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The Effects of Toxaphene Piscicide on Benthic Macroinvertebrates

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ABSTRACT: The long-term effects of toxaphene piscicide on benthic macroinvertebrates was examined from 1962 to 1966 in Brewer Lake, Ontario. The immediate effect of treatment was a dramatic decrease in the abundance of all benthic macroinvertebrates within one month. The complete eradication of all benthic macroinvertebrates was not achieved. The phantom midge, *Chaoborus punctipennis,* was extirpated, with no repopulation within the four years following treatment. Prior to treatment this species constituted 58% of the abundance of benthic macroinvertebrates. A significant increase in abundance of benthic macroinvertebrates occurred from 1964 through 1966, due to an increase in chironomid larvae, following the reduction of predator populations. The population of oligochaetes showed little effect from the toxaphene treatment, with a general increase in abundance during this study.

Prior to treatment the highest numbers of benthic macroinvertebrates were collected in the profundal zone. Following treatment the dominant organisms of this zone, *Chaoborus punctipennis* and *Chironomus cucini* were extirpated, with a continuing paucity of benthic macroinvertebrates observed in this zone.

The overall effect of the toxaphene treatment on benthic macroinvertebrates was to extirpate the dominant macroinvertebrate, *Chaoborus punctipennis,* and to restrict the repopulation of the deeper areas of the profundal zone, although during three of the four years following treatment the abundance and biomass of benthic microinvertebrates in the littoral-sublittoral zone was significantly higher than the pre-treatment average.

The increasing demand for bigger and better sport fisheries has prompted many fish management authorities to utilize a variety of piscicides to remove undesirable fish from lakes or streams, for the purpose of restocking with more desirable game fish. In 1962, Brewer Lake, in Algonquin Park, Ontario, was treated with toxaphene, a chlorinated camphene, for the purpose of restocking the lake with splake, a lake trout × speckled trout hybrid. As

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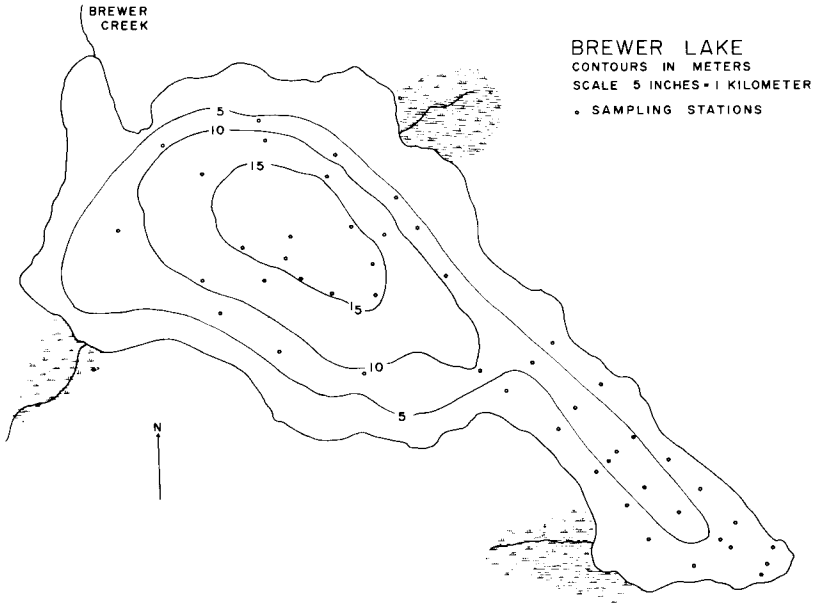

Fig. 1. Brewer Lake, Algonquin Park, Ontario.

splake are primarily insectivorous in their feeding habits, this study was initiated to determine the immediate effects of toxaphene on benthic macroinvertebrates and extended over several years to examine the long-term effect of fish removal on the benthic community.

Brewer Lake (Fig. 1) is a small oligotrophic lake located in the Precambrian Shield of Northern Ontario (78°18'W, 45°36'N), with a surface area of 64.8 hectares (160 acres). A long narrow bay, 6 m or less in depth, occupies the southeastern third of the lake. The large central area of the lake has a maximum depth of 16 m. Three small creeks enter the lake, one flowing from Lake Saint Anthony in the south and two from marsh areas on the northeast and southeast shores. The lake drains to the northwest through Brewer Creek into Costello Lake.

