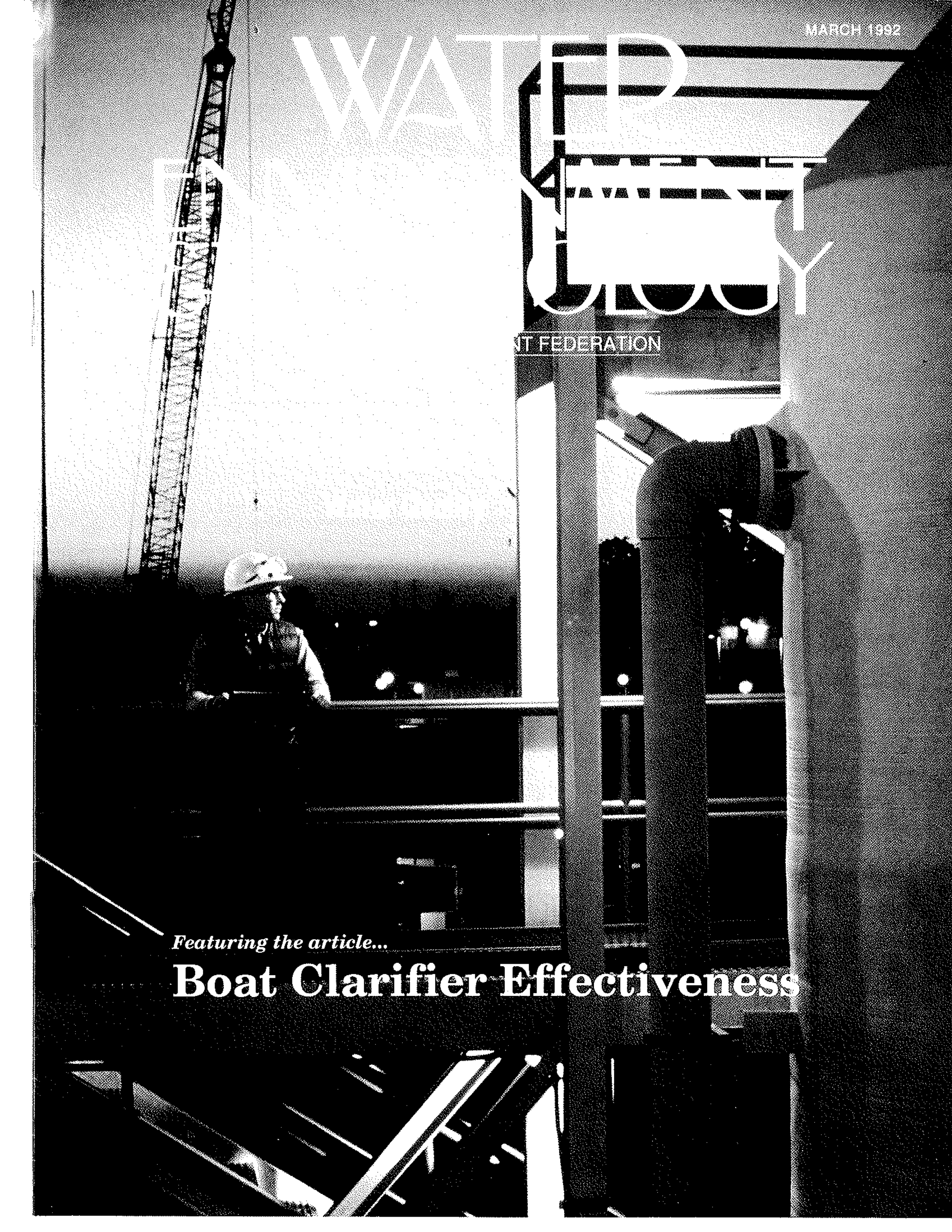
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Boat Clarifier Effectiveness

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Billy G. Justus, George L. Harp

Curia Creek begins just west of Cave City, Ark., in the rolling southern portion of the Salem Plateau. The stream winds in a southeasterly direction across the rugged Springfield Plateau, enters the Mississippi Embayment, and then joins the Black River below its confluence with the Strawberry River.

