomus sp.	3	4	2	5		14	0.0017	119.1	4.3
May	6	Parachironomus sp.		2		7		9	0.0011	76.6	2.8
		Total	61	67	54	113	33	328	0.0405	2791.5	100
		Density by volume	0.03	0.04	0.03	0.08	0.02	0.0405			
		Density by area	2596	2851	2297.9	4809	1404	2791.5			

			REPLICATE						volume	No./m2	%
		VOL*(cm3)	1800	1600	1900	1800	1800	8900.0	Density	area	of
DATE	STA	TAXA	1	2	3	4	5	Total	(cm3)	0.0235m	total
May	7	Gammarus fasciatus	3		6	3	1	13	0.0015	110.6	5.9
May	7	Oligochaeta	12	12	27	38	14	103	0.0116	876.6	46.4
May	7	Pisidium sp.	5	2	4	5	1	17	0.0019	144.7	7.7
May	7	Corbicula fluminea	3	2	1	1		7	0.0008	59.6	3.2
May	7	Sphaerium sp.	1	1				2	0.0002	17.0	0.9
May	7	Chaoborus sp.	10	6			11	27	0.0030	229.8	12.2
May	7	Phylocentropus sp.	1					1	0.0001	8.5	0.5
May	7	Coleotanypus sp.	5	8	6	3	10	32	0.0036	272.3	14.4
May	7	Glyptotendipes sp.			2			2	0.0002	17.0	0.9
May	7	Endochironomus sp.				1		1	0.0001	8.5	0.5
May	7	Peloscolex sp.	2	3	4	1	5	15	0.0017	127.7	6.8
May	7	Pagastiella sp.	1					1	0.0001	8.5	0.5
May	7	Parachironomus sp.					1	1	0.0001	8.5	0.5
		Total	43	34	50	52	43	222	0.0249	1889.4	100
		Density by volume	0.024	0.021	0.0263	0.029	0.024	0.0249			
		Density by area	1830	1447	2127.7	2213	1830	1889.4			

			REPLICATE						volume	No./m2	%
		VOL*(cm3)	0	1200	1500	1500	1500	5700.0	Density	area	of
DATE	STA	TAXA	1	2	3	4	5	Total	(cm3)	0.0235m	total
May	8	Gammarus fasciatus		29	7	9	7	52	0.0091	442.6	16.4
May	8	Oligochaeta		30	23	27	35	115	0.0202	978.7	36.3
May	8	Pisidium			1			1	0.0002	8.5	0.3
May	8	Corbicula fluminea		44	28	29	26	127	0.0223	1080.9	40.1
May	8	Laevapex sp.			2			2	0.0004	17.0	0.6
May	8	Coleotanypus sp.		5		3	1	9	0.0016	76.6	2.8
May	8	Polypedilum sp.		1		1	3	5	0.0009	42.6	1.6
May	8	Physa sp.		1	2			3	0.0005	25.5	0.9
May	8	Cryptochironomus sp.		1				1	0.0002	8.5	0.3
May	8	Syrphidae larva		1				1	0.0002	8.5	0.3
May	8	Turbellaria			1			1	0.0002	8.5	0.3
		Total	0	112	64	69	72	317	0.0556	2697.9	100
		Density by volume	0	0.093	0.0427	0.046	0.048	0.0556			
		Density by area	0	4766	2723.4	2936	3064	2697.9			

Table 5. continued.