Thermal stratification occurs from mid-May to early November, with hypoxial conditions occurring below 14 m from September to November.

On 4 June 1962 the lake was treated with toxaphene at a concentration of 0.015 ppm and the three inflowing creeks treated with rotenone. Fish were prevented from coming upstream from Costello Lake by a screened highway culvert.

Methods

Benthic samples were collected with a 23- × 23-cm Ekman grab during 1962 and 1963 and with a 15- × 15-cm grab from 1964 to 1966. In 1962, 48 grab samples (Fig. 1) were collected 1 wk prior to treatment and again 1 mo following treatment. Three sets of 48 grab samples were taken in 1963, six sets in 1964, and four sets in 1965 and 1966, at approximately 1 mo intervals during the summer. Samples were washed through a brass screen (mesh No. 30), preserved in 70% ethyl alcohol, and sorted in white enamel pans. For determination of dry-weight biomass, organisms were dried at 105°C for 24 hr. Species diversity (d) was determined by the equation of Margalef (1958), which expresses the relationship between the number of species (s) and the natural logarithm of the total number of individuals (N).

$$d = (s - 1)/(\ln N)$$

The statistical analysis of data was based on tests of one-way analysis of variance and the Kramer (1956) extension of Duncan's multiple range test. Comparisons were made at the 0.05 level of significance.

Results

Following toxaphene treatment in 1962, Brewer Lake was toxic to all fish placed in test traps at depths of 3, 5, 6, 8, 10, and 13 m. The lake remained toxic to fish in test traps at all depths throughout the summer.

In May 1963 test traps indicated no toxicity at any depth. On 31 May 1963, 4375 (F_1) fingerling splake were released into the lake. In August, test traps indicated that the lake was again toxic to fish at tested depths of 3, 7, 10, and 13 m. No splake were recovered at any time during this summer.

In 1964, 4400 fingerling splake were released, 5000 fingerlings in 1965, and 1000 fingerlings in 1966. Reported catches of splake were minimal during these years.

SEASONAL ABUNDANCE OF BENTHIC MACROINVERTEBRATES: Twenty-seven taxa of benthic macroinvertebrates (Table 1) were collected during this study, with the majority of species collected from the littoral-sublittoral zone of the lake. A minimum of 11 taxa was collected during each of the 19 sampling periods.

Species diversity varied from 1.27 to 2.05, with a mean value of 1.63 for the 19 collecting periods. The value of 1.27 was determined for July 1963, 1 yr after treatment, with a value of 1.98 determined 1 mo later.

Prior to the treatment of Brewer Lake with toxaphene, phantom midges, chironomids, and oligochaetes made up 95% of the numbers of benthic macroinvertebrates collected (Table 2), with phantom midges constituting 58% of the abundance. Following treatment, phantom midges constituted only 1% of the abundance, with chironomids making up 57% and oligo-

Table 1. The species of benthic macroinvertebrates collected at various depths in Brewer Lake, Algonquin Park, Ontario, from 1962 through 1966.

	Depth (m)														
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Turbellaria															
Rhabdocoelida	X														
Dugesia sp.	X	X													
Oligochaeta															
Limnodrilus hoffmeisteri	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Tubifex tubifex	X		X												
Stylaria fossularia	X														
Hirudinea															
Helobdella sp.	X	X													
Amphipoda															
Hyalella azteca	X	X													
Insecta															
Odonata															
Argia sp.	X	X													
Ephemeroptera															
Hexagenia limbata	X	X	X												
Megaloptera															
Sialis sp.	X	X													
Trichoptera															
Cheumatopsyche sp.	X	X													
Coleoptera															
Haliplidae	X														
Diptera															
Ceratopogonidae															
Palpomyia complex	X	X	X	X											
Chaoboridae															
Chaoboris punctipennis					X	X	X	X	X	X	X	X	X	X	X
Chironomidae															
Ablabesmyia monilis		X		X											
Procladius freemani		X	X	X	X	X	X		X	X		X	X		
Procladius bellus	X	X	X		X	X		X	X						
Orthocladiinae	X	X		X											
Chironomus cucini								X	X	X	X	X	X	X	X
Chironomus attenuatus		X	X	X		X		X	X						
Cryptotendipes casuarius	X	X													
Phaenopsectra coracina								X	X	X	X	X	X	X	X
Tanytarsus sp.	X	X	X	X	X										

Table 1. Continued.