In 1968, Cave City built a wastewater holding pond, which could accommodate approximately 1200 residents. The community reached this population by the mid-1970s and untreated domestic wastewater from the pond began to enter the nearby headwaters of Curia Creek.

As time passed, the situation worsened. In dry weather, Curia Creek became intermittent above the pond, and the wastewater effluent represented 100% of the stream flow. As a result, the stream's headwaters became extensively polluted, and the stench of domestic wastewater could be detected in the stream up to 2 km downstream of the effluent discharge.

In 1987, to alleviate Curia Creek water-quality deterioration and accommodate the town's growing population, Cave City, Ark., built a new wastewater treatment plant. The new Cave City plant uses innovative boat clarifier technology, which eliminates the need for an external clarifier structure or a return sludge removal and pumping system by locating the clarifier in the oxidation ditch. Because equipment operation and maintenance are reduced in the clarification zone, there are fewer problems with cold-climate applications and lower energy costs (Stensel, 1986).

Boat clarifiers produce effluents that meet secondary treatment standards; however, their long-term performance was not documented when the new Cave City plant was built. To assess long-term performance of the Cave City treatment plant's boat clarifier technology, a study was conducted to monitor Curia Creek aquatic macroinvertebrates below the treatment plant effluent and determine the nature of their recovery from conditions present before the technology was implemented.

STUDY SET UP

Because the point source of pollution—the plant's discharge—was located at Curia Creek's headwaters, two stations were established in the upper region of the creek (see Box *Upper Curia Creek*). The first station, Curia 1, was approximately 100 m below the plant's discharge and the second station, Curia 2, was approximately 2.3 km downstream, just above a county road bridge.

Even during dry periods, stream flow at Curia 2 was greater than at Curia 1 because of inflowing groundwater from several springs between the two stations.

A control station, Jackson 1, was established on Jackson Creek, which is a tributary of Curia Creek, about 2.8 km southeast of Curia 1. Stream order, stream flow, water depth, and substrate composition at this station are comparable to those at Curia 1.

Sample collection and analysis. Macroinvertebrates were collected from each station 12 times between May 1987 and November 1988. Monthly sampling started 2 months before secondary treatment began. Bimonthly sampling was initiated midway through the study because of the delayed on-line date of the new facility and continued for 3 months after tertiary treatment began.

On each sampling date, each station was sampled qualitatively for 1.5 man-hours using a Turtox Indestructible™ dip net. Specimens were permanently preserved in 70% ethanol.

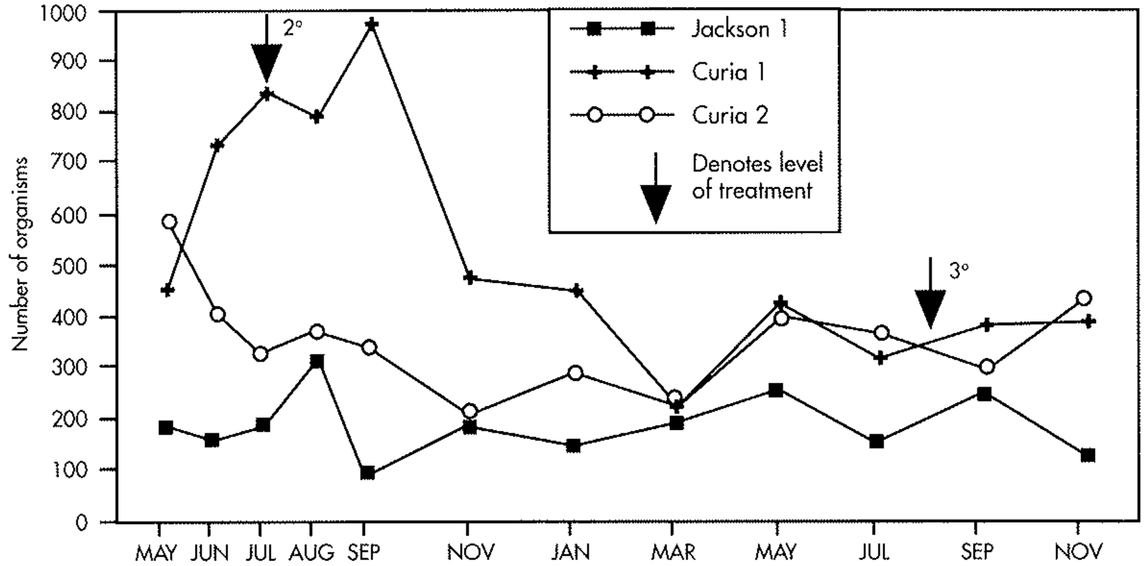
All macroinvertebrates were sorted and identified in the laboratory. Simpson diversity, Simpson dominance, Shannon-Weiner diversity, H'max, and evenness values were calculated for each macroinvertebrate collection (see Table), and stream order for all stations was determined (see Box *Parameter Definitions*).

