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Report No. 1414

FURTHER STUDIES ON THE USE OF FISH POISONS IN MICHIGAN LAKES

By

CLARENCE M. TAUBE, KIYOSHI G. FUKANO AND FRANK F. HOOPER

ABSTRACT

Rotenone was first used in Michigan as a fish poison in 1934. Since that time, 73 lakes and ponds have been treated to eliminate undesired species. Various preparations that contain rotenone have been used. Powdered derris and cube have been employed most often, but recently emulsifiable rotenone and Fishtox have come into the picture.

With only one known exception, lakes treated with the powder preparations have lost their toxicity within one month after treatment. On the other hand, 10 of the 17 lakes that were treated with either Fishtox or emulsifiable rotenone have remained poisonous to fish for longer than one month; Fishtox was applied to six of these lakes and emulsifiable rotenone to four of them. Duration of toxicity after these Fishtox treatments has ranged from more than 8 months but less than 13 months to more than 28 months but less than 36 months; one lake was poisonous after 33 months. Duration of toxicity in the four lakes in which emulsifiable rotenone was used ranged from more than one month but less than 8 months to more than 9 months but less than 13.

There was pronounced reduction in numbers of fish-food organisms in five lakes treated with Fishtox and in one lake treated with emulsifiable rotenone. More than double the quantity of toxicant that usually

has been employed was used in each of these lakes. It was suspected that the Fishtox used in these waters contained some poison, or possibly synergistic poisons, besides rotenone.

As a result of these experiences, tests were run on the effect of various rotenone preparations on bottom fish-food animals and on fish for comparison of effects.

On a lake that was treated with the emulsifiable product and which remained toxic more than 8 months, bottom samples were collected before and after treatment. Here the poison significantly affected only one invertebrate organism, the phantom midge Chaoborus sp., and this animal showed recovery in numbers 13 months after the lake had been treated.

Laboratory experiments were carried on in aquaria on several kinds of invertebrates with emulsifiable rotenone, cube powder and a mixture of cube and a household detergent, Tide. Each rotenone-bearing preparation was used at a concentration of 1.0 p.p.m. The midge Tendipes decorus was the only bottom invertebrate that was seriously affected, and there was no apparent difference in effect of the three compounds on this species.

Laboratory tests were run on bluegills with the same three kinds of preparations that were used on invertebrate animals. Included in these tests were two different concentrations of the toxicants (1.0 p.p.m. and 0.5 p.p.m.), water of two different temperatures, and waters that varied in alkalinity and color. The emulsifiable product generally killed fish sooner than did either cube powder or the combination of cube and Tide.

Neither field experiences nor the laboratory tests indicated that soft water remains toxic longer than hard water upon treatment with rotenone. Lakes with outlets have stayed poisonous for shorter periods of time than have landlocked lakes.

Although the initial cost of emulsifiable rotenone exceeds that of powdered derris and cube, the greater ease of mixing and applying the emulsifiable product balances this difference to some degree. Furthermore, the emulsifiable rotenone does not cause discomfort to the workmen as the powdered forms often do, and it disperses more readily, thereby giving better insurance of complete kill of fish.

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Nearly twenty years have elapsed since pioneering experiments were carried out in Michigan on the use of rotenone as a fish poison to eliminate undesired species present in lakes and ponds. Since that time eradication of fish populations with rotenone, followed by restocking, has become a widely used procedure. Solman (1950), Smith (1950), and Krumholz (1948) have published summaries of the extensive literature on the use of poisons in fisheries management. In Michigan and other states powdered derris root and cube root were used until several new types of rotenone preparations became available. The products now marketed that have been commonly employed include a wetable paste containing 3 per cent rotenone and an emulsifiable liquid with 5 per cent rotenone, manufactured by S. B. Penick and Company, New York, and a preparation sold under the trade name of Fishtox by the Standard Supply Distributors of Wenatchee, Washington. Neither emulsifiable rotenone nor Fishtox requires the laborious mixing prior to application that powdered forms of rotenone require. Moreover, they apparently disperse more thoroughly throughout the water than do the powdered preparations. In Michigan, however, certain difficulties have been encountered in using these two products. A number of lakes treated with emulsifiable rotenone and Fishtox have remained toxic for long periods of of time (for at least 33 months in one instance). These products apparently have killed appreciably more bottom fish-food organisms in several lakes than ordinarily occurs when powdered derris or cube is used.

