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Effects of the lampricide, 3-trifluoromethyl-4-nitrophenol (TFM) on the macroinvertebrates of a hardwater river

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Abstract

The effects of the lampricide, TFM, on the benthic macroinvertebrates in the Rouge River, a hardwater tributary to Lake Ontario was examined at 1 untreated and 2 treated sites over a 7 month period. Drift samples were collected from one one of the treated sites during the 5 days bracketing treatment. Significant decreases in relative abundance attributable to TFM were recorded for *Chimarra* sp., *Dugesia* sp. and Tubificoidea 2–19 d following treatment. Large reductions were also exhibited by *Caenis* sp. and Lumbricidae. Two-thirds of the Chironomidae genera and Nematoda tended to decline in abundance 2 d after treatment at only one of the treated sites, probably due to a 2.5 h longer treatment. This decline was followed by a significant increase to greater than pretreatment abundances 17 d later undoubtedly as a result of an upward migration of macroinvertebrates from within the hyporheos. Partial recolonization of the TFM-sensitive benthic taxa was evident 19 d after lampricide treatment with complete recolonization 6.5 months later. With the exception of *Caenis* sp. those taxa in the present study found to be TFM-sensitive were in accordance with those found in softwater field studies.

Chimarra sp., *Dugesia* sp., *Hemerodromia* sp., Lumbricidae and Tubificoidea exhibited substantial increases in drift abundance resulting from TFM treatment. Generally drift abundance of the taxa returned to pretreatment levels within 12 h following the completion of treatment. The drift abundance of *Chimarra* sp. and *Dugesia* sp. remained above normal throughout the rest of the sampling period likely due to continued irritation or mortalities induced by the presence of TFM in the substrate. Generally, drift was a good indicator of those taxa likely to experience a decline in abundance as a result of TFM treatment.

Introduction

Coincident with the invasion of the parasitic sea lamprey *Petromyzon marinus* Linnaeus into the Great Lakes was a decline in abundance of several economically important fishes (Smith & Tibbles, 1980). In 1958, a chemical control program was initiated to reduce the number of larval lamprey inhabiting about 400 Great Lakes' tributaries. The biocide in use then, and now, is the selectively toxic lampricide, 3-trifluoromethyl-4-nitrophenol (TFM) (Smith & Tibbles, 1980). Toxicity of TFM to larval lamprey is known to vary with water quality, being inversely proportional to both hardness and pH (Applegate *et al.*, 1961; Dawson *et al.*, 1975, 1977).

Mortalities of nontarget stream organisms following field applications of TFM have been reported for several diverse taxa, including lotic macroinvertebrates (Smith *et al.*, 1974; Gilderhus & Johnson, 1980). Accordingly, many taxa of Diptera, Ephemeroptera, Trichoptera, Annelida, Pelecypoda and Turbellaria have exhibited TFM sensitivity during 24–96 h LC50 toxicity studies (Smith, 1967; Chandler & Marking, 1975; Maki *et al.*, 1975). Further, toxicity to both TFM sensitive and resistant taxa appears to vary with pH and hardness in a manner similar to that described for larval sea lamprey (Applegate *et al.*, 1961; Fremling, 1975).

Stream treatments with TFM are shorter in duration than biossays, usually ranging from 8–20 h (NRCC, 1985). The effects of TFM on nontarget benthic macroinvertebrates has been studied almost exclusively in softwaters where TFM treatments are generally both shorter in duration and lower in concentration than in hardwater tributaries. Thus, Torblaa (1968) found no consistent pattern of change in numbers of riffle dwelling macroinvertebrates 1 week after treatment among several softwater Great Lake tributaries. Similarly, in a softwater tributary to Lake Michigan benthic macroinvertebrate taxa did not significantly change in abundance 3 days after treatment with TFM (Haas, 1970). Dermott & Spence (1984), in their study of two softwater tributaries of Lake Superior, found only Philopotamidae Trichoptera and Lumbriculidae to be significantly reduced in abundance 3 weeks after TFM treatment.

The invertebrate fauna of hardwater streams is usually different from that of softwaters, often containing more diverse taxa and abundant populations (Mann, 1955; Clarke & Berg, 1959). In the only study of the effects of a lampricide on a hardwater stream Dermott & Spence (1984) found the mixture of TFM with 0.8% 2,5-dichloro-4-nitrosalicylanilide (TFM-2B) caused significant reductions in Hirudinea, Oligochaeta and Turbellaria while many insects increased in numbers 4 d after treatment. This lampricide mixture is more toxic to many macroinvertebrates than TFM alone (Gilderhus & Johnson, 1980; NRCC, 1985). Generally, the hardwater tributaries to the lower Great Lakes are treated only with TFM.

The present study was undertaken to examine changes in the relative abundance of the riffle dwelling macroinvertebrate fauna of a southern Ontario hardwater stream, the Rouge River, following the application of TFM.

Materials and methods

Macroinvertebrates were collected from 3 riffle sites along the lower reaches of the Rouge River (Fig. 1) between October, 1983 and May, 1984. The middle and lower portions of the Rouge River drain an area of approximately 210 km^2 (Environment Canada, 1983) and flows through predominantly residential areas that afford the stream little canopy before entering Lake Ontario. Mean annual discharge in 1983 was 1.61 m$^3 \cdot s^{-1}$ (Environment Canada, 1983). Daily discharge was subject to wide seasonal changes in 1983 varying between 0.18 and 12.88 m$^3 \cdot s^{-1}$. Alkalinity, total and calcium hardness was 196±1 (±SD), 256±2 and 213±6 mg$\cdot l^{-1}$ as $CaCO_3$, respectively, when measured in late October (APHA, 1971). Conductivity was 635±3 μmhos (Radiometer, Model CDM3) and pH, 8.33±0.04. Dissolved oxygen was in excess of 85% of air saturation.

Site I (untreated) was located 1 km upstream from the application site and was approximately 11.8 m in length and 9.3 m in width. Site II was approximately 0.9 km downstream from the point of application and was 15.3 m long by 11.8 m wide. Site III was 4.8 km downstream from the application point and was 17.9 m long by 12.2 m wide. Sites I-III had approximate depths of 20, 24 and 25 cm, respectively. Substrate particle size composition within the upper 15 cm was examined for 3 samples from each of the 3 sites according to the procedures and classification of Cummins (1962). Sites I and III contained 21 and 25% by dry weight cobbles, respectively. Site I contained the greatest amount of pebbles, 51%, while sites II and III had 45% pebbles. Site II had 47% gravel, while Sites I and III contained 22 and 24% gravel, respectively. Site II also had the greatest amount of sand, 8.6%. Sites I and III had 6.3 and 6.8% sand, respectively.

The Rouge River was treated with TFM October 25th and 26th, 1983, as part of the Department of Fisheries and Oceans 1983 sea lamprey control program. During chemical treatment, maximum concentrations of 8.20–9.45 mg TFM$\cdot l^{-1}$ were maintained for 15 h at Site II. Maximum concentrations of 7.70–8.60 mg TFM$\cdot l^{-1}$ were maintained for 13.5 h at Site III. Detectable concentrations were recorded for 16.5 h at Site II and 19 h at Site III.

