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Effects of the lampricide, 3-trifluoromethyl-4-nitrophenol (TFM) on the macroinvertebrates of Wilmot Creek

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SUMMARY

1. The effects of the lampricide, TFM, on the benthic macroinvertebrates in Wilmot Creek, a hardwater tributary to Lake Ontario was examined over 1 year. Drift samples were collected during the 88 h bracketting TFM treatment.

2. Significant decreases in relative abundance attributable to TFM were exhibited by *Dolophilodes* sp., *Cricotopus* sp., *Microtendipes* sp. and Tubificoidea throughout the 50.5 weeks following treatment. A significant reduction was exhibited by *Orthocladius* sp. 1.5 and 7.5 weeks after treatment however a significant increase to pretreatment abundances occurred 50.5 weeks later.

3. Recolonization of the substratum appeared to occur rapidly for those taxa that were moderately reduced by treatments with TFM. However those that were largely eliminated took much longer in re-establishing pretreatment abundances.

4. Increases in drift abundance observed during treatment were generally an accurate indicator of the TFM-sensitive macroinvertebrates, the most sensitive of which (*Dolophilodes* sp., *Dugesia* sp. and Tubificoidea) responded immediately following the introduction of TFM. Branchiobdellida, *Diamesia* sp., *Dicranota* sp., Lumbricidea and Nemouridae exhibited increases in drift abundance 8-10 h after the introduction of TFM and were considered less sensitive than the former taxa since they did not decline in benthic abundances.

INTRODUCTION

The parasitic sea lamprey (Petromyzon marinus Linnaeus) invaded the Great Lakes prior to 1835 (Lark, 1973) and by the mid-1940s it was apparent they had significantly reduced commercial fish stocks (Smith and Tibbles, 1980). In 1958 a chemical control programme using the selectively toxic lampricide, 3-trifluoromethyl-4-nitrophenol, (TFM) was introduced and directed towards reducing numbers of larval sea lamprey inhabiting Great Lake tributaries (Applegate, Howell and Smith, 1958; Chandler and Marking, 1975; Dawson, Cumming and Gilderhus, 1975, 1977; N.R.C., 1985). Toxicity of TFM to larval sea lamprey varies with water quality, being inversely proportional to both hardness and pH (Applegate et al., 1961; Dawson et al., 1975, 1977).

Generally TFM, at field concentrations is not thought to have deleterious effects on most lotic inhabitants. However, several sensitive benthic macroinvertebrate species have been identified (Smith, Tibbles and Johnson, 1974; Gilderhus and Johnson, 1980). Controlled toxicity tests based on 24-96 h LC50s indicate some Diptera, Ephemeroptera, Trichoptera, Annelida, Pelecypoda and Turbellaria taxa to be among the most TFM-sensitive macroinvertebrates (Smith, 1967; Chandler and Marking, 1975; Geissel and Johnson, 1975; Maki et al., 1975). Further, toxicity to both TFM-sensitive and resistant taxa appears to vary with water hardness and pH in a manner similar to that described for sea lamprey larvae (Applegate et al., 1961; Fremling, 1975; Kawatski et al., 1975).

Stream treatments with TFM are of shorter duration than bioassays, usually ranging from 8-20 h (NRC, 1985). The effects of field applications of TFM on non-target macroinvertebrates has largely been studied in softwater stream communities where treatments are both shorter in duration and lower in concentration than in hardwater. In a study of two softwater tributaries of Lake Superior, Dermott and Spence (1984) found Philopotamidae Trichoptera and Lumbricidae significantly declined in abundance 3 weeks following TFM treatment as compared with untreated portions of the same stream. In a similar study, lotic macroinvertebrate taxa did not significantly change in abundance 3 d following treatment (Haas, 1970). In a study of several softwater Great Lake tributaries Torblaa (1968) found families of riffle dwelling macroinvertebrates were depleted in some streams while not in others 1 week after treatment. However in those streams where a decline in abundance did occur the macroinvertebrate numbers were re-established to pretreatment levels 6 weeks to 1 year following treatment.

The invertebrate communities of hardwater streams are usually more diverse in taxa and rich in numbers than those of softwaters (Clarke and Berg, 1959; Mann, 1955; Hall, 1960; Maitland, 1965). In a hardwater tributary to Lake Ontario the lampricide mixture TFM with 0.8% 2', 5-dichloro-4'-nitrosalicylanilide (TFM-2B), a mixture more lethal to many invertebrates than TFM alone (Gilderhus and Johnson, 1980), caused a significant reduction in abundance of Hirudinea, Oligochaeta and Turbellaria while many Insecta increased 4 d following treatment (Dermott and Spence, 1984). In the Rouge River, a suburban hardwater tributary to Lake Ontario relative abundance of _Chimarra_ sp., _Dugesia_ sp. and Tubificidae declined following TFM treatment with complete recolonization 6.5 months later (Kolton et al., 1985). Large reductions were also exhibited by _Caenis_ sp., Lumbricidae, Nematoda and many Chironomidae genera 2 d after treatment at 1 of 2 treated sites followed by an increase to greater than pretreatment abundance 17 d later. The most TFM-sensitive genera increased substantially in drift abundance during and for a short period following treatment.

Urban and suburban rivers, such as the Rouge River, that are subject to large, rapid fluctuations in discharge have generally been found to harbour less diverse benthic fauna than typical stenothermic, trout producing streams (Hynes, 1960). The present study was undertaken to examine changes in the relative abundance of the riffle dwelling macroinvertebrate fauna of a southern Ontario, hardwater, trout producing stream, Wilmot Creek following treatment with TFM.

MATERIALS AND METHODS

Wilmot Creek is a 4th order stream characterized by many pools and riffles typical of a stenothermic trout stream. The upper and middle portions of the stream drains an area of approximately 83 km^2 (Environment Canada, 1983). Mean daily discharge in 1982 and 1983 was 1.08 and 0.96 $m^3.s^{-1}$, respectively (Environment Canada, 1983). The mean daily discharge ($\pm$ SD) during TFM treatment, mid-October, 1983 was 0.42 ± 0.02 $m^3.s^{-1}$. At this time, conductivity was 435 ± 5 µmhos (Radiometer, Model CDM3) and pH 8.24 ± 0.06, (APHA, 1971). Alkalinity, total and calcium hardness was 192 ± 1, 227 ± 3 and 184 ± 3 $mg.l^{-1}$ as $CaCO_3$, respectively. Dissolved oxygen was in excess of 90% air saturation.

Macroinvertebrates were collected from 2 riffle sites along the middle reaches of Wilmot Creek (Fig. 1) from October 1983 to October 1984. Site I was located 3.5 km downstream from the lampricide application site and was approximately 8.0 m long, 6.0 m wide with a mean ($\pm$ SD) depth of 28.7 ± 3.1 cm. Site II was 1.8 km downstream from site I and was approximately 13.0 m long, 6.5 m wide with a mean ($\pm$ SD) depth of 21.3 ± 5.9 cm. Substrate particle size composition within the upper 15 cm was examined for 3 samples from each site according to the classification of Cummins (1962):

Site	Substrate composition, % dry weight ($\pm$ SD)						
	Cobbles	Pebbles	Gravel	Very Coarse Sand	Coarse Sand	Medium Sand	Fine Sand or less
I		65.2±14.8	19.7±1.9	6.3±1.0	4.8±1.3	2.8±0.9	1.3±0.6
II	17.5±16.0	57.3±16.0	14.5±1.1	5.9±0.8	2.7±1.1	1.6±0.6	0.8±0.6

Wilmot Creek was treated with TFM October 20-21, 1983, as part of the Department of Fisheries and Ocean's sea lamprey control programme. TFM passed over site I during a 24 h period and reached concentrations of 5.3-6.7 mg TFM.1^{-1} for 18 h. Passage time of the chemical at site II was 23 h with a peak concentration of 5.3-6.0 mg TFM.1^{-1} for 17.5 h.

Benthos was sampled at each site 2 days before and 1.5, 7.5 and 50.5 weeks following treatment. Benthic samples were collected using a T-sampler (Mackie and Bailey, 1981) fitted with nitex (363 µm pore size). A middle portion of each site, 5.5 m long by the stream width was designated the sample area. 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. Taking care not to sample within 1 m of shore 15 equally spaced samples were collected from each transect.