RESULTS AND DISCUSSION

Aquatic macroinvertebrates collected in this study were quite diverse and their numbers fluctuated greatly (Figure 1).

Jackson 1. The control station was

Figure 1—Number of Organisms Collected



Upper Curia Creek

Stream gradient in the upper region of Curia Creek is about 6 m/km. Two large waterfalls cut across sandstone outcrops between the two stations, and long pools separated by riffles exist above and below each fall. Bedrock in the area consists of Boone Limestone, St. Peter Sandstone, and Powell Dolomite. The stream substrate consists of bedrock, sandstone, cobble, and gravel mixed with sand (Arkansas Department of Pollution Control and Ecology, 1985).

the most heterogenous and therefore the most stable station; of the 193 macroinvertebrate taxa collected during this study, 138 occurred at Jackson 1. Macroinvertebrate diversity was greater at Jackson 1 than at the other two stations for most of the samples. Further, more taxa were collected at this station in 6 of the 12 samples (Figure 2). Diversity was the highest for the first four and the last five samples collected at Jackson 1 and the lowest for the three middle samples, which were collected in November, January, and March, thus showing a distinct seasonal fluctuation.

Without exception, Jackson 1 samples contained fewer organisms than did samples from other stations. Consequently, the percentages of the total standing crops of the four most abundant taxa were lower than at the other stations—chironomids, 13.6%; *Physa*, 7.7%; *Pisidium*, 6.8%; and astacids, 6.1%.

Macroinvertebrate taxa such as *Perlesta placida*, *Allocapnia*, and *Helichus* were commonly collected at Jackson 1. *P. placida* represented approximately 17% and 25% of the total organisms in May 1987 and May 1988, respectively. Fifteen specimens of *Allocapnia* were collected in November 1988, approximately 11% of the total organisms collected on that date. *Helichus* adults were collected in approximately 58% of the samples; collection of the these beetles was sporadic throughout the study.

Aquatic macroinvertebrates such as plecopterans and some dryopoid beetles that were collected at this site have special adaptations that allow them to extract DO from water (see Box *Macroinvertebrate Adaptations*); their presence thus indicates a fairly pristine environment and that Jackson 1 was a suitable control.

The biological requirements of many taxa limit them to lotic environments such as unpolluted streams that typically contain diverse habitats and high DO concentrations. The fact that several taxa were collected that extract DO from the water and require relatively high oxygen concentrations is further evidence that this stream is relatively stable.

Chironomid larvae represented only 14% of the organisms collected at this station and were the dominant organisms in August and September 1987 and March 1988. In these three samples, they represented 11% to 36% of the total number of macroinvertebrates. Chironomids and *Physa* were the only taxa collected on every sampling date.