Benthos was sampled at each site prior to and following stream treatment. Pretreatment samples were taken 1 day before TFM application at Site I, and 3 days before application at Sites II and III. Posttreatment samples were taken 2 and 19 days following TFM application at all sites. Samples were also taken 210 days after treatment at Sites I and III. This sampling was not conducted at Site II due to the placement of a 1 m high water barrier a short distance upstream from this site 166 days following treatment. The barrier severely altered the substrate and no more samples could be collected

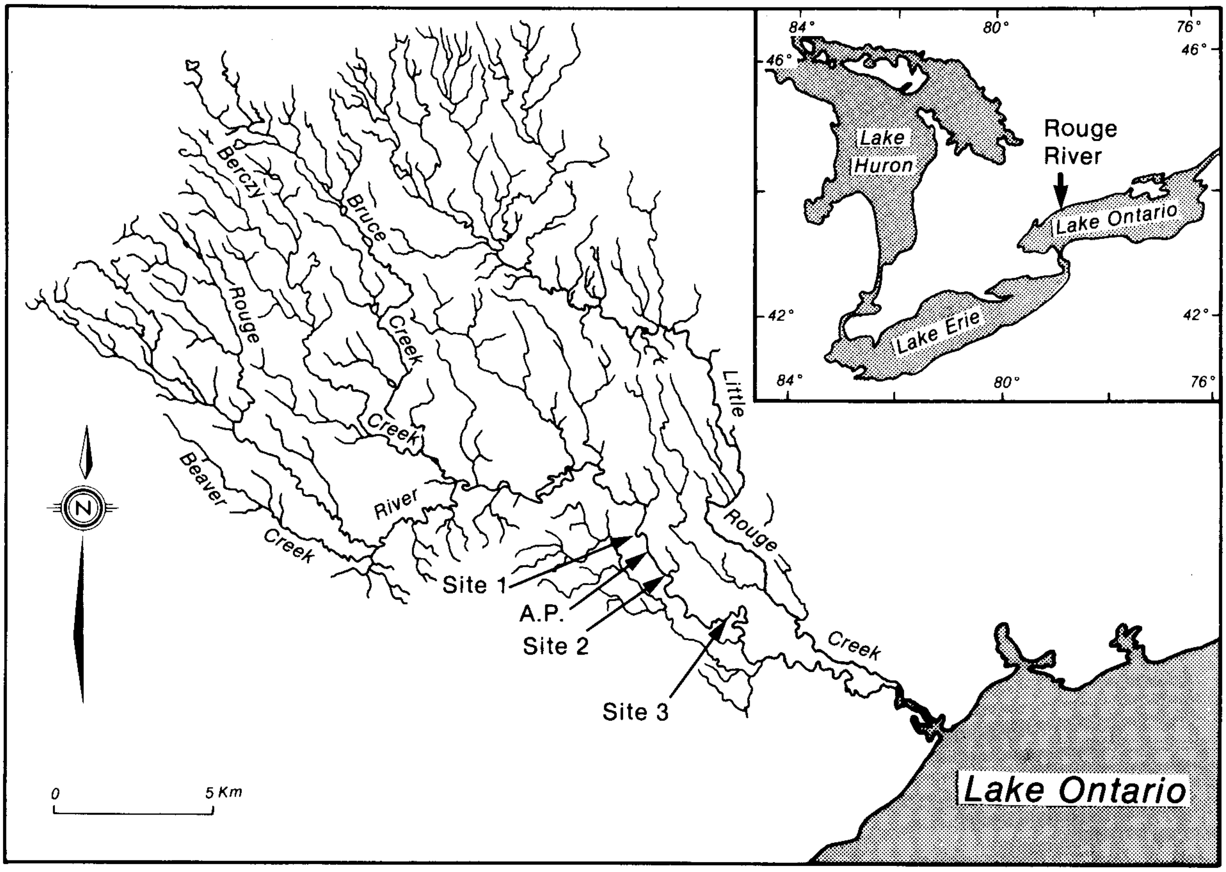

Fig. 1. Location of the sampling sites (Sites I, II and III) and TFM application point (AP) on the Rouge River, hardwater tributary to Lake Ontario.

at Site II. Invertebrate drift was collected at Site III for a 1 h period every 4 h between October 23rd (0700 h) and 28th (0700 h).

Benthic samples were collected using a Surber type sampler, a T-sampler (Mackie & Bailey, 1981) fitted with nitex netting (363 μm pore size). A middle portion of each site, 5.5 m long, was designated the sampling area. The substrate was not sampled within 1 m of either shore. A total of 12 transects across the width, 0.5 m apart, were marked at each site. On each sampling date, 2 previously unsampled transects were randomly selected. From each transect, 15 equally spaced samples were collected.

Invertebrate drift was collected with three rectangular drift nets (aperature 1350 cm^2, 363 μm pore size) held in place by aluminum posts driven into the stream bed. Nets were placed approximately equidistant across the stream width 4 m downstream from Site III and no closer than 2 m from either shore. Stream discharge was measured every 4 h with a portable current meter. Due to differences in collection efficiencies among the 3 nets, numbers and percentages are given for the cumulated total in all nets at any given time.

Samples were preserved in 10% formalin. Macroinvertebrates and detritus collected in benthic samples were separated from the substrate in the laboratory by swirling the contents in a pail of water and repeatedly decanting the suspended organic material onto a 363 μm screen (Platts *et al.*, 1983). The reliability of this method was confirmed by taking 5 random samples that had been previously 'swirled' and carefully sorting through the remaining substrate under 12× magnification. A mean of 3.0 ± 1.8 organisms per sample were found in samples previously yielding an average of

381 organisms. No single taxon or taxonomic group was found more frequently than another following microscopic examination.

Macroinvertebrates were generally identified to genera using the taxonomic keys provided by Brown (1972), Edmunds *et al.* (1976), Klemm (1982), Mackie *et al.* (1980), McAlpine *et al.* (1981), Merrit & Cummins (1978), Oliver & Roussell (1983), Wiggins (1977), and Wood (1963). A reference collection of the macroinvertebrates identified is on file with the Department of Environmental Biology, University of Guelph.