DATE	STA	VOL* (cm3) / TAXA	REPLICATE 1500 / 1	1200 / 2	1200 / 3	1400 / 4	1400 / 5	6700.0 / Total	volume Density (cm3)	No./m2 area 0.0235m	% of total
May	9	Gammarus fasciatus	24	34	25	8	14	105	0.0157	893.62	23.9
May	9	Oligochaeta	19	19	18	25	33	114	0.0170	970.21	26.0
May	9	Pisidium sp.	5	8	6	9		28	0.0042	238.30	6.4
May	9	Corbicula fluminea	15	24	11	10	10	70	0.0104	595.74	15.9
May	9	Sphaerium sp.	2	1		4	2	9	0.0013	76.60	2.1
May	9	Dromogomphus sp.					1	1	0.0001	8.51	0.2
May	9	Chaoborus sp.	1		1		2	4	0.0006	34.04	0.9
May	9	Hydrolimax grisea		1				1	0.0001	8.51	0.2
May	9	Phylocentropus sp.		1				1	0.0001	8.51	0.2
May	9	Oecetis sp.	1	1	1	1	3	7	0.0010	59.57	1.6
May	9	diptera pupa			1			1	0.0001	8.51	0.2
May	9	Coleotanypus sp.	11	7	13	9	12	52	0.0078	442.55	11.8
May	9	Parachironomus sp.	7			1	1	9	0.0013	76.60	2.1
May	9	Chironomus sp.			2			2	0.0003	17.02	0.5
May	9	Polypedilum sp.	6	7	2	12	6	33	0.0049	280.85	7.5
May	9	Cryptochironomus sp.			1		1	2	0.0003	17.02	0.5
May	9	Physa sp.		1				1	0.0001	8.51	0.2
May	9	Corixidae adult		1	1			2	0.0003	17.02	0.5
		Total	91	105	82	79	85	442	0.0660	3761.70	100
		Density by volume	0.061	0.088	0.0683	0.056	0.061	0.066			
		Density by area	3872	4468	3489.4	3362	3617	3761.7			

DATE	STA	VOL* (cm3) / TAXA	REPLICATE 1300 / 1	1500 / 2	800 / 3	1000 / 4	1400 / 5	6000.0 / Total	volume density (cm3)	No./m2 area 0.0235m	% of total
May	10	Gammarus fasciatus	10	14	14	2	6	46	0.0077	391.5	22.3
May	10	Oligochaeta	15	24	11		8	58	0.0097	493.6	28.2
May	10	Corbicula fluminea	10	7	4	3	4	28	0.0047	238.3	13.6
May	10	Sphaerium sp.	1	1		1		3	0.0005	25.5	1.5
May	10	Rangia cuneata			1			1	0.0002	8.5	0.5
May	10	Hydrolimax grisea	1				1	2	0.0003	17.0	1.0
May	10	Oecetis sp.	1					1	0.0002	8.5	0.5
May	10	Oecetis pupa			1	1		2	0.0003	17.0	1.0
May	10	diptera pupa				1		1	0.0002	8.5	0.5
May	10	Palpomyia sp.			3			3	0.0005	25.5	1.5
May	10	Coleotanypus sp.	12	11	6	4	5	38	0.0063	323.4	18.4
May	10	Polypedilum sp.		5	2	1	5	13	0.0022	110.6	6.3
May	10	Endochironomus sp.		1	2			3	0.0005	25.5	1.5
May	10	Amnicola sp.	1				1	2	0.0003	17.0	1.0
May	10	Peloscolex sp.	1	1			2	4	0.0007	34.0	1.9
May	10	Parachironomus pupa		1				1	0.0002	8.5	0.5
		Total	52	65	44	13	32	206	0.0343	1753.2	100
		Density by volume	0.04	0.043	0.055	0.013	0.023	0.0343			
		Density by area	2213	2766	1872.3	553.2	1362	1753.2			

GLOSSARY OF COMMUNITY INDICES

Notes and formulas for the community and biotic indices used in this report. All of the values presented were based on taxa identification levels similar to that given in Kirby-Smith and VanDover (1979). Although more precise identifications may be possible, they would notbe directly comparable using these indices. This would be true in comparing these results to those of other studies as well.