	Depth (m)														
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Mollusca															
Pisidium sp.	X	X	X	X											
Gyralis sp.		X		X											
Elliptio sp.		X	X												
Amnicola limosa	X	X													

chaetes 15%. The various miscellaneous groups of macroinvertebrates increased from 5 to 28% of the abundance.

Within 1 mo following treatment the abundance of benthic macroinvertebrates decreased sharply (Fig. 2), and continued in low abundance through the summer of 1963. Because no collections were taken in the late summer of 1962 and the concentration of toxaphene used was relatively low (0.015 ppm), it cannot be assumed that all of the benthic macroinvertebrates died following treatment, but rather, only a severe reduction in the population level occurred. The abundance of benthic macroinvertebrates increased sharply during 1964, reaching 688 ind m^{-2} in September, and 752 ind m^{-2} in May 1975, followed by a decline in abundance in 1966.

The average abundance of benthic macroinvertebrates collected in 1965 and 1966 was comparable and significantly higher (0.05 level of confidence) than the average abundance for 1964, 1963, and the pre- and post-treatment periods of 1962. The average abundance determined for the pre-treatment period was comparable to the average abundance for 1964 and 1966. The average abundance for 1963 and the post-treatment period of 1962 was also comparable and significantly lower (0.05 level of confidence) than any of the other collecting periods.

Table 2. The abundance of benthic macroinvertebrates in Brewer Lake, Algonquin Park, Ontario during pre- and post-treatment periods from 1962 to 1966.

	Pre-treatment		Post-treatment	
	No.	%	No.	%
Chaoboridae	516	58	120	1
Chironomidae	317	36	5442	57
Oligochaeta	10	1	1397	15
Miscellaneous	47	5	2658	28
Total	890	100	9617	100

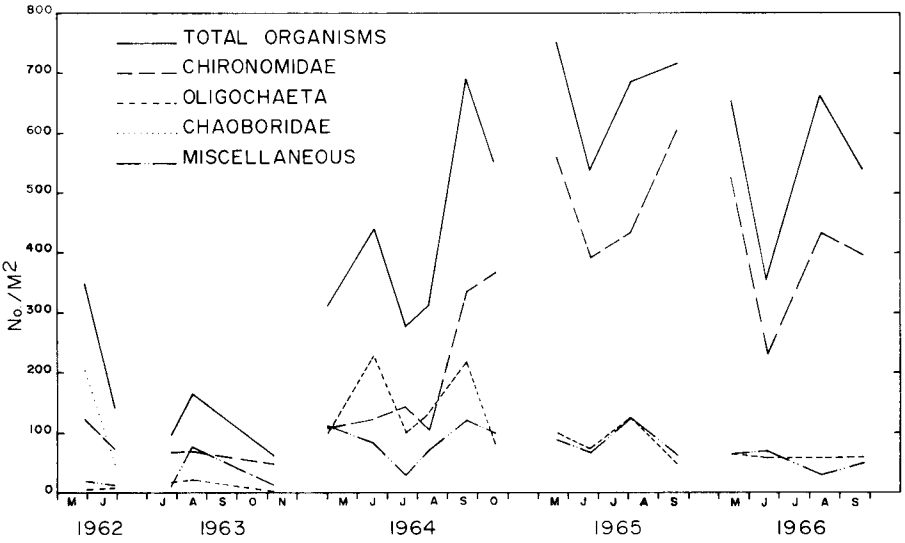

Fig. 2. The abundance of benthic macroinvertebrates in Brewer Lake, Ontario from 1962 through 1966, following toxaphene treatment.

Chaoborus punctipennis (Fig. 2) had the most dramatic change in abundance in post-treatment collections. Prior to treatment, chaoborid larvae totaled 58% of the benthic macroinvertebrates, with an average abundance of 201 ind m^{-2}. No larvae were collected from 1963 through 1966.