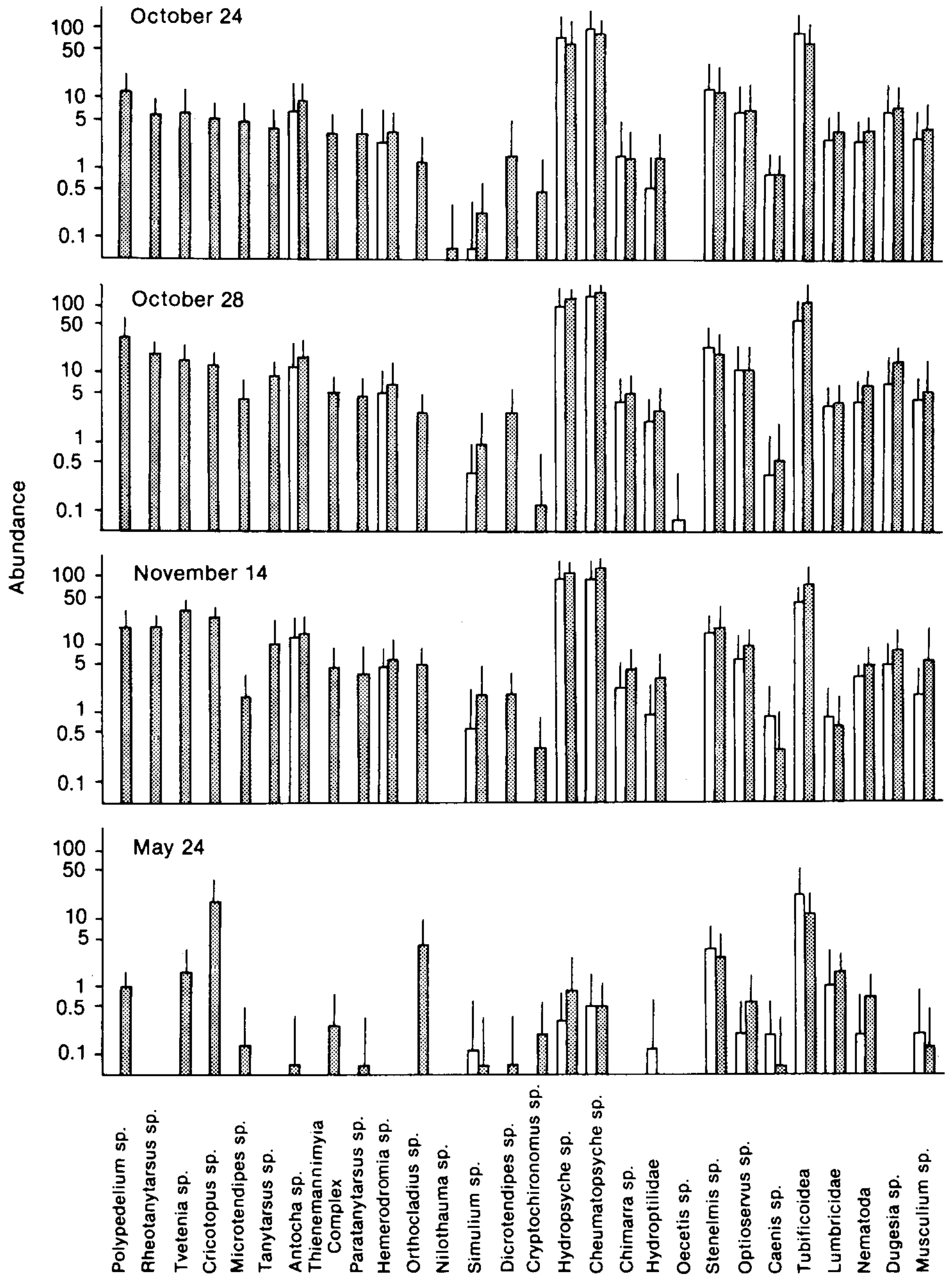

Fig. 2. Mean relative abundance of the dominant taxa of benthic macroinvertebrates collected from the Rouge River at site I before (October 24, 1983) and after the application of the lampricide, TFM (October 25–26, 1983). Open and solid bars represent the results for the 2 transects from which 15 samples each were collected. The vertical line above each bar represents 1 S.D. Chironomidae genera were identified from 1 of the 2 transects.

Results

The macroinvertebrate community of the 3 riffle sites was represented by 68 taxa. Of these, 28 taxa each had relative abundances greater than 0.2% of the total abundance of all 3 sites (Figs. 2, 3, 4). The relative abundances of the remaining 40 taxa combined comprised only slightly more than 1% of the total number of macroinvertebrates collected (Table 1).

The sampling distribution across each transect for each of the 28 major taxa was found to be a contiguous distribution through the use of a chi-square goodness of fit test for negative binomials (Elliott, 1973). The random clumping across the transects and between the sites excluded the possibility of stratification of taxa within the riffle areas therefore the 15 samples taken from each of the two transects at each site for each time were combined to give a sample size of n=30. The contiguous distribution of the taxa necessitated the use of an ln (x+1) transformation (Steel & Torrie, 1980) in order to normalize the data for further analysis. The effects of TFM on each of the major invertebrates was determined by a 3×4 (sites × time) ANOVA table using the normalized data.

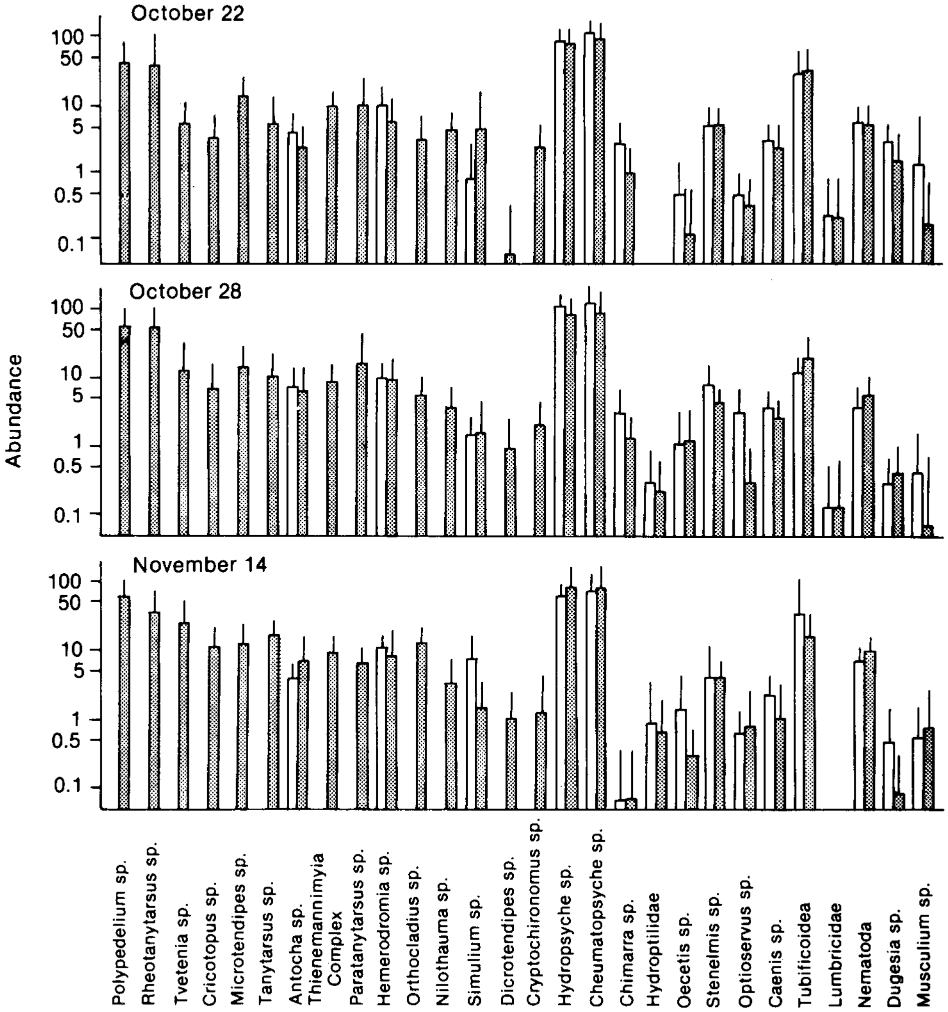

Fig. 3. Mean relative abundance of the dominant taxa of benthic macroinvertebrates collected from the Rouge River at site II before (October 22, 1983) and after the application of the lampricide, TFM (October 25–26, 1983). Open and solid bars represent the results for the 2 transects from which 15 samples each were collected. The vertical line above each bar represents 1 S.D. Chironomidae genera were identified from 1 of the 2 transects.

The benthic community structure prior to the application of TFM was generally similar among the sites. *Hydropsyche* sp., *Cheumatopsyche* sp. and Tubificoidea were consistently abundant at the 3 sites with mean relative abundances of 21.4, 19.7 and 20.4%, respectively. Genera of the Chironomidae were also well represented in pretreatment samples, collectively comprising a mean relative abun-