The purpose of this paper is to summarize observations on the biological effects of emulsifiable rotenone and Fishtox on Michigan lakes and to report the results of recent laboratory and field tests on toxicity of rotenone compounds to fish and invertebrate animals.

Methods

In general, methods employed in applying fish poisons to the lakes mentioned in this paper were those that have been widely used. Powdered derris was mixed into a thick aqueous suspension, and some water was also used with the emulsified rotenone. Fishtox, which came in the form of a thick paste, was likewise premixed with water before application. Portable pumps operated from small boats were used to distribute the suspension of powdered derris or the diluted emulsifiable and Fishtox preparations over the lake surface and into the depths. Usually the products have been used at a concentration of 0.55 p.p.m. Most applications were made in the latter part of August or early in September when water temperatures are high enough to make the poison effective and when the deeper parts of stratified lakes contain little or no oxygen and thus do not require treatment. However, concentrations were nearly always determined on the basis of the entire volume of the lake. Most treatments made since 1946 have been by the Lake and Stream Improvement Section of the Fish Division, Michigan Department of Conservation.

In field studies on the effect of fish poisons on bottom invertebrates, a 6-inch x 6-inch Ekman dredge was used for bottom sampling. Samples were sieved through a No. 30 wire mesh screen, and were either sorted in the fresh state or else were preserved with 10 per cent formalin. In the laboratory, organisms in preserved collections were separated from the detritus, identified, and counted.

Fish used in toxicity tests were bluegills (Lepomis macrochirus) that averaged two inches in length. Invertebrates tested in the laboratory were: dragonflies (Libellula, Leucorrhinia, Erythemia), damselflies (Enallagma), leeches (Erpobdella punctata), midge larvae (Tendipes decorus), and Cladocera (Daphnia magna). The test fish and invertebrates, except midge larvae and Daphnia, were collected near the public fishing site at Whitmore Lake, Washtenaw County. The midge larvae came from the Huron River just below the outfall of the Ann Arbor sewage disposal plant. Daphnia magna were from a culture maintained by the Fish Division of the Museum of Zoology, University of Michigan.

In all toxicity tests at least three experimental animals were used. Tests were carried out in one-gallon pickle jars. Fish poisons were tested in combination with a variety of lake waters. The waters used, their methyl-orange alkalinity, color, and pH are given in Table II.

Fish and invertebrates were conditioned in the test water for one hour before each experiment. In most cases, duplicate experiments were run at room temperature (70°-75°F.) and in a water bath of Ann Arbor city water which varied in temperature between 60° and 66° F. Compounds tested were emulsifiable rotenone (Liquid Noxfish; S. B. Penick & Co.) that contained 5 per cent rotenone, powdered cube root that also had 5 per cent rotenone, and a mixture of powdered cube root and the household detergent Tide.

History of fish eradication

Since the start of the poisoning program in 1934, 73 lakes and ponds have been treated by the Fish Division, Michigan Department of Conservation. Nearly all of the applications have been made to eliminate undesirable populations of warm-water fish. After detoxification most of these lakes have been planted with trout. Several of them have been treated two or more times, either because warm-water fish were reintroduced after the initial treatment, or because the kill was incomplete. Emulsifiable rotenone has been used in 7 lakes and Fishtox was used in 11 lakes, including one lake in which the two preparations were applied at different times. In 56 lakes the powdered form of either derris or cube root has been used. Incomplete kills of fish have been reported from use of all three poisons. Most instances of incomplete kills have apparently been due to inadequate distribution of the poisons. Fishtox used in treating lakes in 1949 effectively eradicated the population of only one out of six lakes in which it was used. The poison was believed to have been below standard in strength in these treatments. Krumholz (1950); Smith (1950), quoting Alderdice, 1949, Anthony, 1949, and Smith, 1949, report treatments in which Fishtox failed to be effective.