Macroinvertebrate drift was collected at site II during a 1 h period at 4 h intervals for 32 h before and following TFM treatment and at 2 h intervals during treatment. A rectangular drift net (aperature 1350 cm^2, 363 µm pore size) held in place by aluminum posts driven into the stream bed was placed in the centre of the stream 4 m downstream from site II. Stream discharge was measured twice daily using the stream profile area and current readings (March/McBirney Model 201 m portable current meter) at 0.5 m intervals across the stream.

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 12X 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, Jensen and Benner (1976), Klemm (1982), Mackie, White and Zdebra (1980), McAlpine et al. (1981), Merritt and Cummins (1978), Oliver and Roussell (1983), Pennak (1978), Wiggins (1977), and Woods (1963). A reference collection of the macroinvertebrates identified is on file with the Department of Environmental Biology, University of Guelph.

RESULTS

The macroinvertebrate community at both riffle sites was represented by 83 taxa. Of these, 35 major taxa each had relative abundances greater than 0.3% of the total abundance at both sites. The relative abundance of the remaining 48 taxa together comprised less than 7% of the total macroinvertebrates collected.

The benthic data was found to be contagious using the chi-square goodness of fit test for negative binomials. A log (x + 1) transformation was used to normalize the data for further analysis. The two transects were combined to give a sample size of n = 30 and the data analysed using a 2 x 4 (sites x times) ANOVA table. The least squared means were then compared to determine differences over time within and between sites.

The benthic community 2 d prior to the application of TFM was largely similar at both sites (Fig. 2 and 3). Of the major taxa, *Baetis* sp., *Cheumatopsyche* sp., *Ephemerella* sp., *Hydropsyche* sp., *Optioservus* sp. and *Paraleptophlebia* sp. were 6 of the 8 most abundant genera comprising more than 53% of the total abundance at each site. *Baetis* sp., *Hydropsyche* sp. and *Ephemerella* sp. together comprised more than 40% of those collected. However there were some differences between sites.

The non-Chironomidae Diptera at site I represented a large portion of the benthic community (Fig. 2). *Antocha* sp. and *Dicranota* sp. together comprised nearly 10% of the macroinvertebrates collected. Chironomidae accounted for 10 of the 35 taxa yet comprised less than 8% of total abundance.

Conversely, at site II Chironomidae represented about 20% of the invertebrate community of which *Tanytarsus* sp. and *Cricotopus* sp. were the most abundant. The non-Chironomidae Diptera were less abundant, together comprising not more than 6% of the organisms. There were almost twice as many macroinvertebrates collected at site II as compared with site I prior to treatment with TFM.

Changes in relative abundance of the macroinvertebrate taxa following treatment with TFM were almost as varied as the taxa themselves. However, the most common trend exhibited at site I was an increase in relative abundance 1.5 weeks after treatment followed by an overall decline of varying magnitude 6 and 49 weeks after the first posttreatment sample. *Baetis* sp. and *Optioservus* sp. increased approximately 130 and 40%, respectively, above pretreatment abundances 1.5 weeks after treatment. This was followed by a decline 7.5 and 50.5 weeks after treatment to relative abundances still in excess of pretreatment abundances. *Tanytarsus* sp. increased more than 5-fold, 1.5 weeks after treatment followed by a slight decline in relative abundance 6 weeks later and a large significant reduction to about pretreatment numbers the next autumn. *Nanocladius* sp. and *Diamesia* sp. (Chironomidae) increased in relative abundance throughout 1983 followed by a significant decline to about or below pretreatment values the following autumn, respectively. A few taxa exhibited an increase in relative abundance throughout the study; for example *Dugesia* sp. increased significantly from a mean of 0.10 ± 0.31 individuals per sample prior to treatment to 1.47 ± 1.91 individuals per sample about 1 year later.

Conversely, several taxa declined in relative abundance 1.5 weeks after the application of TFM followed by either a restoration to pretreatment values or a further decline in abundance. *Dicranota* sp., *Ephemerella* sp. and *Rhyacophila* sp. exhibited a slight reduction in relative abundance 1.5 weeks after treatment followed by a substantial decline of 45% or more 6 weeks later. However, the relative abundances increased significantly to pretreatment values almost 1 year after treatment. A few taxa exhibited a steady decline in relative abundances throughout the study, the largest single decline occurring 1.5 weeks following treatment. Notably, Tubificoidea, *Microtendipes* sp., *Cricotopus* sp. and *Dolophilodes* sp. experienced reductions from pretreatment relative abundance of 70% or more, the latter two significantly, with no sign of recovery almost 1 year later. *Dolophilodes* sp. was completely absent from samples 7.5 weeks following treatment.

Changes in relative abundance of the macroinvertebrate fauna collected at site II closely resembled those described at site I (Fig. 3). *Dolophilodes* sp. exhibited a significant decline in relative abundance of 93%, 1.5 weeks after TFM treatment, similar to that found at site I, with no apparent recovery during the remainder of the study. The taxa at site II more often exhibited significant changes in relative abundance than at site I, probably due to the greater number of individuals. *Microtendipes* sp. exhibited a decline in pretreatment relative abundance at both sites, of about 75% 1.5 weeks following TFM treatment, however the decline was significant at site II. Further, changes in relative abundance of Tubificoidea were similar to those described for site I, however, reductions in relative abundance 7.5 and 50.5 weeks after treatment were significant only at site II. *Orthocladius* sp., abundant only at site II prior to treatment, was almost eliminated from 1983 posttreatment samples followed by a significant increase to pretreatment relative abundances almost 1 year after treatment.

The community structure of the drift prior to the application of TFM was generally different from the benthos at nearby site II (Fig. 4, 5 and 6). Of the 55 taxa present in the drift Baetis sp. and Paraleptophlebia sp. were the most abundant, comprising 14.0 and 11.5% of the total number of organisms collected, respectively. Hydropsyche sp., Ephemerella sp. and Cheumatopsyche sp. ranked 1st, 3rd and 4th, respectively, in abundance in the pretreatment benthic samples however together represented only 6.3% of the organisms collected in the drift. Dolophilodes sp. comprised 3.0% of the total drift abundance and 0.2% of the total benthic organisms prior to TFM treatment. Chironomidae were well represented in pretreatment drift samples, comprising 28.2% of the total. Dugesia sp. and Lumbricidae were not found in pretreatment drift samples. Tubificoidea and Dicranota sp. were each represented by only 1 individual prior to treatment with TFM.

Daily patterns in drift abundance were evident for few of the taxa. Drift abundance of Baetis sp., Paraleptophlebia sp. and Thienemannimyia complex was greatest at night (Fig. 4 and 5). During the 24 h period prior to treatment, 65 and 82% of Baetis sp. and Paraleptophlebia sp. captured in the drift occurred during the evening. The largest drift samples were collected 3 hours after sunset and 1 hour before sunrise. Conversely, drift abundance of early instar Orthocladiinae and Hydracarina increased during the day.

The community structure of the drift changed markedly after the introduction of TFM. Tubificoidea and Dugesia sp. together represented 0.4% of the pretreatment drift, yet accounted for 30.9 and 5.2% of the drift during treatment, respectively (Fig. 6). Total drift abundance of Lumbricidae and Dolophilodes sp. increased from 0.7 and 3.0% before treatment to 2.0 and 13.2% during treatment, respectively. Branchiobdellida, Diamesia sp., Dicranota sp. and Nemouridae together comprised 1.5% of the pretreatment drift however increased to 7.7% of the drift during treatment.

Dugesia sp., Dolophilodes sp. and Tubificoidea drift abundance increased 1-3 hours following the introduction of TFM, coincident with peak TFM concentrations. Branchiobdellida, Diamesia sp., Dicranota sp., Lumbricidae and Nemouridae exhibited increases in drift 8-10 hours after the introduction of TFM. Dolophilodes sp. and Tubificoidea continued to exhibit moderately inflated drift abundances during the posttreatment sampling period. Diamesia sp. and Nemouridae posttreatment drift abundances continued to remain about equal to treatment abundances 6 to 18 hours following TFM treatment, respectively.