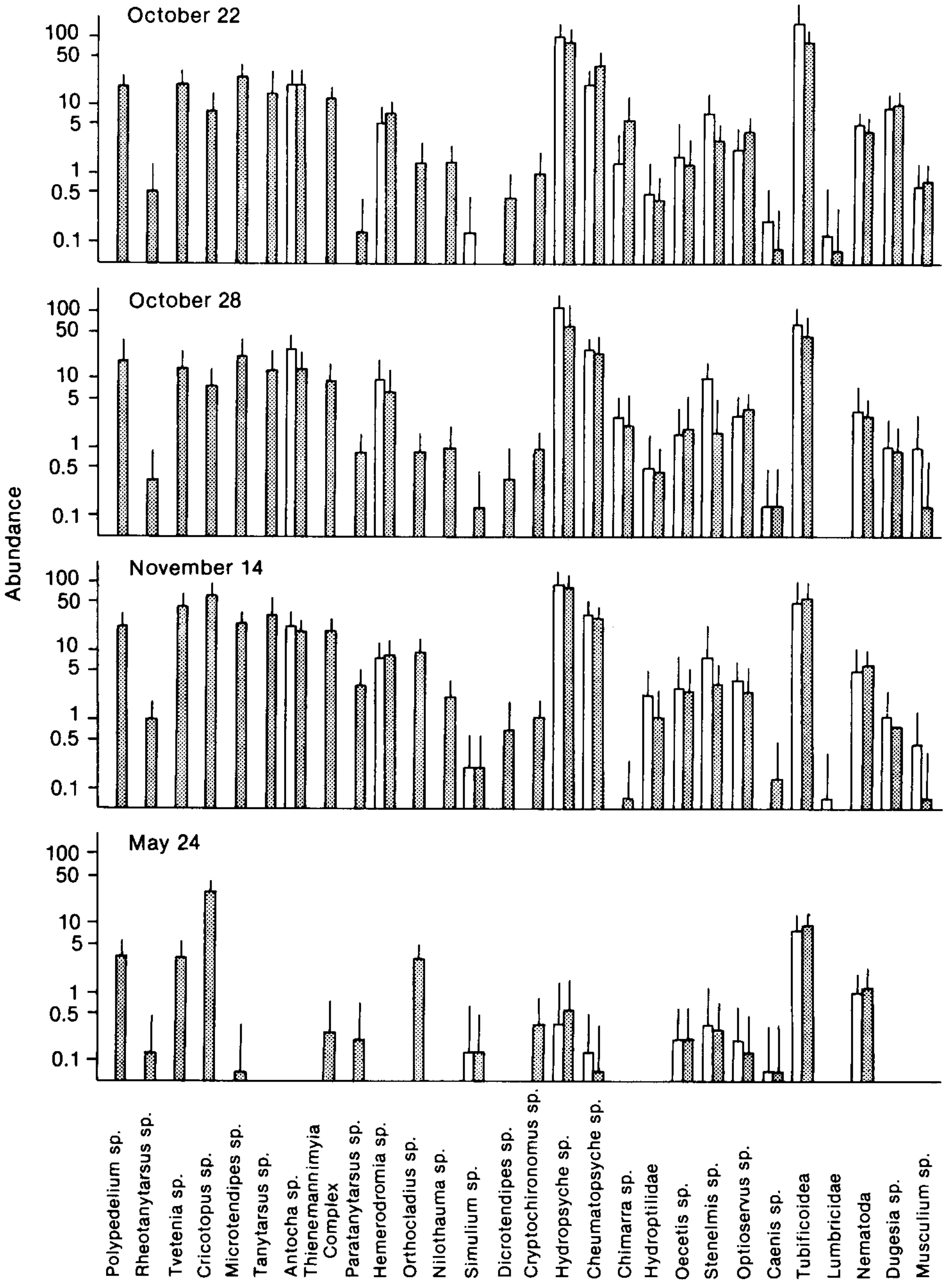

Fig. 4. Mean relative abundance of the dominant taxa of benthic macroinvertebrates collected from the Rouge River at site III before (October 22, 1983) and after the application of the lampricide, TFM (October 25–26, 1983). Open and solid bars represent the results for the 2 transects from which 15 samples each were collected. The vertical line above each bar represents 1 S.D. Chironomidae genera were identified from 1 of the 2 transects.

dance among the sites of 25.3%. However, some notable differences in community structure did occur among the sites.

At Site I, *Hydropsyche* sp., *Cheumatopsyche* sp. and Tubificoidea were most abundant and represented 69.8% of the macroinvertebrates collected on Oct. 24, prior to TFM treatment (Fig. 2). *Stenelmis* sp., *Dugesia* sp., *Antocha* sp. and *Optioservus* sp. were the next most abundant taxa and collectively comprised 10.7% of the total. The Chironomidae were represented by 12 genera and together accounted for 14.2% of the collected benthos. *Polypedilium* sp. was the most abundant chironomid and accounted for 4.1% of the benthic macroinvertebrates.

At Site II the Chironomidae accounted for a much greater proportion of the benthos, 36.8%, than at Site I (Fig. 3). *Polypedilium* sp. and *Rheotanytarsus* sp. were the most abundant chironomids with a cumulative relative abundance of 21.4%. Conversely, *Stenelmis* sp., *Dugesia* sp., *Antocha* sp. and *Optioservus* sp. were less than half as abundant as at the upstream site. *Cheumatopsyche* sp. and *Hydropsyche* sp. together represented 45.5% of the benthos at Site II, similar to Site I. Tubificoidae accounted for 8.1% of the benthos, approximately one-half the relative abundance at Site I.

Tubificoidea and *Hydropsyche* sp. were the most abundant taxa at Site III, together representing 54.1% of the macroinvertebrates collected (Fig. 4). *Cheumatopsyche* sp. was less than 30% as abundant as at the 2 upstream sites, yet ranked third at Site III. Chironomidae genera accounted for 24.9% of the benthos. *Microtendipes* sp., *Tvetenia* sp., *Polypedilium* sp., *Tanytarsus* sp. and *Thienemannimyia* sp. complex collectively represented 22.1% of the totals collected. *Antocha* sp. and *Dugesia* sp. were more than twice as abundant as at the upstream sites.

All taxa were represented at each site prior to the application of TFM; however, *Caenis* sp., *Paratanytarsus* sp. and *Rheotanytarsus* sp. were present in very small numbers at Site III (Fig. 4). Lumbricidae was poorly represented at both treatment sites, but abundant at Site I.

Most taxa from the untreated Site, I, changed appreciably in their numbers between late October and early May. Generally, the macrobenthos exhibited an increase in abundance from before treatment and 2 days after. Trichoptera, Coleoptera, many Diptera genera, Nematoda and *Musculium* sp. increased in relative abundance 2 days after treatment, often by 50% or more of the earlier abundances. Significant increases ($P<0.05$) were exhibited by Trichoptera genera, *Optioservus* sp., *Polypedilium* sp., *Antocha* sp. and *Hemerodromia* sp. Subsequently, the relative abundances of most taxa at Site I declined 17 days later.

A few taxa at Site I did not follow the pattern described above. *Caenis* sp. and *Cryptochironomus* sp. decreased in relative abundance 2 days after treatment followed by an increase to near pretreatment relative abundances 17 days later. Many of the most abundant Chironomidae genera and *Simuliium* sp. experienced significant and continual increases in relative abundance from October to November. *Tanytarsus* sp. and *Tvetenia* sp. increased from means of 3.5±3.2 and 5.9±6.9 individuals per sample during pretreatment sampling to 10.3±11.0 and 30.9±15.3 19 days after treatment, respectively. *Dugesia* sp. increased in relative abundance 2 days after treatment followed by a significant reduction to less than initial values during the November sampling. The relative abundances of Lumbricidae and Tubificoidea remained stable between pretreatment samples and the first posttreatment samples but decreased significantly 17 days later. *Microtendipes* sp. decreased significantly in relative abundance throughout the study.

In May, 1984, 210 days after treatment, relative abundances were, on the whole, greatly reduced compared with those found 2 and 19 days following treatment. The abundances of all but three taxa were reduced by 75% or more from the second posttreatment sampling. Although *Cricotopus* sp. experienced a significant decline from 19 days after treatment to the following spring, the mean number of organisms per sample, 18.7±18.3, was much higher than that of the pretreatment samples, 5.0±2.8. Relative abundances of *Cryptochironomus* sp. and *Orthocladius* sp. declined slightly 210 days following treatment. Lumbricidae experienced an increase from a mean of 0.8±1.2 to 1.4±1.9 individuals per sample for the same period.

Relative abundances of many of the macrobenthic taxa collected at Site II followed the same trends from 2 days to 19 days after treatment as those at Site I. Coleoptera and Trichoptera genera, with the exception of *Chimarra* sp. and Hydroptili-

Table 1. Mean number (±S.D., n=30*) of the less abundant taxa of benthic macroinvertebrates from 3 sites in the Rouge River before (October 22⁺, 1983) and after the application of the lampricide, TFM (October 26, 1983).