Simpson dominance index: based on Simpson (1949) where it was proposed that two individuals (taxa) drawn at random from a population could be assigned a probability of belonging to the same taxa. The original form of the equation was of use only in finite populations and thus another formula was proposed that gives an unbiased estimate

$$\hat{\lambda} = \sum_{i=1}^{S} \frac{n_i(n_i - 1)}{n(n-1)}$$

where n_i is the number of individuals in the ith species or taxa; n is the total number of all individuals; and s is the total number of species. This index does not take into account that any or all of the taxa encountered may be aggregated by microhabitat, breeeding , or behavior.

Richness: Margalef's index was used and has the form

$$R = (S-1)/\ln N$$

where S is the number of taxa and N is the number of individuals. Richness generally increases with increasing water quality but some areas may be naturally lower in productivity. Variability of substrate is another confounding factor.

Evenness: This index is based on the J' of Pielou (1977) which expresses the relationship that abundance of individual species have to the total abundance. When all species are equally represented, the index would be at a maximum and would decrease as the species diverge in abundance. The equation has the form

$$e = H'/\log S$$

where H' is the Shannon index (below) and S is the number of species or taxa.

Shannon diversity index: this index is based on information theory and is a measure of the average degree of "uncertainty" in predicting the identity of a randomly chosen individual from a collection of S taxa and N individuals. The equation has the form

$$\hat{H}' = -\sum_{i=1}^{S}\left[\left(\frac{n_i}{n}\right)\ln\left(\frac{n_i}{n}\right)\right]$$

where n_i is the number of individuals in the ith species (taxa) of S species and n is the total number of individuals in each sample. The estimate derived from this equation is biased because the total number of individuals in the community will be greater than that found in any single sample.

Shannon-Weaver mean diversity: this index summarizes the information collected on species composition. This index utilizes the richness of taxa and composition of taxa, and since these two parameters may vary independently of each other, may not detect subtle changes in community structure. The equation has the form

$$d = C/N\ [\ N \log_{10} N - \Sigma\ (n_i \log_{10} n_i)]$$

where C is a constant (3.321928) which converts the $\log_{10}$ to $\log_2$; N is the total number of individuals; and n_i is the total number of individuals in the ith species (taxa).

Hilsenhoff taxa index: This index relies on subjective values given to various benthic taxa expressing their tolerance to organic pollution. These values are given in Hilsenhoff (1977) and in Klemm et al. (1990). Those organisms that do not have values listed are given an intermediate value of 3. The values are based on the following scheme: *tolerant*, those organisms that are associated with gross organic contamination (values of 4 and 5); *facultative*, those organisms that show a wide range of tolerance (values of 2 and 3); and *intolerant*, organisms not associated with organic pollution or moderate reductions in oxygen (values of 0 and 1). The equation has the form

$$HBI = \Sigma\ (n_i\ a_i)/\ N$$

where n_i is the number of individuals in the ith taxa; a_i is the index value of that taxa; and N is the total number of individuals in the sample. Index values below 1.75 indicate excellent water quality, 1.76-2.50 indicate good water quality, 2.51-3.75 indicate fair water quality, and 3.76-4.00 indicate poor water quality. Values over 4.00 indicate serious water quality problems.

Common dominants index: this index is used to compare sites that are upstream of a particular impact to sites downstream of the impact. This index requires that the upstream site is similar in substrate, current, and water body size and that it be free of external sources of contamination. The index is derived by dividing the number of abundant taxa in common by the number of abundant taxa at the upstream site. The result is multiplied by 100 to form a percentage. This index is subjective in that the investigator must determine which taxa are to be included in the abundant category. This index is used by NC Division of Environmental Management. The levels of impact are 81-100% (no impact), 51-80% (slight impact), 21-50% (moderate impact) and 20% or less (severe impact).

Common taxa index: this index measures the number of taxa in common at two sites relative to the maximum number of taxa at either site. It is derived by dividing the number of taxa in common by the maximum number of taxa and the result is multiplied by 100. The impact values are categorized as >70% (no impact), 50-70% (slight impact), 30-49% (moderate impact), and <30% (severe impact).