Daily drift patterns were generally unaffected during and subsequent to TFM treatment. Baetis sp., Paraleptophlebia sp., and Thienemannimyia complex remained most abundant in the drift samples at night and Hydracarina during the day. Early instar Orthocladiinae drift remained greatest during the day but in much reduced numbers.

DISCUSSION

The application of the larval lampricide TFM in Wilmot Creek, a hardwater tributary to Lake Ontario did not have a deleterious affect on most of the benthic macroinvertebrate taxa. Of the 35 dominant taxa, 4 exhibited significant declines in benthic relative abundance throughout the study following treatment. Two of these taxa and a few that did not decline in benthic samples increased in drift abundance during and, in a few cases, following treatment.

The response of *Dolophilodes* sp. and Tubificoidea to lampricide treatment was consistent with that observed in other studies. In a field study of two softwater tributaries to Lake Superior, Dermott and Spence (1984) found Philopotamidae (*Dolophilodes* sp. and *Chimarra* sp.) to be absent at all treated riffles 3 weeks after TFM treatment with little change in abundance at the untreated riffles ($p < 0.05$). In a similar study of the Rouge River (Lake Ontario), comparable in hardness and pH to Wilmot Creek, *Chimarra* sp. and Tubificoidea exhibited significant reductions ($p < 0.05$) at the treated sites 19 d following TFM treatment (Kolton et al., 1985). In the Rouge River, drift abundance of Tubificoidea and *Chimarra* sp. increased during treatment in a manner similar to that found for Tubificoidea and *Dolophilodes* sp. in the present study (Kolton et al., 1985). In neighbouring Soper Creek, daytime drift rates of Tubificoidea indicated a significant increase during treatment with TFM-2B (Dermott and Spence, 1984). Philopotamidae gather their food in fine mesh nets utilizing the finest food particles in suspension of any Trichoptera (Wiggins, 1977). The relatively large surface area, to which TFM (Bothwell, Beeton and Lech 1973; Kempe, 1973; Thingvold, 1975; NFRL, 1983a, b) and Bayer 73 (NFRL, 1983a, b) are known to bind, when ingested by Philopotamidae almost certainly will contain disproportionately large quantities of lampricides which could act as a stomach poison.

Chironomidae are generally regarded as being among the most resistant invertebrates to lampricide treatments (Gilderhus and Johnson, 1980; NRC, 1985). However in the present study Cricotopus sp., Microtendipes sp. and Orthocladius sp. exhibited significant declines in relative abundance following treatment. In Soper Creek Chironomidae of the family orthocladiinae (Cricotopus sp. and Orthocladius sp. inclusive) declined in abundance at one treated site and increased at the other 4 d after treatment (Dermott and Spence, 1984). Not one of 12 Chironomidae genera (including Cricotopus sp., Microtendipes sp. and Orthocladius sp.) declined in numbers at the treated sites of the Rouge river related to the untreated site during the 6.5 month period following treatment (Kolton et al., 1985). Similar to the few other studies that collected drift samples, there was not an increase in drift abundance of Orthocladiinae genera attributable to lampricide treatment.

Abundance of Dugesia sp. in the benthos rose significantly throughout the study despite a large increase in drift during the application of TFM. Smith (1967) concluded from toxicity tests using waters of unspecified hardness that Turbellaria would experience 100% mortality during stream treatment. An increase in drift rates of Turbellaria during treatment and a corresponding decline in benthic abundance 2 and 4 d following treatment was observed in the Rouge River and Soper Creek, respectively (Kolton et al., 1985; Dermott and Spence, 1984).

Increases in drift abundance during treatment were generally an accurate indicator of the TFM-sensitive macroinvertebrates, the most sensitive of which responded immediately. Dolophilodes sp., Dugesia sp. and Tubificoidea increased in drift abundance to catastrophic proportions coincident with peak TFM concentrations. Maki (1980) observed similar immediate increases in the numbers of drifting organisms following TFM application and attributed it almost entirely to a few TFM-sensitive species. Erpobdella sp., Dugesia sp., Tubificoidea and Chimarra sp. increased in drift abundance 1.5 h after the introduction of TFM into the Rouge River with corresponding declines in benthic abundance of the latter three (Kolton et al., 1985). Erpobdella sp. was present in only a few benthic samples. Branchiobdellida, closely related to Hirudinea, together with Diamesia sp., Dicranota sp., Lumbricidae and Nemouridae exhibited increases in drift abundance 8-10 h after the introduction of TFM into Wilmot Creek. These taxa did not exhibit declines in benthic abundance associated with lampricide treatment however they or representatives from the same family have been described as TFM-sensitive in prior studies. Dermott and Spence (1984) found significant increases in drift abundance during the treatment of Soper Creek by all Oligochaetes, Piscicolidae and Erpobdellidae. However, only Lumbricidae and Piscicolidae exhibited a significant decline in benthic abundance. In the same study Nemouriade and Syndiamesia sp. (same family as Diamesia sp.) exhibited declines in benthic abundance following lampricide treatment. The latter also increased significantly in drift abundance during stream treatment (Dermott and Spence, 1984). Dicranota sp. increased in drift abundance during treatment of the Rouge River, however did not decline in benthic abundance subsequent to TFM treatment (Kolton et al., 1985).

TFM treatment generally did not affect the diurnal drift patterns of the less sensitive macroinvertebrates in Wilmot Creek. Early instar Orthocladiinae exhibited the greatest drift abundances during the day, however following treatment their abundances were greatly reduced. The pretreatment diurnal patterns of drift were not obviously altered in the Rouge River during the 48 h period following TFM treatment (Kolton et al., 1985).

In this and other studies drift rates following treatment with lampricides remained above pretreatment levels (Dermott and Spence, 1984; Kolton et al., 1985). Tubificoidea and Dolophilodes sp. exhibited the greatest increase in drift and continued to have inflated rates 26 to 30 h after treatment, respectively. Similarly in the Rouge River 2 of the 3 fauna most abundant in the treatment drift, Dugesia sp. and the Philopotamidae, Chimarra sp. continued to exhibit high drift rates during a 48 h posttreatment period (Kolton et al., 1985). However, in the same study Tubificoidea did not exhibit a continued increase in drift following treatment. Conversely, Tubificoidea drift abundance was still inflated 4 d after treatment of Soper Creek while Dugesia sp. was not (Dermott and Spence, 1984). Diamesia sp. and Nemouridae posttreatment drift abundances were about equal to treatment abundances 6 to 18 h following treatment, respectively. Dermott and Spence (1984) found several invertebrate taxa drifted more ($p < 0.05$) during the lampricide treatment than 3 d before or 4 d after treatment while only 1 of these taxa also declined in abundance at the riffle sites. They concluded that increased drift and not invertebrate mortality is the major impact of lampricide treatments. The percentage of drifting organisms killed by TFM in contrast to those induced to leave the substrate as a result of sublethal affects has not been investigated. The fate of invertebrates drifting within the water column containing lampricides is not well understood. Drifting insects are presumably most susceptible to predation (NRC, 1985), particularly during the day (Allan, 1978; Ringler, 1979) if fish feed during treatment. Hansen and Kawatski (1976) found Chinonomus tentans Fabricus was immobilized at TFM concentrations 1/6 the 24-h LC50. During treatment drifting invertebrates likely remain immobile within the water column, exposed to lampricides for extended periods where Hexagenia sp. nymphs are twice as susceptible as burrowed individuals (Fremling, 1976). In sediment-water systems abiotic binding of TFM to the sediments (Bothwell et al., 1973; Kempe, 1973; Thingvold, 1975) and hyperactivity in Arthropods was shown to be induced by TFM (Maki, Geissel and Johnson 1975). The increase posttreatment drift rates exhibited by the fauna most sensitive to larval lampricides may be due to continued irritation of burrowed individuals by lampricides bound to the substrate.