Classification	Pretreatment			Post treatment							
	October 22⁺ Site			October 28 Site			November 14 Site			May 24 Site	
	1	2	3	1	2	3	1	2	3	1	3
DIPTERA											
Atherix sp.		0.17±0.38			0.43±0.86			0.27±0.52			
Bezzia sp.	0.03±0.18	0.27±0.69	0.90±1.06	0.13±0.35	0.37±0.67	0.67±1.24	0.27±0.64	0.63±1.10	1.60±2.21		
Dicranota sp.	0.03±0.18	0.03±0.18	0.20±0.41	0.13±0.43	0.08±0.18	0.70±2.20	0.17±0.46	0.03±0.18	0.73±1.17	0.10±0.31	
Hexatoma sp.								0.03±0.18			
Limnophora sp.								0.03±0.18			
Tipula sp.	0.03±0.18		0.10±0.31		0.03±0.18	0.23±0.50			0.10±0.31		
CHIRONOMIDAE											
Diamesa sp.							0.07±0.26				
Lymnophyes sp.	0.07±0.26			0.07±0.26			0.07±0.26				
Potthasia sp.			0.07±0.26	0.13±0.35			2.31±1.69		0.53±0.92		
Thienemanniella sp.					0.07±0.26						
Xenochironomus sp.					0.13±0.35						
TRICHOPTERA											
Glossosoma sp.	0.03±0.18							0.03±0.18			
Helicopsyche sp.		0.20±0.48	0.93±1.48		0.30±0.75	0.80±1.10		0.40±0.62	1.20±2.12	0.07±0.37	
Hydroptila sp.	0.53±1.17	0.43±0.68	0.73±1.02	1.13±1.22	1.30±2.32	0.37±0.72	2.93±1.82	1.07±1.48	0.30±0.70	0.03±0.18	
Rhyacophila sp.	0.03±0.18	0.07±0.37						0.10±0.40			
COLEOPTERA											
Berosus sp.		0.03±0.18	0.27±0.52		0.03±0.18	0.20±0.48		0.03±0.18	0.20±0.41		
Dubiraphia sp.	0.13±0.35		0.47±0.68	0.23±0.50		0.37±0.67	0.07±0.26	0.10±0.40	0.23±0.43	0.03±0.18	
Ectopria sp.	0.33±0.55	0.03±0.18	0.17±0.38	0.43±0.82	0.03±0.18	0.13±0.43	0.33±0.66	0.03±0.18	0.07±0.26		
Promoresia sp.					0.03±0.18						
EPHEMEROPTERA											
Baetis sp.	0.03±0.18		0.30±0.47		0.03±0.18	0.07±0.26		0.13±0.43	0.07±0.26	0.17±0.38	0.57±0.86
Ephemera sp.		0.13±0.35							0.03±0.18		
Ephemerella sp.		0.03±0.18						0.03±0.18			
Heptageniidae sp.								0.03±0.18			

Table 1. Continued.

Classification	Pretreatment			Post treatment							
	October 22⁺ Site			October 28 Site			November 14 Site			May 24 Site	
	1	2	3	1	2	3	1	2	3	1	3
Isonychia sp.				0.03 ± 0.18							
Paraleptophlebia sp.								0.10 ± 0.40			
Pseudocloen sp.	0.03 ± 0.18	0.10 ± 0.40					0.03 ± 0.18	0.17 ± 0.46			
Stenonema sp.	0.03 ± 0.18	0.10 ± 0.40	0.03 ± 0.18		0.07 ± 0.26		0.17 ± 0.59		0.03 ± 0.18		
MEGALOPTERA											
Sialis sp.	0.30 ± 0.70	0.33 ± 0.66		0.27 ± 0.58	0.50 ± 0.94	0.07 ± 0.26	0.23 ± 0.43	0.47 ± 0.63			
LEPIDOPTERA											
Paragyractis sp.		0.03 ± 0.18	0.03 ± 0.18						0.03 ± 0.18		
HIRUDINEA											
Helobdella sp.	0.20 ± 0.61		0.07 ± 0.26	0.23 ± 0.50		0.03 ± 0.18	0.07 ± 0.26				
TURBELLARIA											
Gyratrix sp.		0.03 ± 0.18									
ARACHNOIDEA											
Aquatic spider								0.07 ± 0.26			
Hydrocarina	0.20 ± 0.48	0.27 ± 0.58	0.27 ± 0.58	0.83 ± 1.26	0.23 ± 0.50	0.70 ± 0.99	0.13 ± 0.35	0.33 ± 0.66	0.50 ± 1.31	0.03 ± 0.18	
CRUSTACEA											
Copepoda										0.03 ± 0.18	0.03 ± 0.18
Ostracoda		0.40 ± 0.72	0.30 ± 1.02		0.20 ± 0.61	0.07 ± 0.37		0.13 ± 0.35	0.07 ± 0.26	0.43 ± 0.86	0.10 ± 0.31
Lirceus sp.	0.10 ± 0.31				0.03 ± 0.18						
GASTROPODA											
Ferrissia sp.	0.03 ± 0.18	0.03 ± 0.18			0.03 ± 0.18	0.03 ± 0.18	0.07 ± 0.26				
Physella sp.	0.13 ± 0.35	0.30 ± 0.54	0.07 ± 0.26	0.03 ± 0.18	0.30 ± 0.75	0.07 ± 0.37		0.43 ± 1.17	0.07 ± 0.26		
Pseudosuccinea sp.		0.03 ± 0.18									
PELECYPODA											
Pisidium sp.				0.03 ± 0.18							

* n = 15 for Chironomidae genera.

⁺ Site 1 pretreatment samples were collected October 24, 1983.

dae, increased in relative abundance two days after TFM application followed by a decline about 3 weeks later. The Diptera, including the Chironomidae, generally followed the trends exhibited at site I, with increases in relative abundance 2 days after treatment followed by a decline 17 days later. *Tanytarsus* sp. and *Tvetenia* sp. continued to increase in relative abundance throughout the first 2 posttreatment samplings, as at Site I. *Paratanytarsus* sp. increased appreciably 48 h after exposure to TFM followed by a significant decrease 17 days later. *Cryptochironomus* sp. steadily decreased in abundance throughout the October and November posttreatment sampling.

A few taxa at Site II exhibited a decline in relative abundance shortly after TFM treatment followed by a partial or complete recovery 17 days later. Nematoda, *Simuliium* sp. and Tubificoidae declined in relative abundance by 18, 45 and 48% respectively, following treatment. Subsequently, their abundance increased to approximately pretreatment levels 19 days after TFM application. Relative abundance of *Nilothauma* sp. and *Musculium* sp. tended to decline 2 days after treatment with TFM followed by a partial recovery in the November sampling. Numbers of *Caenis* sp. and *Chimarra* sp. remained stable 2 days after exposure to TFM and then declined significantly 17 days afterward, the latter to near elimination. Lumbricidae, although represented by few individuals prior to lampricide application, declined after treatment and was absent from the November samples. *Dugesia* sp. declined in relative abundance by 85% shortly after lampricide treatment followed by a further reduction 17 days later.

Taxa at Site III exhibited various responses throughout the study. *Antocha* sp., *Cricotopus* sp. and *Hemerodromia* sp. followed the same patterns as exhibited at the two upstream sites. *Cryptochironomus* sp., *Microtendipes* sp., *Paratanytarsus* sp., Coleoptera and many of the Trichoptera genera remained within 10% of pretreatment relative abundances during the autumn of 1983. This was followed by a significant reduction in numbers the next spring. Also, the relative abundances of each of eight genera of Chironomidae and the Nematoda tended to decline 2 days after treatment in contrast to an increase in these taxa at Site I during the same time period. The Chironomidae genera and Nematoda at site III then significantly increased in abundance 17 days later.

Other taxa at Site III experienced greater and more persistent declines in relative abundance following the application of TFM. *Caenis* sp., *Dugesia* sp. and Tubificoidea exhibited patterns similar to those at Site II. However, the extent of the decline in *Dugesia* sp. and Tubificoidea was much greater than at Site II with relative abundance decreasing by 90 and 55% respectively 48 hours following lampricide treatment. A further reduction by Tubificoidea of approximately 10% occurred 17 days later followed by a significant reduction the following spring. The relative abundance of *Musculium* sp. at Site III declined steadily throughout the duration of the study, whereas, at Site II *Musculium* sp. exhibited a pattern of recovery following and initial decline after TFM treatment. *Chimarra* sp. experienced the greatest reduction in relative abundance at Site III, 98.3% 19 days following treatment with TFM.

The May 1984 samples revealed that each of the 28 most abundant macroinvertebrate taxa collected at Site III had significantly declined in relative abundance. For each of these taxa a similar pattern of equal magnitude, occurred at the untreated site.