Although powdered derris and cube root are the least expensive of these preparations, both are difficult to mix and apply. The powder must be premixed with water before it can be effectively applied. The addition of a small quantity of detergent (e.g., Tide) appears to aid in mixing the powder. If the cost of labor and supervision is included in cost estimates of lake poisoning, the powdered form of rotenone may prove to be the most expensive. Further considerations, such as the discomfort encountered by personnel inhaling the powdered rotenone dust and the more complete dispersement of the emulsified product, make the latter more desirable for fish eradication.

Detoxification of lakes after treatment

Dissipation of rotenone in lakes after treatment ordinarily is rapid. The practice in Michigan has been to wait 30 days after poisoning before restocking. Before plantings are made the lake usually is tested by placing fish in containers and observing their survival. Alkalinity, turbidity, and temperature are thought to be some of the factors that influence the rate of detoxification. Clemens and Martin (1953) found that clear-water ponds of low alkalinity (16 p.p.m.) treated with emulsifiable rotenone lost their toxicity in three to six days, whereas in clear ponds of high alkalinity (60-284 p.p.m.) detoxification took one to three days. Turbid ponds of high alkalinity took one to two days longer.

Dissipation of rotenone was slower during the winter than the summer months. M'Gonigle and Smith (1938) reported that McCormick Lake, a Nova Scotian lake of low alkalinity treated with powdered derris, remained toxic for about one month.

In 11 Michigan lakes, trout have failed to survive when tested or planted one month or more after treatment with various fish poisons. Fishtox was used in six of these lakes, emulsifiable rotenone in four, and powdered derris root in one lake (Table I). Five lakes located within the Pigeon River Trout Research Area, Otsego and Cheboygan counties, have remained toxic to trout 18 months or longer after treatment with Fishtox. These lakes were poisoned in September, 1950. The concentration of Fishtox was higher (1.2-1.7 p.p.m.) than in other treatments because the previous shipment in 1949 apparently was below normal strength, as mentioned before. These lakes were toxic when tested in the spring and fall of 1951, and in the spring of 1952. Tests made in September of 1952, however, indicated that all of the lakes had recovered. Accordingly, brook trout (Salvelinus fontinalis) were planted in October. Good returns from these plantings were obtained from West Lost and South Twin lakes, but no fish were recovered from this planting in Lost and North Twin lakes, and only one trout was caught from Hemlock Lake. The failure of these plantings in Lost and North Twin lakes, after tests made in September of 1952 had indicated loss of toxicity in surface waters, suggests that toxic substances were absent in the upper water but were present in the hypolimnion or in the profundal mud, and were dispersed throughout