The Chironomidae had the greatest species diversity and increased dramatically in the average abundance of larvae from 1964 through 1966, but also showed some varying trends when individual species were examined.

Phaenopsectra coracina and *Chironomus cucini,* two large species of chironomids found only in the profundal zone, were low in abundance in 1962, with neither species collected in 1963. *Chironomus cucini* was not collected from 1963 through 1966. *Phaenopsectra coracina* had a sharp increase in abundance during 1964, reaching 140 ind m^{-2} in 1965, and remained abundant in 1966 (Fig. 3).

Procladius freemani (Fig. 3) was collected in low numbers at nearly all depths in 1962. It was not collected in 1963. It increased sharply in abundance from 1964 through 1966, but only in the littoral-sublittoral zone of the lake.

The subfamily Orthocladiinae was collected in small numbers in the littoral-sublittoral zone during 1962 and 1963, was not collected in 1964 and 1965, and reappeared in 1966 (Fig. 3).

Tanytarsus sp. was also collected in low numbers in the littoral zone in 1962 and was absent in 1963. Specimens were again collected in the late

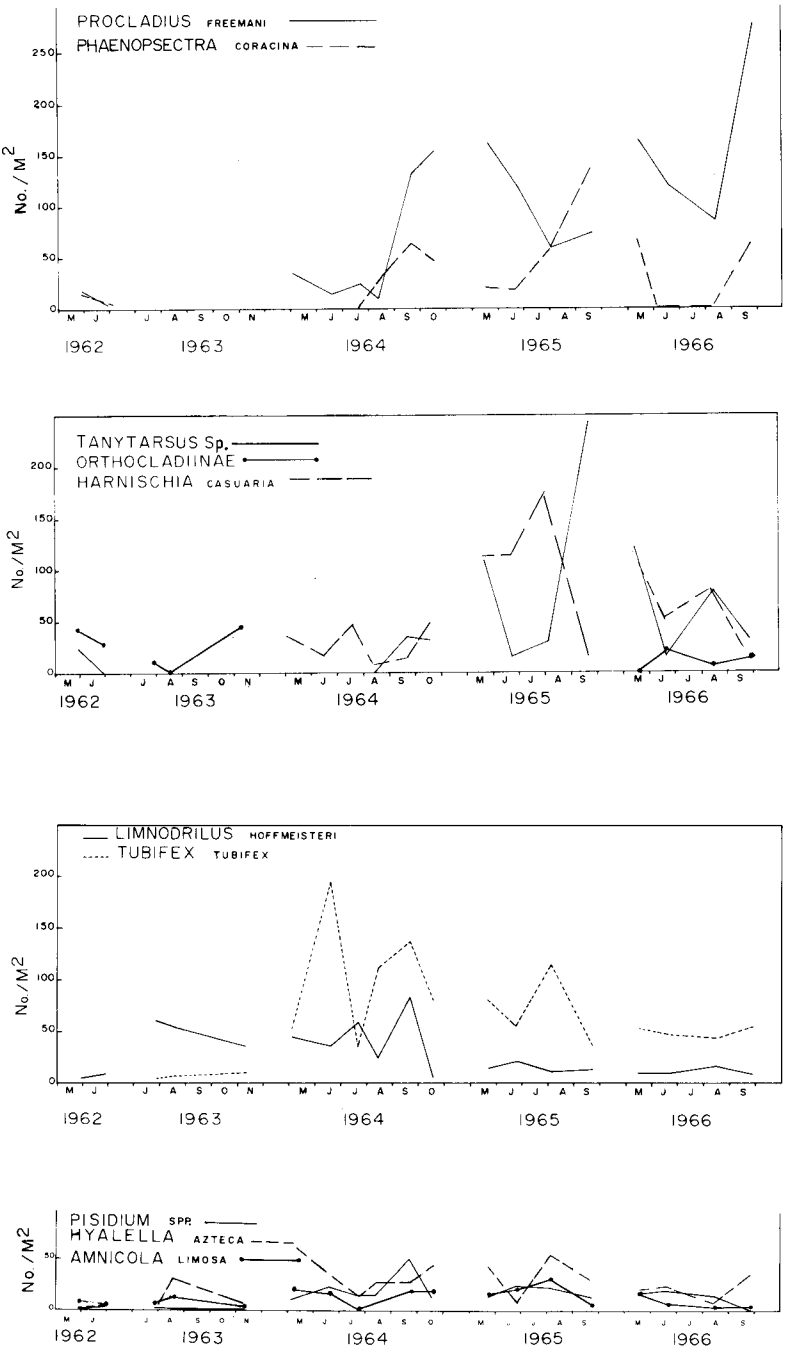

Fig. 3. The abundance of benthic macroinvertebrates species in Brewer Lake, Ontario from 1962 through 1966, following toxaphene treatment.

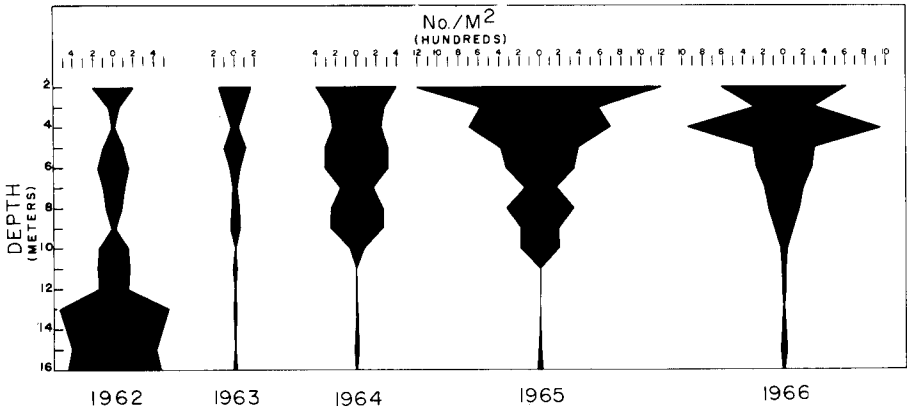

Fig. 4. The bathymetric abundance of benthic macroinvertebrates in Brewer Lake, Ontario from 1962 through 1966, following toxaphene treatment.

summer of 1964, then showed a sharp increase in abundance in 1965, reaching 243 ind m^{-2}, and remained abundant in 1966 collections (Fig. 3).