Jackson 1's biotic stability in the first half of the study, as opposed to those of the Curia Creek stations, can be attributed to the fact that Jackson Creek received less pollution than did Curia Creek, which was negatively affected by the tremendous amounts of material in the effluent from the wastewater pond.

Curia 1. Curia 1 was less taxonomically heterogenous than the other two stations; only 109 taxa were collected (Figure 2). Diversity at this station was relatively low in the first seven samples (see Table); however, the last five samples indicated an increase in species richness. These diversity indexes are comparable to those exhibited by the control station throughout the study. Indexes for Simpson and Shannon-Weiner diversities and H'max were lowest in nine samples; however, diversity index values were higher than or intermediate to those from the other stations in three of the last four samples.

In eight samples, the total number of organisms collected at this station was higher than at the other two sampling stations (Figure 1). As a result, the total macroinvertebrate standing crop at Curia 1 was 33% greater than the crop at Curia 2 and 65% greater than the crop at Jackson 1. Of the four Curia 1

Parameter Definitions

Simpson Diversity—the number of randomly selected pairs of individuals that must be drawn from a community to have an even chance of obtaining a pair with both individuals of the same species. It therefore expresses the dominance or concentration of abundance into the one or two commonest species of the community (Poole, 1974).

Shannon-Weiner Diversity—the relative evenness of the abundance of all of the species; relatively independent of sample size (Poole, 1984).

H'max—the calculated theoretical maximum diversity (Wilhm and Doris, 1968). The base 2 logarithm was selected in this study for calculating diversity indexes, as it is the most commonly used log (Cox, 1985).

Evenness—how the individuals are apportioned among the species.

samples in which macroinvertebrate standing crop was intermediate to the other stations, three were in the last five samples.

Organisms that were consistently collected during the first half of the study at Curia 1 were either tolerant of low dissolved oxygen (DO) concentration in the water or were able to use atmospheric oxygen. Examples of such taxa include chironomids, oligochaetes, *Microvelia americana*, belostomatids, *Corisella edulis*, *Peltodytes duodecimpunctatus*, *Laccophilus* larvae, *Tropisternus* larvae and adults, *Plathemis lydia*, and *Pachydiplax longipennis*.