TABLE I

SUMMARY OF PHYSICAL AND CHEMICAL DATA AND DURATION OF TOXICITY

IN SOME LAKES TREATED BY THE MICHIGAN DEPARTMENT OF CONSERVATION

WITH FISHTOX AND EMULSIFIABLE ROTENONE

Lake and County	Area in acres	Maximum depth in feet	Depth of thermocline in feet	Connected streams	Methyl orange alkalinity, p.p.m.	Date treated	Rotenone product used, p.p.m.	Observed duration of toxicity in months	
								More than	Less than
Hilltop, Gogebic	22.0	54	18-27	None	4-6	Aug. 8, 1949	Fishtox 0.55	*	2
Perch, Marquette	23.7	23	16-19	None	2-3	Aug. 9, 1949	Fishtox 0.55	*	1-1/2
Dutch Fred, Schoolcraft	27.5	45	20-27	None	35	Aug. 12, 1949 Oct. 24, 1949	Fishtox 0.55 Derris and Fishtox 0.55	+ *	1/3
O'Brien, Alcona	10.3	30	12-21	Outlet	162-172	Aug. 15, 1949 Aug. 14, 1950	Fishtox 0.55 Fishtox 0.55	+ *	3
Wilson, Marquette	26.7	22	12-21	Inlet Outlet	52-54	Aug. 10, 1949 Aug., 1950	Fishtox 0.55 Fishtox 0.55	+ 8	13
Hemlock, Cheboygan	5.9	64	15-26	None	160-198	Sept. 25, 1950	Fishtox 1.5	19	24
Lost, Otsego	3.5	55	15-23	None	144-193	Sept. 25, 1950	Fishtox 1.2	33	*
West Lost, Otsego	3.7	44	15-23	None	133-146	Sept. 25, 1950	Fishtox 1.2	19	24
South Twin, Otsego	3.9	34	15-26	None	106-110	Sept. 25, 1950	Fishtox 1.2	19	24
North Twin, Otsego	4.7	44	20-26	None	43-50	Sept. 25, 1950	Fishtox 1.2	28	36
Section 4, Otsego	2.6	72	15-23	None	149-198	Sept. 25, 1950	Emul. rotenone 1.7	9	13
Holland, Luce	5.2	22	15-20	None	18-23	Aug. 13, 1949 Oct. 24, 1949	Fishtox 0.55 Emul. rotenone 0.55	+ 1	8
Tank, Luce	36.0	51	16-27	Intermittent outlet	3-6	Aug. 10, 1950	Emul. rotenone 0.5	1	9
Irwin, Alger	10.0	38	15-25	None	5-10	Sept. 12, 1951	Emul. rotenone 0.55	8	13
Blair Pond, Marquette	13.7	7	Not present	Inlet Outlet	45-46	Sept., 1951	Emul. rotenone 0.75	*	9
Portage Creek Pond, Jackson	12.6	8	Not present	Inlets (4) Outlet	192-195	March 31, 1950	Emul. rotenone 0.35	*	2/3
Roland, Baraga	40.5	22	10-15	Outlet	11	Sept. 2, 1953	Emul. rotenone 0.5	*	2
[redacted]									
Weber, Cheboygan &	31.0	41	20-32	None	3-10	Aug. 19, 1948	Powdered derris 0.55	2	11

* Not determined.

& Weber Lake is included because of the slow detoxification after treatment with powdered derris.

\+ Incomplete kill.

the lake at the time of the fall overturn. Water samples collected from the hypolimnion of Lost Lake in August, 1953 (33 months after treatment) killed bluegills within two hours. This water had been aerated with a standard aquarium aerator for 24 hours before the test. At the time of the experiment, the dissolved oxygen concentration was 8.3 p.p.m. Bluegills were tested similarly with water from North Twin Lake and survived for the duration of the test (four days). This species also lived through a 96-hour test made after the bottom water had been circulated for 24 hours over a sample of the profundal mud of the lake. The result of the latter experiment suggests that the toxic property of the water was removed by some type of chemical exchange that took place at the surface of the aerated mud. A qualitative chemical test for rotenone made on the bottom water of Lost Lake, using the procedure outlined by Saila (MS.), was negative. Histological examination of the gill filaments of a fish that had died in this water (made by Dr. L. N. Allison, Fish Pathologist, Michigan Department of Conservation) showed no sign of the type of damage to the gill epithelium that is characteristic of fish killed with rotenone (Danneel, 1933). This finding was further evidence that the toxic chemical was a substance quite different from rotenone in physiological action.

Of seven lakes that have been treated with emulsifiable rotenone, at least four have remained toxic one month or longer. Section 4 Lake, Otsego County, was toxic for at least nine months after treatment. Irwin Lake, Alger County, retained its toxicity for at least eight months. The other two lakes were toxic in the fall for about one month after treatment but were suitable for fish the following spring. One lake (Weber Lake, Cheboygan County) in which powdered derris was used, apparently remained poisonous for at least two months. It was planted with trout approximately two months after treatment, and at that time there was no indication that the water was still toxic. About a month later, however, large numbers of dead trout appeared on the shores. Subsequent nettings indicated that all of this planting had died. In this lake, as in Lost and North Twin lakes where the treatment was with Fishtox, mortality apparently did not occur immediately after stocking but may have occurred coincidentally with water movement during the fall overturn.