Cryptotendipes casuarius (Fig. 3) was not collected in Brewer Lake prior to treatment nor following treatment in 1962 and 1963. In 1964 it was collected in moderate numbers in the littoral zone, then showed a sharp increase in abundance in 1965 and 1966.

Oligochaetes (Fig. 2) were only moderately abundant during 1962 and 1963, but increased in abundance in 1964, reaching 231 ind m^{-2} in June 1963, then decreased during 1965 and 1966. Only three species of oligochaetes were collected, with *Limnodrilus hoffmeisteri* (Fig. 3) low in abundance during 1962, but increasing sharply in 1963 and reaching 84 ind m^{-2} in 1964, then decreasing in abundance during 1965 and 1966. *Tubifex tubifex* (Fig. 3) was not taken in collections during 1962. It occurred in low numbers during 1963, then increased sharply in abundance in 1964, reaching 232 ind m^{-2}, but declined slowly in abundance in 1965 and 1966. *Stylaria fossularis* was collected only infrequently.

Various miscellaneous macroinvertebrates (Fig. 2) (sphaeriid clams, amphipods, leeches, turbellarians, mayflies, dragonflies, and sialid larvae) were low in abundance in 1962, but increased moderately in 1963 through 1966. The amphipod *Hyalella azteca* (Fig. 3) was collected in low numbers during 1962, but increased moderately from 1963 through 1966. The fingernail clam *Pisidium* sp. (Fig. 3) occurred in low numbers during 1962 and 1963 then increased moderately from 1964 through 1966. The snail *Amnicola limosa* (Fig. 3) occurred in low numbers during 1962 and increased slightly in 1963 through 1966. The remaining benthic macroinvertebrates were collected too infrequently to show any distribution pattern.