The community structure of the drift prior to the application of TFM generally resembled that of the benthos at nearby Site III (Fig. 5a and b; Table 2). Of the 53 taxa present in the drift, *Hydropsyche* sp. and Tubificoidea (Fig. 5a) were the most abundant, as they were in the benthos, together comprising 29.7% of the total number of organisms collected. However, Ostracoda (Fig. 5a) which was rarely present in the benthic samples accounted for 28.8% of the organisms collected in the pretreatment drift. The Chironomidae genera together totaled 16.6% of the drift with *Cricotopus* sp. (Fig. 5b) appearing in greater numbers than were found in the benthic samples. *Antocha* sp. (Fig. 5b) was well represented in the pretreatment drift samples while *Dugesia* sp. (Fig. 5a) was relatively scarce. Lumbricidae was present in greater numbers in the drift than in the benthic samples. Orthocladinae pupae (Fig. 5b), *Physella* sp. and Lymnaeidae (Table 2) were generally absent in the benthic samples but ranked 7th, 12th and 14th respectively in total abundance of drift.

The number of organisms found, within several taxa, was closely related to river discharge. The number of Ostracoda captured declined sharply from 152 to $2 \cdot h^{-1}$ as discharge decreased from 4800 (0700 h, Oct. 24) to 2300 $m^3 \cdot h^{-1}$ (0700 h, Oct. 27). Other taxa which exhibited a direct relationship with discharge were *Hydropsyche* sp., *Cheumatopsyche* sp. (Fig. 5a), *Thienemannimyia* complex, *Cricotopus* sp. (Fig. 5b) and *Tvetenia* sp. (Table 2). Tubificoidea and Lumbricidae (Fig. 5a) were most affected by river discharge during the first two days of sampling. *Physella* sp. and Lymnaeidae (Table 2) were abundant only during the first hour drift was collected. Thereafter, they were either absent or present in low numbers.

Daily patterns in drift abundance were evident for many of the insect taxa. *Oecetis* sp. (Fig. 5b) was most abundant during the daylight hours, particularly at 1500 h, and was lowest between 0300 and 0700 h. *Tvetenia* sp., *Antocha* sp. and Orthocladinae pupae were also most abundant during the daylight hours. The only non-insect taxa to exhibit a daily pattern of activity was Hydrocarina which peaked at 1500 h. *Microtendipes* sp., *Cricotopus* sp. (Fig. 5b) and *Helicopsyche* sp. (Fig. 5a) were most abundant during the hours of daylight. *Cheumatopsyche* sp. (Fig. 5a) was the only invertebrate that was more abundant during the hours of darkness.

The community structure of the drift samples changed considerably during the application of TFM. *Dugesia* sp. and Tubificoidae together represented less than 18% of the invertebrates col-

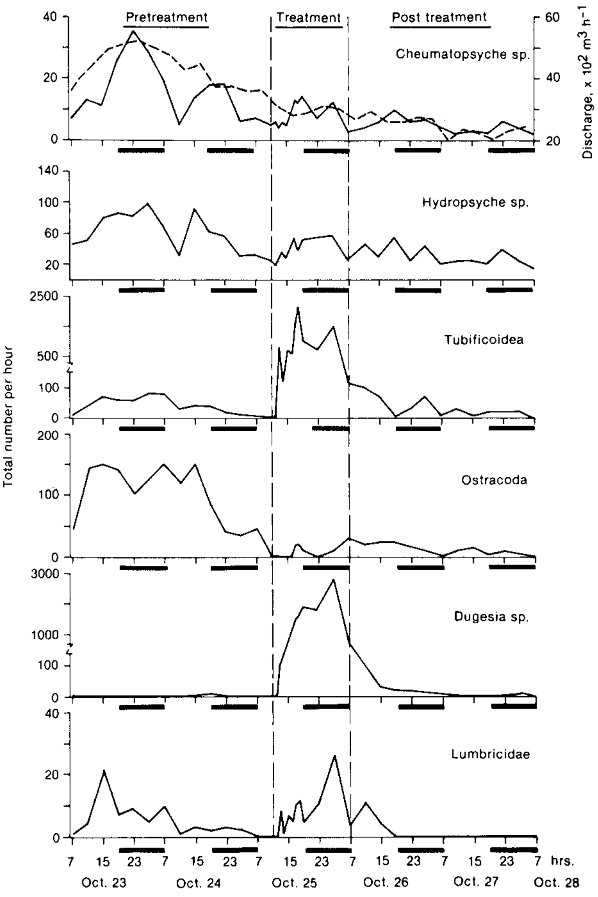

Fig. 5a. The total drift net accumulation of various taxa during a 5½ day period including a 20 hour interval of TFM treatment. Samples were taken from the Rouge River, 1983, 5.8 km downstream from the lampricide application point. Hours of darkness are indicated by heavy horizontal bars below the absca.

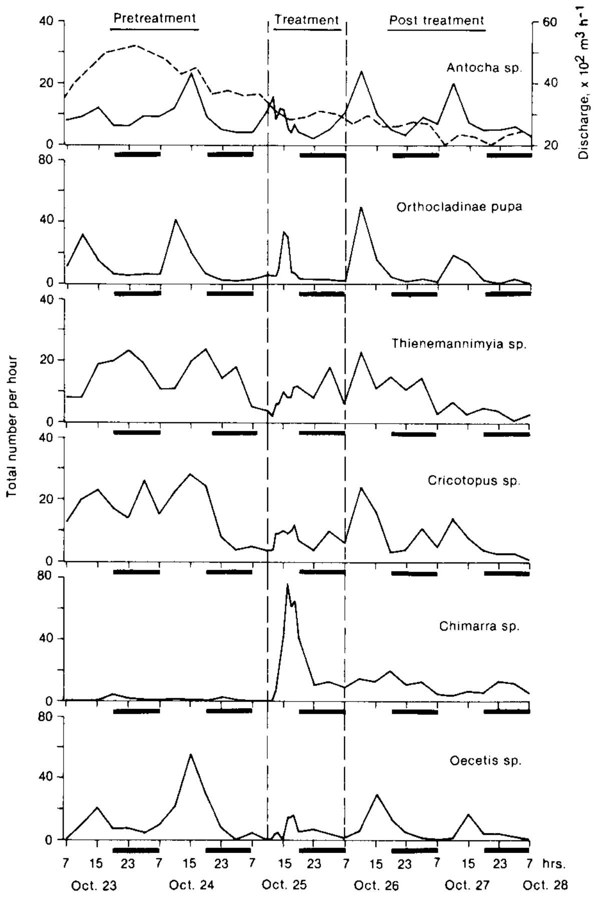

Fig. 5b. The total drift net accumulation of various taxa during a 5½ day period including a 20 hour interval of TFM treatment. Samples were taken from the Rouge River, 1983, 5.8 km downstream from the lampricide application point. Hours of darkness are indicated by heavy horizontal bars below the abscissa.

Table 2. Mean (±SD) number of macroinvertebrates collected in drift samples for a 1 h period every 4 h prior to, during and following the application of TFM to the Rouge River, Oct. 1983. Samples were taken 5.8 km from TFM application point.