Laboratory tests on toxicity of rotenone compounds to fish

Laboratory comparisons of the length of time bluegills survived in emulsifiable rotenone, cube root, and cube-Tide mixture indicated that in concentrations of 0.5 and 1.0 p.p.m. emulsifiable rotenone kills fish sooner than either of the powdered preparations (Table II). Similar conclusions resulted from field tests of powdered derris and emulsifiable rotenone made in Florida by J. F. Dequine (cited by Solman, 1950). All laboratory tests made with lower concentrations of rotenone (0.1 p.p.m.) gave highly variable results; some fish survived the duration of the experiments (96 hours) in all three preparations, while others died within 48 hours. Such high variability suggests that as the minimum lethal concentration of poison is approached, survival time is strongly influenced by individual differences. A comparison of length of survival in the three lake

TABLE II

TIME IN HOURS AND MINUTES SURVIVED BY BLUEGILLS, *LEPOMIS MACROCHIRUS*, IN VARIOUS ROTENONE PREPARATIONS

Water source	Methyl-orange alkalinity, p.p.m.	Color, p.p.m.	pH range	Mean temp., °F.	Control	Emulsifiable rotenone		Cubé root		Cubé root and Tide	
						1.0 p.p.m.	0.5 p.p.m.	1.0 p.p.m.	0.5 p.p.m.	1.0 p.p.m.	0.5 p.p.m.
Whitmore Lake Washtenaw County	108	less than 10	8.0-8.2	74 64	72:00 * 72:00 *	0:30 0:50	0:40 1:10	1:10 1:35	1:45 2:10	1:30 1:35	1:15 3:10
Spruce Lake Washtenaw County	154	107	...	75 65	96:00 96:00	0:20 0:30	0:25 0:30	0:35 1:15	1:40 2:50	0:55 Not tested	1:30 Not tested
Weber Lake Cheboygan County	4	less than 10	5.9-6.1	75 65	96:00 96:00	Not tested Not tested	1:00 2:45	Not tested Not tested	1:00 3:30	Not tested Not tested	3:30 3:30

* Test terminated after 72 hours.

waters tested (Table II) suggests that fish survived longer in water of low alkalinity (Weber Lake) than in water of high alkalinity. These data, however, fail to indicate any relationship between water color and survival of fish.

Samples of Whitmore Lake water containing 1.0 p.p.m. of emulsifiable rotenone, cube root, and cube-Tide mixture were stored in the laboratory for 30 days and were then tested with bluegills as in the experiments just cited. None of these samples was toxic after storage, indicating that all three preparations decompose rapidly at room temperature.

Toxicity of rotenone compounds to invertebrates in lakes

Numerous field studies (Smith, 1941; Brown and Ball, 1943; Hooper, 1951) and laboratory tests (Leonard, 1939; Hamilton, 1941) have been made on the effect of powdered derris upon plankton and bottom fauna invertebrates. Most of these studies have indicated that powdered rotenone compounds in the range of concentration ordinarily used in fish eradication (less than 1.0 p.p.m.) seriously affect only the planktonic crustacea. Repopulation by crustaceans ordinarily is rapid, and the appearance of Daphnia following poisoning has been used as a sign that the lake is suitable for restocking (Hemphill, 1954).

The most serious reductions in numbers of bottom invertebrates reported for Michigan waters due to the use of fish poisons occurred in six lakes of the Pigeon River Trout Research Area treated with Fishtox and emulsifiable rotenone in September of 1950 (Table III).

TABLE III

AVERAGE NUMBER OF BOTTOM FAUNA ORGANISMS PER SQUARE FOOT IN LAKES OF THE PIGEON RIVER TROUT RESEARCH AREA, BEFORE (1950) AND AFTER (1951) TREATMENT WITH FISH POISONS

(Data furnished by Dr. H. A. Tanner, Colorado Cooperative Wildlife Research Unit, Fort Collins, Colorado)

Lake	Treatment	Number of organisms per square foot	
		June 1950	June 1951
South Twin	Fishtox	153.7	6.8
Section 4	Emulsifiable rotenone	106.9	2.8
Lost	Fishtox	38.6	10.2
West Lost	Fishtox	34.3	2.2
Hemlock	Fishtox	20.0	5.5
North Twin	Fishtox	22.4	1.2