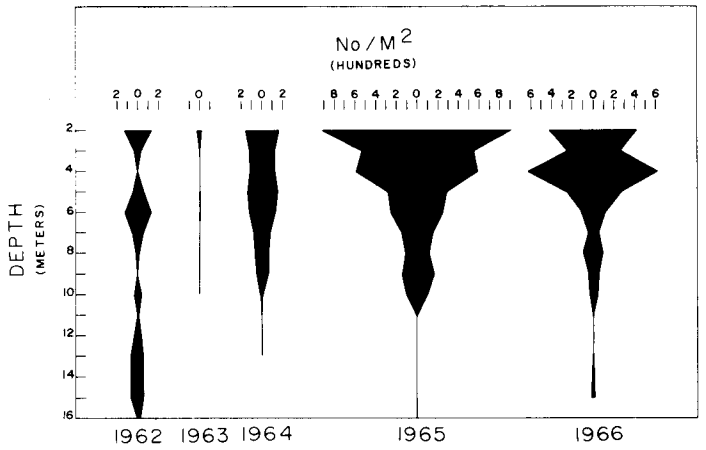

Fig. 5. The bathymetric abundance of chironomid larvae in Brewer Lake, Ontario from 1962 through 1966, following toxaphene treatment.

BATHYMETRIC DISTRIBUTION OF BENTHIC MACROINVERTEBRATES: Prior to the toxaphene treatment in 1962 (Fig. 4), the highest numbers of benthic macroinvertebrates were collected in the profundal zone, below a depth of 12 m. In 1963 benthic macroinvertebrates were collected from the littoral and sublittoral zones, with a severe reduction in abundance from the profundal zone. From 1964 through 1966 the numbers of benthic macroinvertebrate increased markedly compared to pre-treatment collections with the majority of these taken from the littoral-sublittoral zone, and a continuing paucity of organisms in the profundal zone.

In 1962 the bathymetric distribution of chironomids (Fig. 5) prior to treatment showed a moderate abundance of larvae in the littoral, sublittoral, and profundal zones. In 1963 chironomids were absent below a depth of 10 m and collected in very low numbers in the sublittoral zone. In 1964 through 1966, chironomid larvae increased markedly in numbers in the littoral-sublittoral zone compared to pre-treatment collections. Only in 1965 and 1966 were chironomids again collected in the profundal zone, although in very low numbers.

SEASONAL DISTRIBUTION OF MACROINVERTEBRATE BIOMASS: The dry-weight biomass determined in 1962 and 1963 (Fig. 6) following the toxaphene treatment showed a sharp decrease in the total biomass of macroinvertebrates. The average biomass of all macroinvertebrates decreased from 0.087 g m^{-2} in 1962 prior to treatment, to a low of 0.006 g m^{-2} in August 1963. Average biomass increased from 1964 through 1966.

Chaoborus punctipennis had a marked decrease in biomass following treatment, decreasing from a pre-treatment average of 0.057 g m^{-2} to 0.015