Classification	Pretreatment	Treatment	Post treatment
DIPTERA			
Hemerodromia sp.	2.00± 1.62	4.64±4.11	1.67±0.98
Simulium sp.	0.43± 0.51	0.18±0.41	0.42±0.79
Bezzia sp.	0.29± 0.61	0.45±0.52	0.08±0.29
Dicranota sp.	0	1.64±1.63	0.25±0.62
Limnophora sp.	0.07± 0.27	0	0
Sigara sp.	2.64± 3.50	0.82±1.54	2.08±3.00
Tipulidae	0	0.09±0.30	0
CHIRONOMIDAE			
Microtendipes sp.	7.86± 4.69	9.45±3.75	6.75±4.39
Polypedilium sp.	1.50± 1.70	1.27±0.90	0.92±0.67
Rheotanytarsus sp.	1.07± 1.07	0	0.33±0.65
Tvetenia sp.	23.43±48.29	6.09±3.56	5.27±3.41
Tanytarsus sp.	2.07± 0.47	0.73±0.65	1.25±1.06
Paratanytarsus	0.29± 0.47	0.09±0.30	0.08±0.29
Orthocladius sp.	1.21± 0.97	1.00±1.18	0.33±0.49
Nilothauma sp.	0.07± 0.27	0.09±0.31	0
Dicrotendipes sp.	0.21± 0.58	0	0.17±0.40
Cryptochironomus sp.	0.21± 0.58	0	0
Limnophyes sp.	0.07± 0.27	0	0
Procladius sp.	0.07± 0.27	0	0
Zavrelimyia sp.	0.07± 0.27	0	0
TRICHOPTERA			
Hydroptilidae	0.43± 0.65	0.73±1.00	0.17±0.39
Hydroptila sp.	1.64± 1.74	1.45±1.92	1.33±1.15
Helicopsyche sp.	1.43± 2.87	0.45±0.93	0.50±0.90
COLEOPTERA			
Stenelmis sp.	0.79± 0.70	0.45±0.52	0.25±0.45
EPHMEROPTERA			
Caenis sp.	0.64± 0.93	0.27±0.65	0.17±0.39
Baetis sp.	0.93± 0.83	2.00±1.79	1.17±1.27
Ephemera sp.	0.36± 0.50	0	0.08±0.29
Hexagenia sp.	0	0.09±0.30	0
Stenacron sp.	0.71± 1.33	0.91±1.64	0.33±0.65
MEGALOPTERA			
Sialis sp.	0.36± 0.50	0	0
ODONATA			
Catopterygidae	0.21± 0.43	0	0.25±0.62
PLECOPTERA			
Taeniopteryx sp.	0.43± 0.85	0.09±0.30	0.08±0.29
NEMATODA	1.21± 1.25	1.55±2.21	1.25±1.22
PELECYPODA			
Musculium sp.	1.43± 1.60	0.45±0.82	0.25±0.87
GASTROPODA			
Physella sp.	3.71± 6.64	0.09±0.30	0.58±1.00
Lymanaeidae	2.93± 6.07	0.82±1.40	1.25±1.14
HIRUDINEA			
Erpobdella sp.	0.21± 0.58	3.09±2.34	0.33±0.49
CRUSTACEA			
Copepoda	0.21± 0.58	0.09±0.30	0.08±0.29
Amphipoda	0.36± 0.63	0.09±0.30	0
Isopoda	0.21± 0.43	0	0
ARACHINOIDEA			
Hydrocarina	2.00± 4.80	0.91±1.04	1.67±4.58

lected in the pretreatment drift samples however they accounted for 52.9% and 38.6%, respectively of the organisms caught during treatment. *Chimarra* sp. increased from 0.3% of the pretreatment samples to 1.5% during treatment. *Hemerodromia* sp. and *Erpobdella* sp. also had greater totals per hour in treatment samples than during pretreatment (Table 2). *Hydropsyche* sp., Lumbricidae, Orthocladinae pupae and the Chironomidae genera were as abundant in treatment samples as in pretreatment.

Dugesia sp., Tubificoidea, *Erpobdella* sp. and *Chimarra* sp. all exhibited increases in total numbers 1.5 h after the introduction of TFM. *Hemerodromia* sp. started to increase in abundance 4.5 h after TFM application. *Dugesia* sp., Tubificoidea and *Erpobdella* sp. all reached peaks of total drift abundance at different times (*Erpobdella* sp. with a total of 11 at 6.5 h) during TFM treatment but were declining 16 h into the treatment and were generally back to pretreatment levels 8 h following completion of treatment with TFM. *Chimarra* sp. reached its peak 4.5 h after the introduction of TFM and remained above pretreatment levels for the remainder of the collection period. *Hemerodromia* sp. reached an hourly peak of 14 individuals 15.5 h after the introduction of TFM and then declined to pretreatment levels.

Drift samples taken after treatment were similar in composition to those before treatment. Chironomidae genera were slightly more abundant in the posttreatment samples than in the pretreatment, comprising 18.8% of the organisms obtained. The numbers of Ostracoda found in the posttreatment samples declined from those before treatment, as did stream discharge. *Dugesia* sp. and *Chimarra* sp. were found to be substantially more abundant in the posttreatment drift than in the pretreatment.

Discusion

The application of TFM to the Rouge River, a hardwater tributary to Lake Ontario did not affect the relative abundances of most of the river's macroinvertebrate taxa. Of the 68 benthic macroinvertebrate taxa collected, only 5 exhibited significant declines in relative abundance in the upper substrate during a 19 day period following TFM treatment. Most of these taxa, in addition to a few others also increased in drift abundance during the presence of TFM. This increase in drift numbers strengthens the observation that certain macroinvertebrate taxa are TFM-sensitive and that their response to the lampricide is almost immediate.

The response of most of the affected taxa was similar to that observed in earlier studies. Maki *et al.* (1975) found *Chimarra obscura* Walker to be extremely sensitive to TFM during laboratory tests using water of similar total hardness to that of the Rouge River and estimated its numbers would be virtually eliminated in treated streams. Smith (1967) concluded from toxicity tests using waters of unknown hardness that Turbellaria (e.g. *Dugesia* sp.) would also experience total mortality during stream treatments. In the present study, both *Chimarra* sp. and *Dugesia* sp. were nearly eliminated at both treatment sites following TFM application and exhibited large increases in drift abundance during treatment. The decrease in benthic abundance and increase in drift during treatment by Turbellaria was also observed by Dermott & Spence (1984) in their study of Soper Creek, a hardwater tributary to Lake Ontario. *Chimarra* sp. was not found in the hardwater stream studied by Dermott & Spence (1984) however in their study of two softwater tributaries of Lake Superior *Chimarra* sp. was greatly decreased in benthic abundance following TFM treatment.

The large reduction in abundance of *Simuliium* sp. observed in the present study was similar to that predicted by Smith (1967) and Maki *et al.* (1975). Through laboratory tests it was estimated that Simuliidae would suffer 50–100% mortality during stream treatments. The decline of *Simuliium* sp. at site II in the present study was slightly less than 50% 2 days after treatment. However, its numbers were completely restored in the benthos less than 3 weeks later. Conversely, Dermott & Spence (1984) found increases in benthic abundance of Simuliidae following TFM-2B (TFM+0.8% Bayer 73) treatment of Soper Creek, although increases in drift abundance by this taxa were observed during treatment. The only Diptera to exhibit an increase in drift abundance during the present study was *Hemerodromia* sp. (Empididae). Torblaa (1968) observed a decline in benthic abundance of Empididae in some treated softwater streams.

Lumbricidae, although present only in low numbers at the treated sites of the Rouge River declined following TFM application as predicted by Maki *et al.* (1975). In addition, Lumbricidae increased in drift abundance shortly after TFM application and was completely absent from all posttreatment drift samples. Tubificoidea was also seriously reduced in benthic abundance following TFM treatment but not to the extent found by Torblaa (1968) and Chandler & Marking (1975). These studies, conducted in softwaters, found that Tubificoidea was virtually eliminated subsequent to lampricide treatment. Another annelid, *Erpobdella* sp. exhibited significant increases in drift abundance during TFM treatment but was not eliminated from posttreatment benthic samples. Again, the deleterious effects of TFM on the abundance of *Erpobdella* sp. was not as severe as indicated from Smith's (1967) toxicity tests. Dermott & Spence (1984) found increases in drift abundance during the treatment of Soper Creek by all oligochaetes and Erpobdellidae. However, of the oligochaetes only Lumbriculidae exhibited a decrease in benthic abundance, a pattern observed also in softwater streams (Dermott & Spence, 1984).