Tanner (1952) studied the influence of fertilizer upon the production of bottom animals in 1948 and 1950, and also followed changes in the bottom fauna following poisoning in 1950. The data supplied by Tanner (Table III) show that a drastic reduction of bottom fauna organisms took place between 1950 and 1951. Since this reduction occurred in the unfertilized lakes (North and South Twin) as well as in the fertilized lakes (Lost, West Lost, Hemlock, and Section 4), there is no evidence that the observed changes resulted from discontinuing fertilization. Tanner reports (personal communication) that destruction of populations of crayfish, scuds, mayflies, dragonflies, and midges was complete in the five lakes treated with Fishtox. Crayfish, scuds, and dragonflies survived in the lake (Section 4) treated with emulsifiable rotenone, although their numbers were greatly reduced. Such mass destruction of bottom-dwelling invertebrates appears to be unique in records on lake poisoning.

Because the preceding experience indicated that high concentrations of emulsifiable rotenone and Fishtox could be rather destructive to bottom invertebrates, further studies seemed desirable to determine whether lower concentrations of emulsifiable rotenone would also deplete populations of these animals. Consequently a field investigation was made on Irwin Lake, T. 44 N., R. 19 W., Sec. 12, Alger County.

This lake has a surface area of 10 acres. It has a maximum depth of 36 feet and a mean depth of 14 feet. The 5-foot depth contour is close to the boggy shoreline. The bottom soil near shore, and extending out to depths of from 5 to 10 feet, is a detritus mixture composed chiefly of woody plant fibers. The soil in deeper places is an ooze that is commonly classed as pulpy peat.

The water of this lake has sometimes been colored a faint brown, while at other times it has appeared colorless. Methyl orange alkalinity values range from 5 to 10 p.p.m., and the pH is about 5.2. Dissolved oxygen has been found well down into the cold-water strata in summer, so the lake is considered suitable for trout.

The lake supports very few plants other than a moss that grows in fair abundance on the bottom. This moss has been identified as *Dychelyma* sp. by Dr. H. T. Darlington, Professor Emeritus, Michigan State College.

Although brook trout had been stocked here the spring preceding the treatment with rotenone, the yellow perch (*Perca flavescens*) was the only species of fish that the poisoning revealed. The preceding winter three men who fished for two hours on Irwin Lake caught 200 perch that ranged from 5 to 12 inches in length. A 125-foot gill net set over night (September 11-12, 1951) took 18 perch that ranged from 7.6 to 9.5 inches. Examination of scales from these fish showed that they had grown at the average rate for Michigan waters.

Just before treatment with poison, a series of 34 bottom samples was obtained with an Ekman dredge on six transects that were established on the lake. The transects were laid out so as to distribute sampling effort rather uniformly. The lake was treated with a 0.55 p.p.m. concentration of emulsifiable rotenone on September

12, 1951 when the surface water temperature was 66° F. Two men applied the poison in three hours time.

Yellow perch surfaced in distress shortly after treatment began. Despite previous indications of a sizeable population, relatively few dead perch appeared on the surface at any time following the poisoning. Presumably the great majority of the fish settled to the bottom and never floated to the surface. The gill net previously used was reset in its former location but failed to catch anything in 67 hours, so the kill was assumed to have been complete.

During September 14-16 and on October 17, 1951, bottom samples were again collected at the locations previously established. On October 17 the toxicity of the water was tested by immersing brook trout in minnow pail liners in the lake, one lot of three fish just beneath the surface near shore and another lot of three fish in deeper water. After three hours all the trout except one in the container near shore were dead, and this one was nearly dead. All the fish had shown distress after one hour. Dead phantom midge (Chaoborus) larvae had been seen on the surface in considerable numbers the day a after poisoning. On October 17 there also were many of these larvae that had washed up to the shoreline.

The fourth series of bottom samples was collected from Irvin Lake on May 14, 1952, and a test for toxicity was repeated. Four rainbow trout (Salmo gairdneri) were suspended in a minnow pail liner at 18 feet (with sufficient oxygen assured) where the lake was 23 feet deep; another container holding four rainbow trout was placed about one foot below the surface at the shoreline. At the end of 21 hours all the fish near shore were still alive, as were those at 18 feet after 16 hours. After 46 hours three of the four trout in the shoreline container were dead and all were dead after 41 hours in the container set at 18 feet. A control lot of trout that had been placed in nearby Indian River survived throughout the duration of the test.