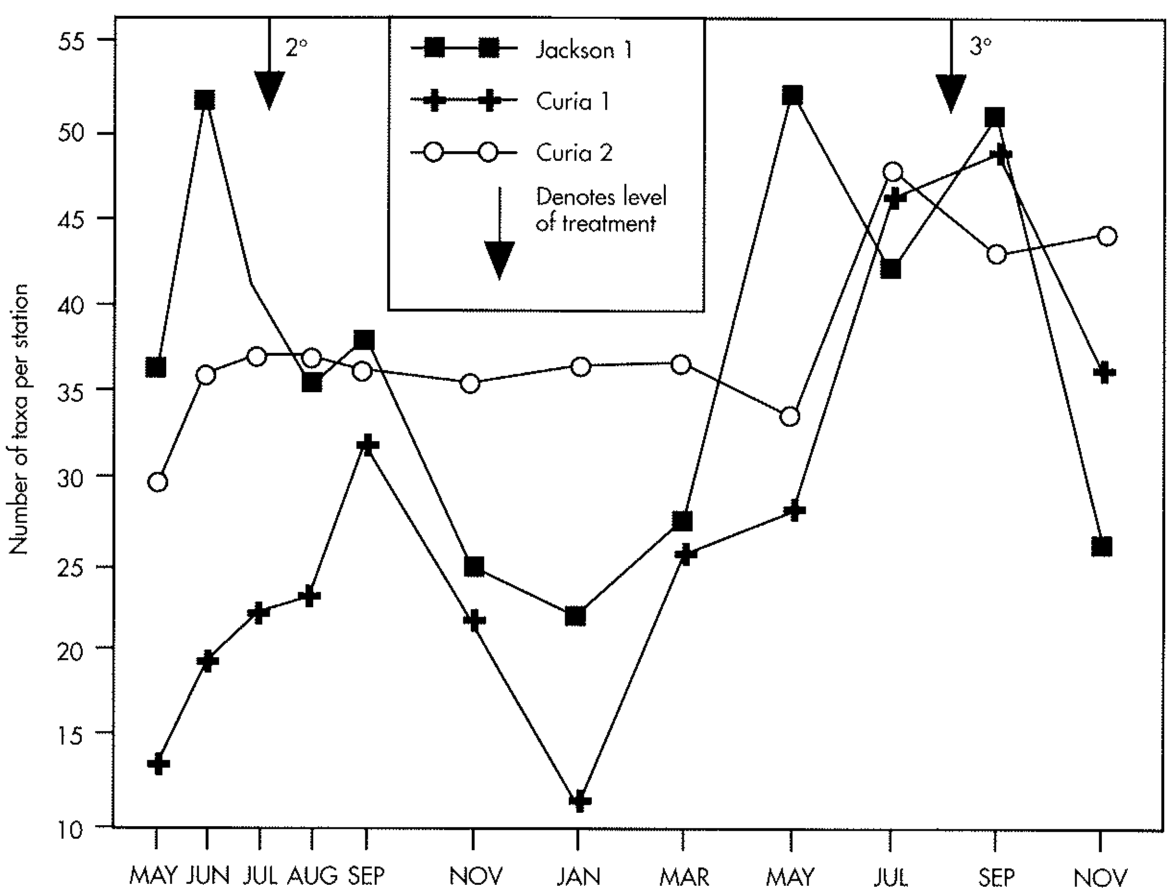
Chironomid larvae, most of which were determined to be *Chironomus*, represented 59.3% of the total macroinvertebrate standing crop at Curia 1. This was the only taxon collected in all samples and was the dominant organism from May 1987 to March 1988, during which time they represented 37% to 87% of the total organisms collected. Chironomids declined significantly in March 1988 and, by the end of the study, were in relatively low numbers.

Many taxa, such as decapods, plecopterans, ephemeropterans, megalopterans, and trichopterans, were seldom collected at Curia 1 during the first half of the study but were collected during the last half; many were collected only in the last third of the study.

Lirceus was the only isopod collected at Curia 1. Only 6% of these organisms was collected during the first half of the study, but, as chironomid numbers decreased, *Lirceus* numbers increased: 50% of the macroinvertebrate standing crop in the November 1988 sample was *Lirceus*.

The fluctuation of biological parameters that were sampled at Curia 1 was not caused by seasonal variation but by the inordinate amount of organic wastes present initially at this station, and later by the improved water quality as a result of effluent treatment by the new treatment plant.

Figure 2—Number of Taxa Collected



Diversity, Dominance, H'Max, and Evenness

Parameter, station	1987 May	June	July	Aug.	Sept.	Nov.	1988 Jan.	May	July	Sept.	Nov.
Simpson Diversity											
Curia 1	0.348	0.314	0.248	0.300	0.387	0.596	0.549	0.830	0.917	0.927	0.728
Curia 2	0.822	0.724	0.802	0.874	0.922	0.809	0.800	0.701	0.836	0.886	0.846
Jackson 1	0.921	0.956	0.933	0.857	0.966	0.855	0.861	0.923	0.951	0.894	0.923
Shannon Diversity											
Curia 1	1.096	1.070	1.053	1.236	1.595	2.096	1.618	3.013	4.189	4.478	2.986
Curia 2	3.096	2.897	3.528	3.786	4.172	3.558	3.315	2.744	3.893	4.023	3.701
Jackson 1	4.285	5.013	4.465	3.774	4.870	3.292	3.259	4.468	4.674	4.362	3.950
Simpson Dominance											
Curia 1	0.652	0.686	0.752	0.700	0.613	0.404	0.451	0.170	0.083	0.073	0.272
Curia 2	0.178	0.276	0.198	0.126	0.078	0.191	0.200	0.299	0.164	0.114	0.154
Jackson 1	0.079	0.044	0.067	0.143	0.034	0.145	0.139	0.077	0.049	0.106	0.077
H'max											
Curia 1	3.697	4.245	4.458	4.521	4.999	4.458	3.322	4.754	5.521	5.584	5.129
Curia 2	4.857	5.169	5.209	5.209	5.169	5.129	5.169	4.999	5.554	5.391	5.425
Jackson 1	5.169	5.700	5.355	5.129	5.245	4.641	4.392	5.670	5.355	5.641	4.641
Evenness											
Curia 1	0.296	0.252	0.236	0.273	0.319	0.470	0.487	0.634	0.759	0.802	0.582
Curia 2	0.637	0.560	0.677	0.727	0.807	0.694	0.641	0.549	0.701	0.746	0.682
Jackson 1	0.829	0.879	0.834	0.736	0.928	0.709	0.742	0.788	0.873	0.733	0.851