Caenis sp., a non-burrowing mayfly, and, in the Rouge River, the most abundant genus with the Ephemeroptera, declined in benthic relative abundance following TFM application. Although some genera of Ephemeroptera have been found to be extremely sensitive to TFM in laboratory tests (Maki *et al.,* 1975; Chandler & Marking, 1975) and field studies (Torblaa, 1968; Haas, 1970; Dermott & Spence, 1984), the sensitivity of *Caenis* sp. has not previously been observed. Smith (1967) found in laboratory toxicity studies that non-burrowing mayflies are reasonably tolerant to TFM and suggested they should not be greatly affected during stream treatments. However, Smith (1967) did not include *Caenis* sp. in his tests.

The sensitivity of some macroinvertebrates to TFM was demonstrated by the increase in drift abundance oberved during the treatment. *Erpobdella* sp., *Dugesia* sp., Tubificoidea and *Chimarra* sp. increased in drift abundance as soon as 1.5 h after the introduction of TFM. Maki (1980) observed similar immediate increases in the total number of drifting organisms following TFM application. A rapid increases in drift abundance has also been noted following the application of another biocide, methoxychlor (Flannagan *et al.,* 1979). Maki (1980) noted that the rise in drift was due almost entirely to a few TFM-sensitive species. Dermott & Spence (1984) found that several taxa increased significantly in drift abundance during treatment while only 1 of these taxa also declined in abundance at the riffle sites. Indeed, they concluded that increased drift is the major effect of lampricide treatment. During the present study *Chimarra* sp., *Dugesia* sp. and Tubificoidea exhibited the greatest increase in drift abundance and they also severely declined in benthic relative abundance after treatment. The drift samples were not analyzed immediately after capture but rather preserved for later identification. It is therefore not possible to comment on the number of organisms killed by TFM in contrast to those induced to leave the substrate through irritation. *Chimarra* sp. and *Dugesia* sp. continued to have high drift rates for the remainder of the drift sampling period.

The effect of TFM on the diurnal drift patterns of less sensitive taxa in the Rouge River is difficult to quantify due to the brief length of the pre and post drift sampling periods. However, it does seem that the diurnal patterns of drift were not obviously affected. The observation that *Oecetis* sp. and *Helicopsyche* sp. were day-drifters while *Cheumatopsyche* sp. was most prevalent at night is in accord with Waters′ (1972) observation that some Trichoptera are day-active while others are night-active. Muller (1966, in Waters, 1968) noted that Hydrocarina was day-active as was observed in this study.

Previous field studies of the effects of TFM treatment on the macroinvertebrates of softwater streams have shown decreases in taxa similar to those observed here. However, comparisons between this study and those by Haas (1970) and Torblaa (1968) are difficult due to differences in sampling protocol. Also, the effects of hardness and pH on benthic community structure are not well understood (Hynes, 1970). This may also be a factor in differences seen between this study and others. Haas (1970) found that after the study stream had been subjected twice within a month to TFM treatment 10 of the 12 taxa studied decreased in abundance of the experimental area, while 5 taxa decreased at the control site, although statistical significances were not demonstrable. Torblaa (1968) used untreated and treated streams as control and experimental sites, respectively and found reductions in abundance of some Ephemeroptera, Plecoptera, Trichoptera and Coleoptera genera 1 week after treatment in some treated streams. Dermott & Spence (1984) found that 3 weeks after treatment with TFM Trichoptera, *Dolophilodes* sp. and *Chimarra* sp. were eliminated from both softwater streams studied. Oligochaetes were reduced by 70%. Decreases in some Ephemeroptera and Plecoptera genera were observed in one of the treated streams (Dermott & Spence, 1984). *Chimarra* sp. and Oligochaeta were similarly affected during the treatment of the Rouge River.

Most of the Rouge River macrobenthic fauna adversely affected by lampricide treatment had begun recolonizing the substratum 19 days after treatment. Torblaa (1968) samples 1 and 6 weeks following TFM treatment and observed recovery in most streams within 6 weeks. Dermott & Spence (1984) found that most invertebrates were able to recolonize a disturbed area of a softwater stream 3 weeks after treatment. Only *Dolophilodes* sp. and *Chimarra* sp. were still absent from the disturbed area 3 weeks later. *Chimarra* sp. was also severely decreased at the Rouge River 19 days after treatment. The Rouge River was treated with a greater amount of TFM and for a longer period of time than the softwater streams studied by Torblaa (1968) and Dermott & Spence (1984). However, recolonization of the Rouge River had begun within about the same time span as found by Dermott & Spence (1984). This rapid recolonization is undoubtedly related to the hardness and pH of the Rouge River. Organisms tolerant of TFM detoxify the accumulated chemical by conjugation with glucuronic acid (Kawatski & Bittner, 1975). In contrast, TFM sensitive taxa such as the annelid worms and leeches (Maki & Johnson, 1977; Metcalfe *et al.*, 1984) accumulate TFM but are unable to biotransform the compound to a less toxic form. This may be true also for some aquatic insects that are sensitive to the lampricide. It is well established that the toxicity of TFM varies inversely with pH and hardness (Applegate *et al.*, 1961). At pH's greater than 6.07 the relative amount of the toxic free phenol form of TFM is decreased thus lowering uptake by organisms (NRCC, 1985). The effect of hardness on the toxicity of TFM is related directly to pH. In hard water free Ca^{++} ions are prevalent and complex with TFM, again reducing the uptake of the chemical (NRCC, 1985). Kawatski & Bittner (1975) observed that as hardness increased the amount of TFM accumulated by *Chironomus tentans* Fabricius was less while elimination was more rapid. That mortalities were less severe among the Tubificoidea and *Erpobdella* sp. in the hardwater of the Rouge River than in softwater studies may reflect an inverse relationship with accumulation. Both *Chimarra obscura* and *Simuliium pugetense* have lower 24 h LC50's than the Annelida at a hardness slightly lower than that of the Rouge River (Maki *et al.*, 1975). These two taxa would, therefore, be expected to be more affected than the annelids even in water of high total hardness. Lumbricidae must have a lower tolerance to TFM than either Tubificoidea or *Erpobdella* sp. The hardness of the Rouge River may also account for the differences in the taxa affected in this study in comparison with the findings of Torblaa (1968) and Dermott & Spence (1984). They found decreases in benthic abundance of several Ephemeroptera, Trichoptera, Plecoptera and Coleoptera genera in treated softwater streams. In the Rouge River only one Ephemeroptera and one Trichoptera genus exhibited decreases. Genera within the Coleoptera were not affected while no Plecoptera were present.

The slightly longer period of exposure to TFM experienced by the benthos at site III over that at site II almost certainly was responsible for the short-term reduction in numbers by many of the Chironomidae genera and Nematoda at site III. The affected genera of Chironomidae and Nematoda returned to pretreatment abundance at site III 19 days after treatment and recolonization by all taxa was complete within 7 months. Recolonization typically occurs through a number of mechanisms including oviposition (Muller, 1954; Ross, 1957) and upstream migration (Ball *et al.*, 1963 in Waters, 1964). Oviposition may be discounted in the present study as sampling took place from autumn to winter. Upstream migration is also improbable as all of the river below the control site was exposed to TFM. Recolonization by downstream migration from untreated areas (Waters, 1964) is possible but would take an extended period of time at site III due to the distance organisms would need to travel. McLay (1970) found various insect genera drifted distances of 0.5.–45.7 m·d-h in a stream similar in depth and mean current velocity to sites II and III. Site III was 4.8 km downstream from the point fo TFM application, therefore recolonization is unlikely to have occurred whitin the 19 day post-treatment period. Recolonization of the upper substrate through vertical ascent from within the hyporheos (Williams & Hynes, 1974) may well have occurred. Chironomidae genera (Hynes, 1974; Williams & Hynes, 1974; Godbout & Hynes, 1982) and Nematoda (Hynes, 1974) have been found to depths of 30–70 cm. It is probable that taxa within the upper strata of the substrate sensitive to TFM were subsequently replenished by individuals from within the hyporheos during the 19 days following treatment. The depth to which TFM penetrates the substratum and the various macroinvertebrate taxa inhabiting the hyporheos will undoubtedly have a large influence on the numbers of non-target macroinvertebrates adversely affected by stream treatments with TFM.

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