Few field studies have followed the effects of lampricides on lotic macroinvertebrates over a time period sufficient to monitor recolonization of the affected taxa. Torblaa (1968) found recovery to be rapid among the riffle-dwelling invertebrate populations of most of the softwater streams studied. In another study of two softwater Great Lake tributaries Dolophilodes sp. and Chimarra sp. were absent and Lumbriculidae and Chloroperlidae were significantly reduced at only the treated sites 3 weeks after treatment (Dermott and Spence, 1984). In a further study of a softwater tributary, Jeffrey et al. (1985) found Tubificoidea was significantly reduced to a depth of 31-40 cm in a treated riffle with no decline in the untreated riffle 2 d after treatment. There was no apparent increase towards pretreatment abundances 1 month later. In the only lengthy study of a hardwater stream treated with TFM, Kolton et al. (1985) observed the sensitive taxa (Caenis sp., Chimarra sp., Dugesia sp. and Tubificoidea) exhibited large declines in abundance 2 d after treatment usually followed by further reductions 17 d later. The moderately sensitive taxa exhibited significant declines in numbers immediately after treatment but had returned to pretreatment values 17 d later. Thirty weeks following treatment all but Chimarra sp. and Tubificoidea relative abundances at the latter site were equal in magnitude to those at the treated site. The findings in the present study are in agreement with those above. The most adversely affected macroinvertebrates (Cricotopus sp., Dolophilodes sp., Microtendipes sp. and Tubificoidea) were dramatically reduced 1.5 weeks after treatment and did not exhibit a return to pretreatment relative abundances 7.5 and 50.5 weeks following treatment.

Recolonization of the substratum appears to occur rapidly for those taxa that are only moderately reduced by treatments with TFM. However taxa that are drastically reduced in abundance take much longer in reestablishing pretreatment numbers, often remaining depleted up to 1 year later. Streams are treated with lampricides every 3-5 years (Applegate et al., 1958). Most streams referenced in this study have been treated several times previously and have supported sizable populations of TFM-sensitive fauna prior to the most recent lampricide treatments (Torblaa, 1968; Dermott and Spence, 1984; Jeffrey et al., 1985; Kolton et al., 1985). The various mechanisms of recolonization have been capable of reestablishing macroinvertebrate populations between successive treatments. It is likely that recolonization of the most sensitive taxa in treated reaches occurs within 1-2 years after treatment through downstream drift from untreated reaches, reproduction and vertical migration of unaffected fauna within the hyporheos.

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REFERENCES

Allan J.D. (1978) Trout predation and the size composition of stream drift. Limnology and Oceanography, 23, 1231-1237.

American Public Health Association (1971) Standard Methods for the Examination of Water and Wastewater. 13th edition, 1971. Washington, D.C. 874 pp.

Applegate V.C., Howell J.H. & Smith M.A. (1958) Use of mononitrophenols containing halogens as selective sea lamprey larvicides. Science 127, 336-338.

Applegate V.C., Howell J.H., Moffett J.W., Johnson B.G.H. & Smith M.A. (1961) Use of 3-trifluoromethyl-4-nitrophenol as a selective sea lamprey larvicide. Great Lakes Fishery Commission Technical Report No. 1, 1-35.

Bothwell M.L., Beeton A.M. & Lech J.J. (1973) Degradation of the lampricide 3-trifluoromethyl-4-nitrophenol by bottom sediments. Journal of the Fisheries Research Board of Canada, 30, 1841-1846.

Brown H.P. (1972) Biota of Freshwater Ecosystems Identification Manual #6. Aquatic Dryopoid Beetles (Coleoptera) of the United States. U.S. Government Printing Office, Washington, D.C. 82 pp.

Chandler J.H. & Marking L.L. (1975) Toxicity of the lampricide 3-trifluoromethyl-4-nitrophenol (TFM) to selected aquatic invertebrates and frog larvae. U.S. and Wildlife Service, Investigations in Fish Control No. 62, 3-7.

Clarke A.H. & Berg C.O. (1959) The freshwater mussels of Central New York. Cornell University Agricultural Experimental Station, Ithaca, New York, 389 pp.

Cummins K.W. (1962) An evaluation of some techniques for the collection and analysis of benthic samples with special emphasis on lotic waters. American Midland Naturalist, 67, 477-504.

Dawson V.K., Cumming K.B. & Gilderhus P.A. (1975) Laboratory efficacy of 3-trifluoromethyl-4-nitrophenol (TFM) as a lampricide. U.S. Fish and Wildlife Service, Investigations in Fish Control No. 63, 13 pp.

Dawson V.K., Cumming K.B. & Gilderhus P.A. (1977) Efficacy of 3-trifluoromethyl-4-nitrophenol (TFM), 2', 5-dichloro-4'-nitrosalicylanilide and a 98:2 mixture as lampricide in laboratory studies. U.S. Fish and Wildlife Service, Investigations in Fish Control No. 77, 1-11.

Dermott R.M. & Spence H.J. (1984) Changes in populations and drift of stream invertebrates following lampricide treatment. Canadian Journal of Fisheries and Aquatic Sciences, 41, 1695-1701.

Edmunds Jr. G.F., Jensen S.L. & Benner L. (1976) The Mayflies of North and Central America. University of Minnesota Press, Minneapolis, Minnesota. 330 pp.

Environment Canada (1983) Surface water data, referenced index, Canada, 1983. Supply and Services Canada, Ottawa, Ontario. 386 pp.

Fremling C.R. (1975) Acute toxicity of the lampricide 3-trifluoromethyl-4-nitrophenol (TFM) to nymphal mayflies (*Hexagenia* sp.). U.S. Fish and Wildlife Service, Investigations in Fish Control No. 58, 8 pp.

Gilderhus P.A. & Johnson B.G.H. (1980) Effects of sea lamprey (*Petromyzon marinus*) control in the Great Lakes on aquatic plants, invertebrates and amphibians. Canadian Journal of Fisheries and Aquatic Science, 37, 1895-1905.

Haas R.C. (1970) The effects of lamprey larvicide on the bottom fauna and periphyton of the Chocolay River, Marquette County, Michigan. Michigan Department of Natural Resources and Development Report No. 200, 66 pp.

Hall R.E. (1960) The Chironomidae of three chalk streams in southern England. International Congress of Entomology, II, I, 178-181.

Hansen C.R. Jr. & Kawatski J.A. (1976) Application of 24-hour postexposure observation to acute toxicity studies with invertebrates. Journal of the Fisheries Research Board of Canada, 33, 1198-1201.

Hynes H.B.N. (1960) The biology of polluted waters. Liverpool Univ. Press, Liverpool. 202 pp.

Jeffrey K.A., Beamish F.W.H., Ferguson S.C., Kolton R.J. & MacMahon P.D. (1985) Effects of the lampricide, 3-trifluoromethyl-4-nitrophenol (TFM) on the macroinvertebrates within the hyporheic region of a softwater Creek. (in press).

Kawatski J.A., Ledvina M.M. & Hansen C.R. Jr. (1975) Acute toxicities of 3-trifluoromethyl-4-nitrophenol (TFM) and 2-5-dichloro-4'-nitrosalicylanilide (Bayer 73) to larvae of the midge (<u>Chironomus tentans</u>). U.S. Fish and Wildlife Service, Investigations in Fish Control No. 57, 7 pp.

Kempe L.L. (1973) Microbial degradation of the lamprey larvicide 3-trifluoromethyl-4-nitrophenol in sediment-water systems. Great Lakes Fisheries Commission, Technical Report No. 18, 1-16.

Klemm D.J. (1982) Leeches (Annelida: Hirudinea) of North America. U.S.E.P.A., Office of Research and Development, Cincinnati, Ohio. 196 pp.

Kolton R.J., MacMahon P.D., Jeffrey K.A. & Beamish F.W.H. (1985) Effects of the lampricide, 3-trifluoromethyl-4-nitrophenol (TFM) on the macroinvertebrates of a hardwater river. (in press).

Lark J.G.I. (1973) An early record of the sea lamprey (Petromyzon marinus) from Lake Ontario. Journal of the Fisheries Research Board of Canada, 30, 131-133.

Mackie G.L. & Bailey R.C. (1981) An inexpensive stream bottom sampler. Journal of Freshwater Ecology, 1, 61-69.

Mackie G.L., White D.S. & Zdebra T.W. (1980) A Guide to Freshwater Molluscs of the Laurentian Great Lakes with Special Emphasis on the Genus Pisidium sp. U.S.E.P.A., Office of Research and Development, Duluth, Minnesota. 150 pp.