were drainage of the old wastewater pond and erosion of organic material from areas of the stream that had once been depositional and had accumulated organic material over time.

Although macroinvertebrate standing crop and diversity indexes for macroinvertebrates collected at Curia 2 fluctuated little throughout the study as a result of the initial recovery of the stream at that station and the expected recovery lag because of the downstream location of Curia 2 to Curia 1, sample data show that more taxa were collected in the last three samples than in any previous sample. Augmented species richness, as exhibited by these samples, resulted not from seasonal variation, as was the case at Jackson 1, but from improved water quality.

The natural recuperative powers of this creek are attested to by the presence of several taxa that are sensitive to wastewater and low DO concentrations, even in the initial stages of the study. For example, more stonefly taxa were encountered at Curia 2 than at any other station. The sporadic occurrence of these taxa is evidence that the stream contained substantial amounts of oxygen throughout the study because organisms such as *Perlesta*, which occurred in the first sample before effluent treatment, are intolerant of low DO concentrations.

BOAT CLARIFIER EFFECTIVENESS

The data collected in this study indicate that the boat clarifier is indeed an effective means of wastewater treatment. Water quality at Curia 1 and 2 approached that of Jackson 1 by the end of the study. This substantial recovery was directly related to secondary effluent treatment by boat clarification, which had a positive effect on water quality and consequently allowed

Boat clarifiers are effective in treating wastewater.

macroinvertebrates to exploit the previously unavailable habitat.

Data from Curia 1 and 2 do not indicate either an increase or decrease in species richness after tertiary effluent treatment began in August 1988. However, this is probably because of the short period the creek was studied after tertiary treatment began and because of the great extent to which Curia Creek had already recovered. ■

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Initially, decomposition of domestic waste at this station resulted in low DO concentrations; only organisms tolerant to low DO concentrations and those that used atmospheric oxygen were collected during the first half of the study. The fact that more organisms were collected in the first half of the study than were collected in the latter half is probably because of the lack of interspecific competition and predation on those taxa present.

The most obvious indication of poor water quality at Curia 1 at the beginning of the study was the presence of the large standing crop of chironomid larvae from May 1987 to January 1988. Because *Chironomus* larvae have the respiratory pigment hemoglobin in their blood, they may not be affected by low DO, even in areas where DO concentrations are as low as 15% of the saturated state. If oxygen concentrations are lower than 15% saturation, the larvae enter a quiescent state, which lowers their metabolic rate and decreases their oxygen demand. The larvae are thus capable of remaining in quiescence until the water's oxygen supply increases. *Chironomus* exhibits a rapid life cycle, and several generations may be produced in the same year (Johannsen, 1969). High numbers are often encountered where there is little competition and predation.

Data indicate that this station began to recover about midway through the study. Macroinvertebrate standing crop, number of taxa collected, and diversity indexes for samples from this portion of the study approached values exhibited by Jackson 1 and Curia 2. Water-quality improvement at Curia 1 was documented by a decrease of tolerant organisms and an increase of pollution-intolerant organisms.