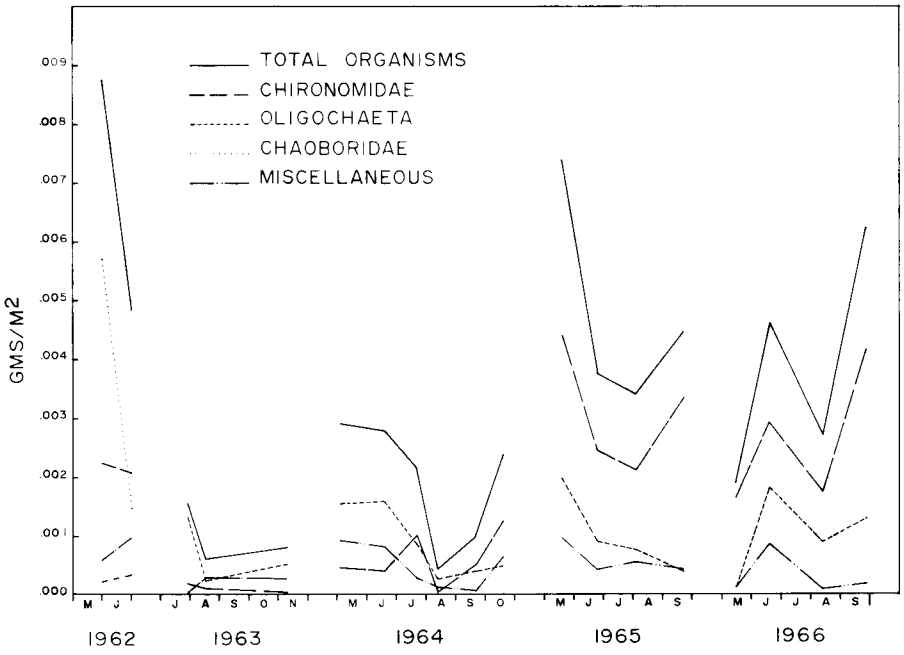

Fig. 6. The biomass of benthic macroinvertebrates in Brewer Lake, Ontario from 1962 through 1966, following toxaphene treatment.

g m^{-2}, 1 mo following treatment. No specimens of chaoborids were collected in 1963 through 1966.

The Chironomidae had only a small decrease in biomass from pre- to post-treatment collections in 1962, but decreased to 0.002 g m^{-2} in 1963. In 1964 the biomass of chironomids increased moderately and showed a marked increase in 1965 and 1966, maintaining levels generally above the pre-treatment average of 0.022 g m^{-2}.

Oligochaetes had a continuous increase in biomass in post-treatment collections compared to pre-treatment levels. The biomass of the miscellaneous macroinvertebrates remained near the pre-treatment level from 1962 through 1966.

Discussion

The immediate effect of the toxaphene treatment of benthic macroinvertebrates was a dramatic decrease in the abundance of all organisms within 1 mo following treatment. Since no samples were taken later on during 1962, it cannot be assumed that all the macroinvertebrate perished, but rather, only a severe reduction in the population occurred. The level of toxaphene used was considerably less than the 0.1 ppm used by Cushing and Olive

(1957) which removed all chironomids within 3 days and all *Chaoborus* within a month in two northern Colorado reservoirs.

The use of toxaphene for the removal of undesirable fish populations is beneficial for purposes of fish management but has proved somewhat undesirable in application because of the variability in detoxification. The variability in the rate of detoxification limits the use of this piscicide in lakes where a rapid return of a sport fishery is desired.

In the past, concentrations of toxaphene used for fish removal have varied from 0.01 through 0.1 ppm (Cushing and Olive, 1957; Kallman, Cope, and Navarre, 1962; Hilsenhoff, 1965; Mayhew, 1959; Hooper and Grzenda, 1957; Johnson, 1966), with some lakes showing a rapid detoxification in 2 days (Kallman, Cope, and Navarre, 1962), while other lakes took several months (Royer, 1966; Tanner and Hayes, 1955) to 3.5 yr (Stringer and McMynn, 1960) to detoxify.

Brewer Lake remained toxic throughout the summer of 1962 and was still toxic to fish set in test traps in October. In May of 1963 test traps indicated no toxicity evident at any depth, yet by August the lake was again toxic to fish set in test traps at depths of 3, 7, 10, and 13 m. No toxicity was evident in 1964.

The reoccurrence of toxic levels of toxaphene to test fish in August 1963 and not in May is somewhat puzzling. It is possible that in May the toxaphene concentration present may have been reduced due to precipitation during the winter. This, with the inactivity of test fish due to the cold water, could give the impression that the lake was detoxified. In August, with increased water temperatures some resuspension of the toxaphene may have occurred, and with the increased activity of test fish may have increased the uptake and concentration level of toxaphene to test fish. This reasoning varies from the effects of temperature on detoxification found by Mitchum (1963), although Stringer and McMynn (1960) found Gallagher Lake, which stratifies thermally, to take 3.5 yr to detoxify.

The factors affecting detoxification appear to be closely related to lake type and to various physical and chemical characteristics. Hemphill (1954), in studies on ponds, and Mayhew (1959), working on strip mines, found alkaline waters to detoxify rapidly, although Tanner and Hayes (1955), working on reservoirs, found toxaphene to remain toxic for more than 7 mo at a pH greater than 8.0.