Maitland P.S. (1965) Notes on the biology of Ancylus fluviatilis in the River Endrick, Scotland. Proceedings of the Malacostra Society of London, 36, 339-347.

Maki A.W. (1980) Evaluation of toxicant effects on structure and function of model stream communities: correlations with natural stream effects. In, Microcosms in Ecological Research. Edited by J.P. Giesey, Jr. U.S. Department of Energy Technical Information Centre, pp. 583-609.

Maki A.W., Geissel L. & Johnson H.E. (1975) Comparative toxicity of larval lampricide (TFM: 3-trifluoromethyl-4-nitrophenol) to selected benthic macroinvertebrates. Journal of the Fisheries Research Board of Canada, 32, 1455-1459.

Mann K.H. (1955) The ecology of British freshwater leeches. Journal of Animal Ecology, 24, 1455-1459.

McAlpine J.F., Peterson B.V., Shewell G.E., Teskey H.J., Vockeroth J.R. & Wood D.M. (1981) Manual of Nearctic Diptera Vol. I:

Biosystematics Research Institute, Research Branch, Agriculture Canada, Ottawa, Ontario. Monograph #27. 674 pp.

Merritt R.W. & Cummins K.W. (1978) An Introduction to the Aquatic Insects of North America. Kendall/Hunt Publishing Co., Dubuque, Iowa. 441 pp.

NFRL (1983a) National Fishery Research Laboratory. Lampricide soil binding. In, Progress Report to Great Lake Fishery Commission: Registration Activities and Sea Lamprey Control Research on Lampricides in January-June 1983. pp. 7-12. Submitted by National Fishery Research Laboratory, P.O. Box 818, La Crosse, Wisconsin 54602.

NFRL (1983b) National Fishery Research Laboratory. Lampricide soil binding. In, Annual Report to Great Lakes Fishery Commission: Registration Activities and Sea Lamprey Control Research on Lampricides in 1982. pp. 14-18. Submitted by National Fishery Research Laboratory, P.O. Box 818, La Crosse, Wisconsin 54602.

NRCC (1985) TFM and Bayer 73 in the aquatic environment. Environmental Secretariat, Publ. No. NRCC 22488. Ottawa, Ont. 203 pp.

Oliver D.E. & Roussel M.E. (1983) The Insects and Arachnids of Canada Part II: The Genera of Larval Midges of Canada. Ministry of Supply and Services Canada, Ottawa, Ontario. 263 pp.

Pennak R.W. (1978) Freshwater Invertebrates of the United States. John Wiley and Sons, Toronto, Ontario. 803 pp.

Platts W.S., Meganan W.F. & Minshall G.W. (1983) Methods for evaluating stream, riparian and biotic conditions. Intermountain Forest and Range Experimental Station, U.S. Department of Agriculture, Forest Service General Technical Report #138. 18 pp.

Ringler N.H. (979) Prey selection by drift feeding brown trout (*Salmo trutta*). Journal of the Fisheries Research Board of Canada, 36, 392-402.

Smith A.J. (1967) The effect of the larval lampricide 3-trifluoromethyl-4-nitrophenol, on selected aquatic invertebrates. Transactions of the American Fisheries Society, 96, 410-413.

Smith B.R. & Tibbles J.J. (1980) Sea lamprey (*Petromyzon marinus*) in Lakes Huron, Michigan and Superior: History of invasion and control, 1936-78. Canadian Journal of Fisheries and Aquatic Science, 37, 1780-1801.

Smith B.R., Tibbles J.J. & Johnson B.G.H. (1974) Control of the sea lamprey *Petromyzon marinus* in Lake Superior, 1935-1970. Great Lakes Fisheries Commission, Technical Report No. 26, 1-60.

Thingvold D.A. (1975) Adsorption, degradation and persistence of 3-trifluoromethyl-4-nitrophenol (TFM) in aquatic environments. Ph.D. Thesis, Univ. of Wisconsin, Madison, Wisconsin. 178 pp.

Torblaa R.L. (1968) Effects of lamprey larvicides on invertebrates in streams. U.S. Fish and Wildlife Service, Special Scientific Report, Fisheries No. 572, 1-13.

Wiggins G.B. (1977) Larvae of the North American Caddisfly Genera (Trichoptera). University of Toronto Press, Toronto, Ontario. 401 pp.

Wood D.M., Peterson B.V., Davies D.M. & Gyorkos H. (1963) The blackflies (Diptera: Simuliidae) of Ontario. Part II. Larval identification, with descriptions and illustrations. Proceedings of the Entomology Society of Ontario, 93, 99-115.

FIGURE LEGENDS

Figure 1. Location of the sampling sites (sites I and II) and TFM application point (AP) on Wilmot Creek, hardwater tributary to Lake Ontario.

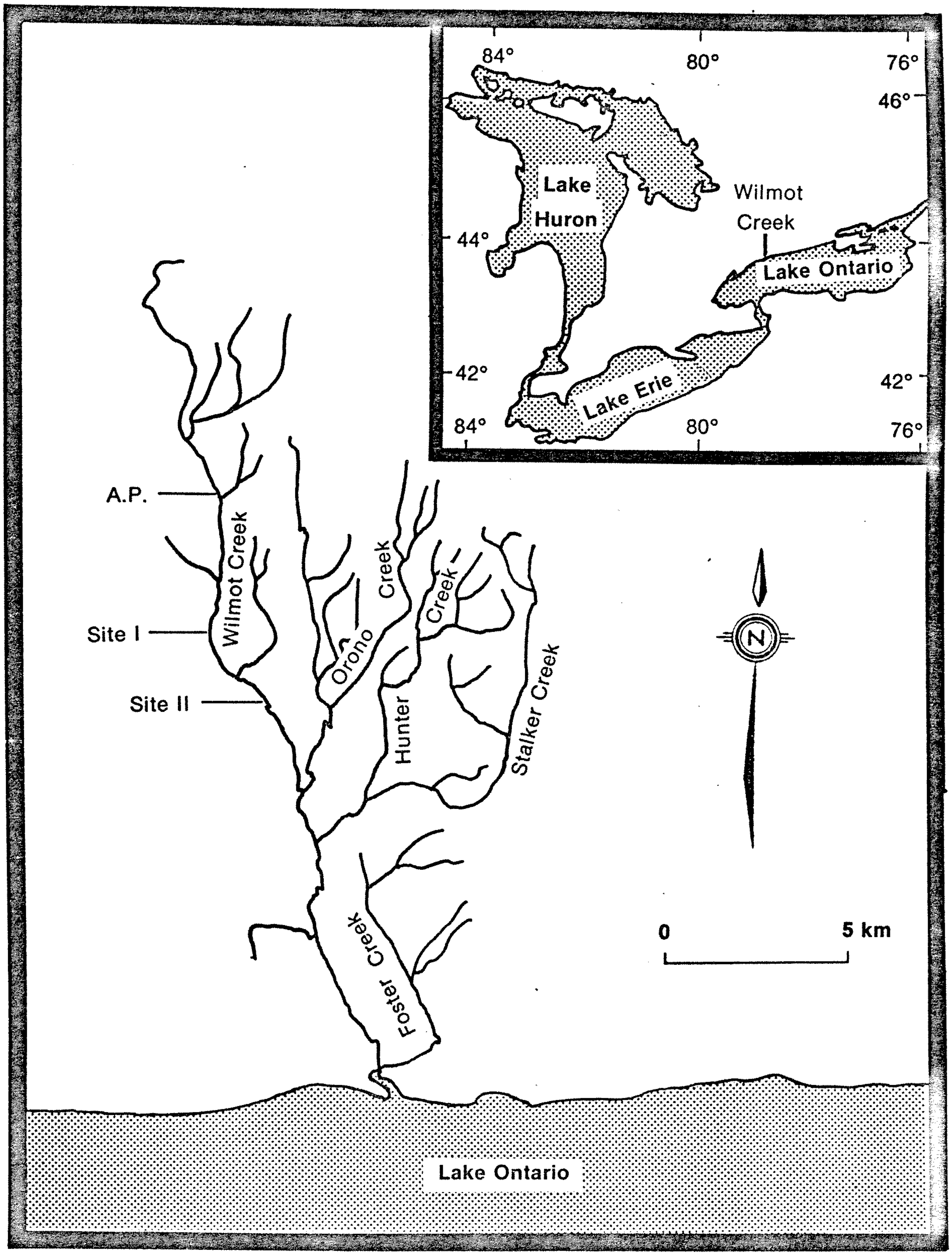
Figure 2. Mean relative abundance of the dominant taxa of benthic macroinvertebrates collected from Wilmot Creek at site I before (October 18, 1983) and after the application of the lampricide, TFM (October 20-21, 1983). Bars represent the combined results for the 2 transects from which 15 samples each were collected. The vertical line above each bar represents 1 S.D.