The decrease in chironomid larvae, first noted in March 1988, continued until the end of the study, when they represented only 1% of the macroinvertebrate standing crop. The decline of this taxon was the result of effluent treatment, which decreased the amount of decomposing organic matter in the water and thereby increased DO concentration. As water quality improved, predators and competitors of the larvae became more common and chironomid numbers were reduced.

The succession of chironomid larvae by *Lirceus* indicates less organic pollution in the aquatic environment. Because *Lirceus* is less tolerant of organic pollution, some species are abundant in the recovery zones of streams polluted by domestic wastewater (Pennak, 1978), and *Asellus*, a close relative of *Lirceus*, often succeeds *Chironomus* downstream from enriched outfalls (Hynes, 1963). Organic enrichment at this station was further evidenced by the presence of a plankton bloom in March 1988 and by large masses of *Cladophora* between March and September 1988.

The appearance of taxa such as decapods, plecopterans, ephemeropterans, megalopterans, and trichopterans as the study progressed indicated habitat improvement at Curia 1 as secondary effluent treatment continued. Stream recovery at this site was further confirmed by the general appearance and odor of the water, which improved tremendously as the study progressed.

These phenomena emphasize the fine line that distinguishes an enriched environment from a slightly polluted one.

Curia 2. Data collected at Curia 2 indicate that this station was intermediate to Curia 1 and Jackson 1 with respect to numbers and kinds of aquatic macroinvertebrates collected and diversity values calculated (see Table). Deviations from this general pattern occurred during the latter stages of the study. For example, more taxa were collected at Curia 2 than at Jackson 1 on four sampling dates, three of which were during the last five sampling periods.

Little data fluctuation was observed at this station; macroinvertebrate standing crop (Figure 1) and diversity indexes were comparable to those for samples collected throughout the study. However, like Curia 1, more taxa were collected in the last three samples (Figure 2).

Most taxa collected at Curia 2 were detritivores such as *Lirceus*, *Gammarus*, astacids, *Caenis*, *Cheumatopsyche*, *Peltodytes duodecimpunctatus*, and chironomids.

Lirceus was the only isopod collected at Curia 2. This taxon was collected in 75% of the samples and was the dominant organism collected in January and November 1988, when it represented 30% to 40% of the specimens, respectively. *Lirceus* also represented 26% of the organisms collected in March 1988. The amphipod *Gammarus* was one of two taxa collected in all 12 samples at Curia 2. This taxon represented the largest number of organisms of any taxon collected at this site. Thirty-three percent of macroinvertebrates collected in the first sample (May 1987) was composed of midge fly larvae, but successive collections did not contain large numbers of this organism.

The much lower macroinvertebrate standing crop and significantly greater diversity at Curia 2 compared to Curia 1 during the initial study period probably resulted from the natural recovery of the stream because of the water's exposure to the atmosphere by turbulence, stream aeration at the two falls between the stations, and surface water dilution with groundwater below the first fall.

Although the data indicate that oxygen was not limiting at Curia 2 during the first half of the study, the large collections of several detritivores, the presence of large masses of *Cladophora*, and a plankton bloom indicate an enriched environment. These phenomena emphasize the fine line that distinguishes an enriched environment from a slightly polluted one. Sources of enrichment

Macroinvertebrate Adaptations

Most plecopteran species are very sensitive to polluting substances, and the presence of stonefly nymphs such as *Perlesta placida* and *Allocapnia* indicates that Jackson Creek is relatively clean (Claassen, 1931) and was a suitable control. *Helichus* beetles extract oxygen from the water with a plastron, a cuticular meshwork of hydrofuge hairs that hold water from the body surface and form a permanent gas film that serves as a gill. Because of this adaptation, the organism is limited to areas of low organic pollutant and high dissolved oxygen (DO) concentrations. Pollutants act as wetting agents to the plastron, and oxygen then diffuses from the insect through this structure if DO is low (Brown 1976).

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