In laboratory experiments, Mitchum (1963) found that temperature was the only factor which significantly affected detoxification and Royer (1966) found a rapid detoxification of toxaphene in Midway Lake until freeze-up followed by increased detoxification the next spring as water temperatures increased. Stringer and McMynn (1960) found that Spectacle Lake, British Columbia, which did not stratify thermally, detoxified in 11 mo while Gallagher Lake which stratified thermally remained toxic for 3.5 yr.

Although the complete eradication of benthic macroinvertebrates in Brewer Lake was not achieved, a significant decrease in the overall abundance was apparent by November 1963. Selective gill-netting following the toxaphene treatment indicated that small fish were absent after 1 mo, with only an occasional common sucker collected during the remainder of 1962 and through the summer of 1963. The most marked effect of toxaphene on benthic macroinvertebrates was the complete removal of the phantom midge, *Chaoborus punctipennis,* from the lake with no repopulation by adults emerging from nearby Lake Costello. Prior to treatment, this organism constituted 58% of the abundance of benthic macroinvertebrates, and its complete and extended absence from the lake following treatment indicates its high sensitivity to low levels of toxaphene. Hilsenhoff (1965) noted a similar effect of toxaphene on *Chaoborus* in Hartlaub Lake, Wisconsin, where populations dropped sharply following treatment and failed to repopulate. He felt that the introduction of brook trout fingerlings probably were responsible for preventing repopulation. Hilsenhoff (1971) reported that *Chaoborus* finally repopulated Hartlaub Lake 4 yr after treatment. The high sensitivity of the first instar larvae of *Chaoborus* to toxicants (Hazeltine 1963) apparently is a critical factor reducing the populations of this insect.

Even with the removal of the dominant benthic macroinvertebrate, a dramatic increase in abundance of benthic macroinvertebrates occurred from 1964 through 1966. This increase can be attributed to the increase in abundance of chironomid larvae following the reduction of predator populations. The eradication of the resident fish population in addition to the removal of the phantom midge, a predator of chironomids and oligochaetes (Berg, 1937; Deonier, 1943; Main, 1953; Stahl, 1966) allowed for the unrestricted repopulation of the littoral and sublittoral zones, although little or no repopulation of the profundal zone below 11 m occurred from 1964 through 1966.

Hooper and Grzenda (1957) found that the standing crop of chironomids in McCarthy Lake, Michigan, was considerably higher 11 mo after treatment of the lake with toxaphene, although the population was composed almost entirely of *Chironomus plumosus*. Hilsenhoff (1965) found that the population of *Chironomus* in Hartlaub Lake, Wisconsin, remained stable for a month after treatment, then within 4 mo became more than 200 times as abundant than at the time of treatment. The following summer the population decreased drastically and was completely absent the following year. Hilsenhoff felt that the introduction of yellow perch into the lake probably aided in the population reduction as they are known to feed heavily on *Chironomus* larvae (Hasler, 1945). Hilsenhoff (1971) found that *Procladius* flourished in Hartlaub Lake from 1963 to 1966 and then was replaced by larvae of *Tanypus*.

The population of oligochaetes in Brewer Lake appeared to be little affected by the toxaphene treatment and showed a general increase in abun-

dance during this study. The absence of fish and *Chaoborus* as predators probably aided in this population increase. Cushing and Olive (1957) and Hooper and Grzenda (1955) found that oligochaetes showed no adverse effects from toxaphene treatments, and Moretti (1948) determined that the oligochaete *Lumbriculus* could survive high concentrations of toxaphene.

The overall effect of the toxaphene treatment on benthic macroinvertebrates was to extirpate the phantom midge from the macroinvertebrate community and to restrict the repopulation of the deeper areas (below 12 m) of the profundal zone, although for 3 of the 4 yr following treatment the abundance and biomass of benthic macroinvertebrates in the littoral-sublittoral zone was above the pre-treatment average.

With the exception of the phantom midge, the general effect of fish removal from Brewer Lake was an increase in the levels of abundance of benthic macroinvertebrates. It can only be presumed that these levels would be reduced when increased levels of vertebrate predators were obtained. The potential for the phantom midge to repopulate the lake exists, but whether it would is unpredictable.

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