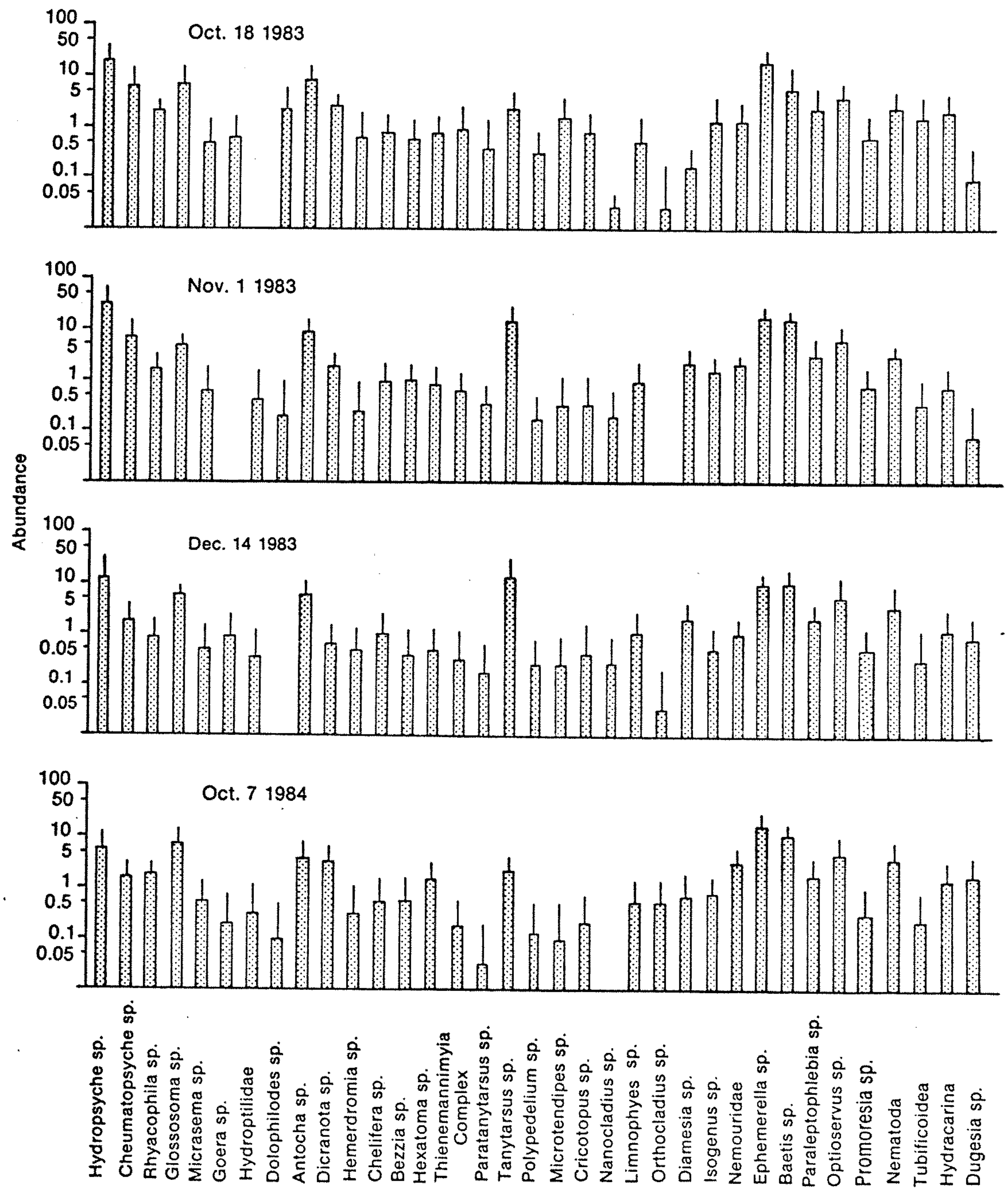
Figure 3. Mean relative abundance of the dominant taxa of benthic macroinvertebrates collected from Wilmot Creek at site II before (October 18, 1983) and after the application of the lampricide, TFM (October 20-21, 1983). Bars represent the combined results for the 2 transects from which 15 samples each were collected. The vertical line above each bar represented 1 S.D.

Figure 4. The total drift net accumulation of various taxa during an 88 h period including the 24 h interval of TFM treatment in Wilmot Creek. Hours of darkness are indicated by the heavy horizontal bars below the abscicca.

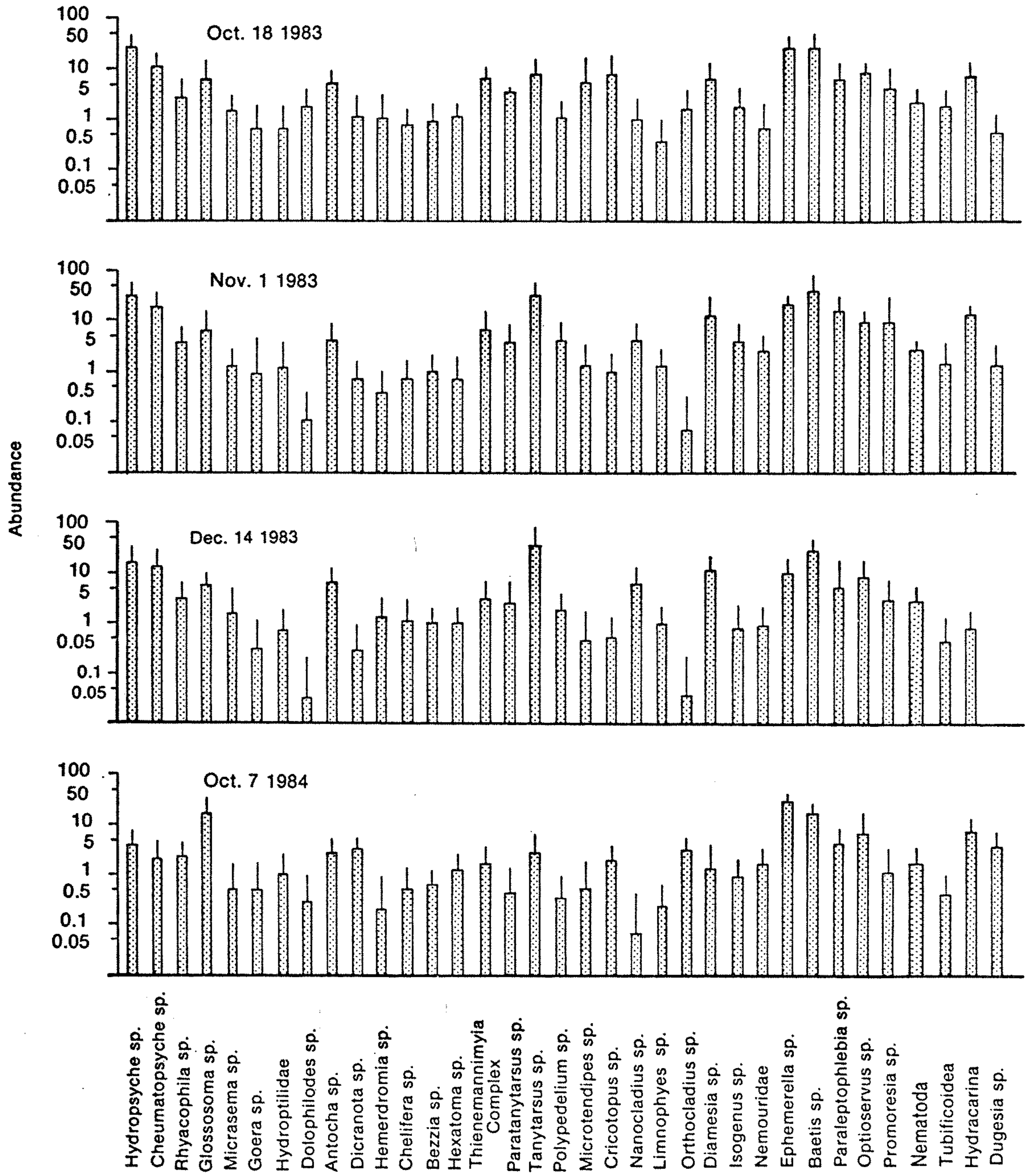
Figure 5. The total drift net accumulation of various taxa during an 88 h period including the 24 h interval of TFM treatment in Wilmot Creek. Hours of darkness are indicated by the heavy horizontal bars below th abscicca.

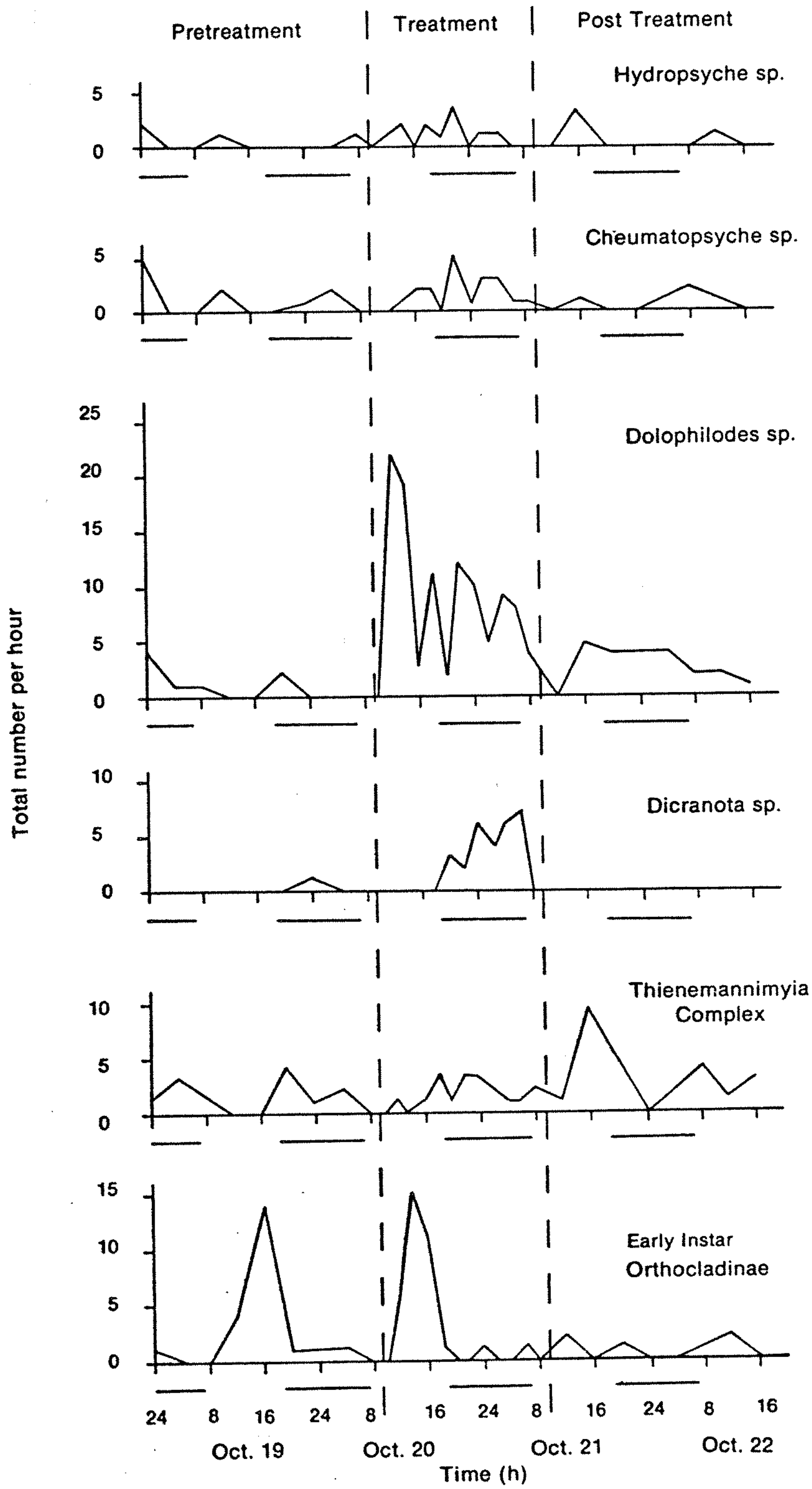
Figure 6. The total drift net accumulation of various taxa during an 88 h period including the 24 h interval of TFM treatment in Wilmot Creek. Hours of darkness are indicated by the heavy horizontal bars below the abscicca.


84°
80°
76°
46°
Lake
Huron
Wilmot
Creek
44°
Lake Ontario
42°
Lake Erie
42°
84°
80°
76°
A.P.
Wilmot Creek
Site I
Site II
Orono
Creek
Creek
Hunter
Stalker Creek
N
0
5 km
Foster Creek
Lake Ontario

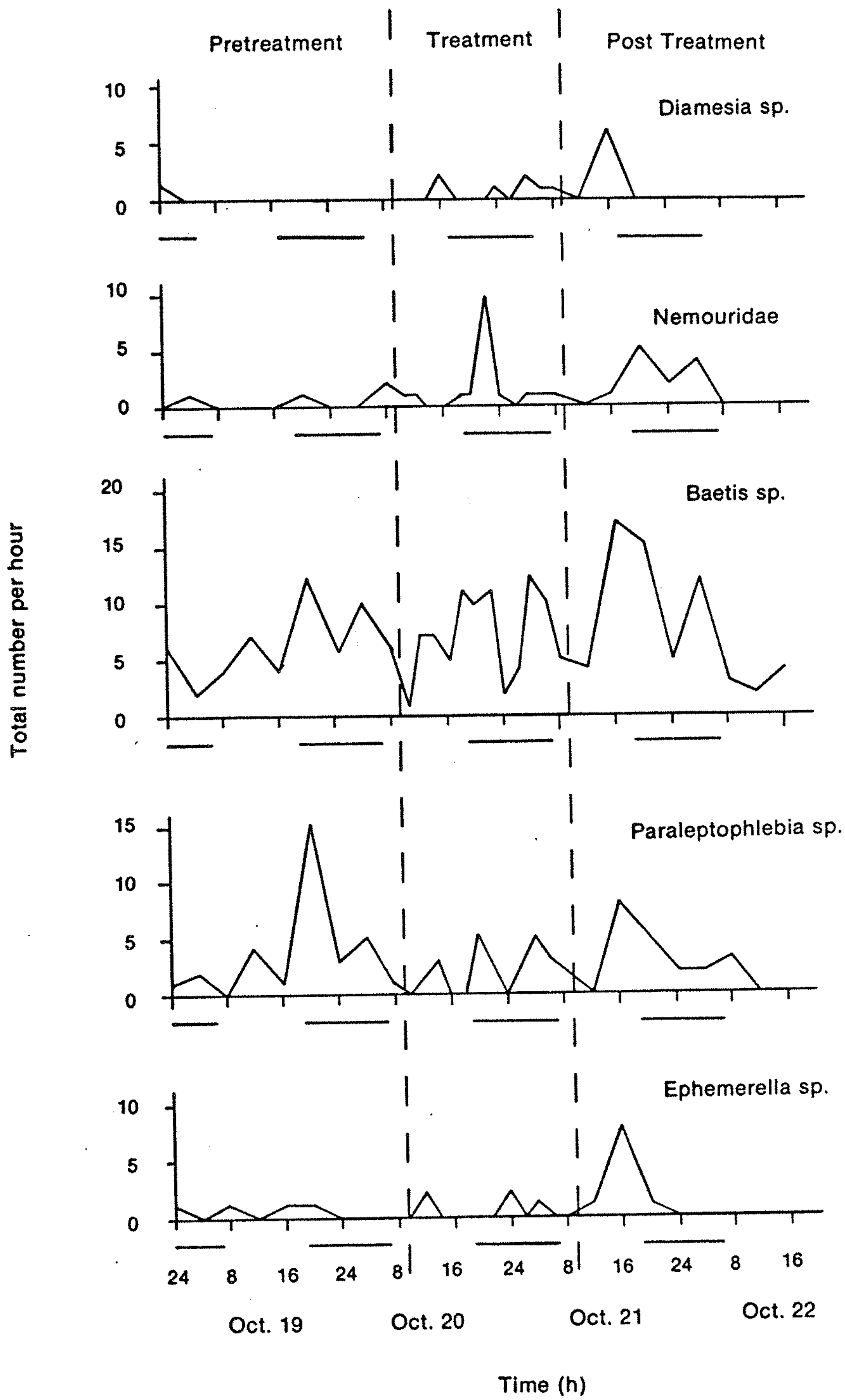


Oct. 18 1983
Nov. 1 1983
Dec. 14 1983
Oct. 7 1984
Abundance
100
50
10
5
1
0.5
0.1
0.05
Hydropsyche sp.
Cheumatopsyche sp.
Rhyacophila sp.
Glossosoma sp.
Micrasema sp.
Goera sp.
Hydroptilidae
Dolophilodes sp.
Antocha sp.
Dicranota sp.
Hemerdromia sp.
Chelifera sp.
Bezzia sp.
Hexatoma sp.
Thienemannimyia Complex
Paratanytarsus sp.
Tanytarsus sp.
Polypedelium sp.
Microtendipes sp.
Cricotopus sp.
Nanocladius sp.
Limnophyes sp.
Orthocladius sp.
Diamesia sp.
Isogenus sp.
Nemouridae
Ephemerella sp.
Baetis sp.
Paraleptophlebia sp.
Optioservus sp.
Promoresia sp.
Nematoda
Tubificoidea
Hydracarina
Dugesia sp.

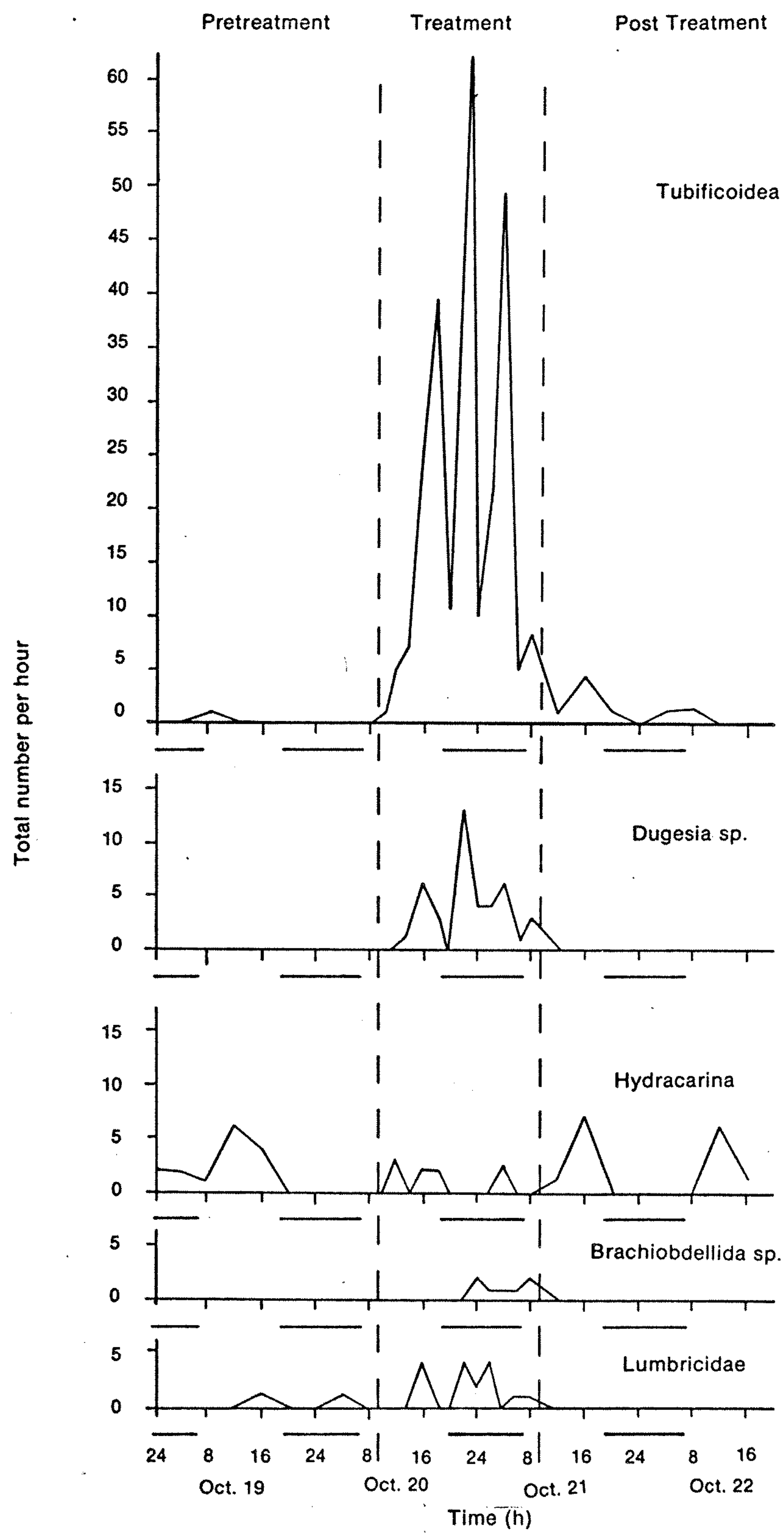

Oct. 18 1983
Nov. 1 1983
Dec. 14 1983
Oct. 7 1984
100
50
10
5
1
0.5
0.1
0.05
Abundance
Hydropsyche sp.
Cheumatopsyche sp.
Rhyacophila sp.
Glossosoma sp.
Micrasema sp.
Goera sp.
Hydroptilidae
Dolophilodes sp.
Antocha sp.
Dicranota sp.
Hemerdromia sp.
Chelifera sp.
Bezzia sp.
Hexatoma sp.
Thienemannimyia Complex
Paratanytarsus sp.
Tanytarsus sp.
Polypedelium sp.
Microtendipes sp.
Cricotopus sp.
Nanocladius sp.
Limnophyes sp.
Orthocladius sp.
Diamesia sp.
Isogenus sp.
Nemouridae
Ephemerella sp.
Baetis sp.
Paraleptophlebia sp.
Optioservus sp.
Promoresia sp.
Nematoda
Tubificoidea
Hydracarina
Dugesia sp.



Pretreatment
Treatment
Post Treatment
Hydropsyche sp.
Cheumatopsyche sp.
Dolophilodes sp.
Dicranota sp.
Thienemannimyia Complex
Early Instar Orthocladinae
Total number per hour
24
8
16
24
8
16
24
8
16
24
8
16
Oct. 19
Oct. 20
Oct. 21
Oct. 22
Time (h)



Pretreatment
Treatment
Post Treatment
Diamesia sp.
Nemouridae
Baetis sp.
Paraleptophlebia sp.
Ephemerella sp.
Total number per hour
10
5
0
10
5
0
20
15
10
5
0
15
10
5
0
10
5
0
24 8 16 24 8 16 24 8 16 24 8 16
Oct. 19
Oct. 20
Oct. 21
Oct. 22
Time (h)


Pretreatment
Treatment
Post Treatment
Total number per hour
Tubificoidea
Dugesia sp.
Hydracarina
Brachiobdellida sp.
Lumbricidae
60
55
50
45
40
35
30
25
20
15
10
5
0
24
8
16
24
8
16
24
8
16
24
8
16
Oct. 19
Oct. 20
Oct. 21
Oct. 22
Time (h)