The last group of 34 bottom samples was taken during October 29 and 30, 1952. The lake had been planted with 850 brook trout (that averaged 6.8 inches in length) on October 7 after test fish introduced by hatchery personnel had survived. Another test was made during the time of the bottom sampling, on October 29 and 30. Brook trout were placed in the shallows and also in a deeper part of the lake. All of the fish (four in each container) were alive after 28-1/2 hours, at which time the test was terminated.

As for the effect of the rotenone treatment on bottom organisms in Irwin Lake, there was no indication of complete destruction of any of the various groups that appeared in the samples. Some kinds appeared so sporadically in dredge hauls that it was difficult to determine whether their absence in a particular set of samples indicated that they were not present at the time of sampling, or were merely missed in sampling (Table IV). Only four groups of animals were present in sufficient numbers to enable statistical analysis of sampling variation (Table V). All of these were aquatic Diptera. Confidence limits at the 95 per cent level were calculated for the mean number of each of these groups present during the various collecting periods. When the number of organisms collected was large (at least 25), the inherent skewness of the distribution in the number of organisms per sample was disregarded and a normal approximation was used to calculate confidence limits. When the total number of organisms was small (i.e., less than 25), confidence limits for the Poisson distribution were used. The wide confidence limits obtained clearly show the high variability obtained in sampling (Table V). Since limits overlap broadly for Tendepes tuxis, Tanytarsus jucundus, and members of the Pelopiinae, the differences between means on various collecting dates are not significant. Only for the phantom midge (Chaoborus sp.) is there clear evidence of population changes between sampling dates. Between September 14-16 and October 17, 1951, a large part of the population disappeared from the lake. The numerous dead larvae observed shortly after the lake was treated, and also about a month thereafter, indicated that this decrease in numbers was due to poison rather than fall emergence of the insects. Recovery of the Chaoborus population was indicated by a significant increase in numbers by October 29, 1952. These data and observations point out once again that Chaoborus is more vulnerable to rotenone than are other aquatic Diptera. Extensive mortality of this midge has also been noted when powdered rotenone compounds were used (Meehean, 1942; Brown and Ball, 1943). This vulnerability may well be related to the fact that the larvae are both limnetic and benthic in their habits.

TABLE IV

AVERAGE NUMBER OF INVERTEBRATE ORGANISMS PER SQUARE FOOT BY DEPTH

RANGES IN IRWIN LAKE BEFORE AND AFTER TREATMENT WITH ROTENONE

(Lake treated on September 12, 1951)

Organism	8-13 feet (11 Ekman samples each period)					14-22 feet (12 Ekman samples each period)					23-35 feet (11 Ekman samples each period)				
	Sept. 9-11 1951	Sept. 14-16 1951	Oct. 17 1951	May 14 1952	Oct. 29,30 1952	Sept. 9-11 1951	Sept. 14-16 1951	Oct. 17 1951	May 14 1952	Oct. 29,30 1952	Sept. 9-11 1951	Sept. 14-16 1951	Oct. 17 1951	May 14 1952	Oct. 29,30 1952
Chaoborus sp.	6.2	4.0	4.4	2.2	1.1	157.7	103.7	18.0	3.0	51.7	49.4	35.3	5.8	2.5	61.1
Tendipes tuxis	12.4	15.3	4.0	1.8	1.4	4.7	13.7	14.0	2.0	2.0	2.5	2.2	0.7	0.4	...
Tendipes plumosus	...	...	...	...	...	...	45.0	0.3	...	...	...	...	...	...	...
Tanytarsus jucundus	13.8	13.4	16.4	13.4	1.4	...	0.3	...	0.3	...	...	...	...	...	...
Pelopiinae	21.1	9.1	24.4	14.9	24.7	2.0	0.7	6.3	3.0	1.3	2.2	...	...	0.4	...
Heleidae	0.7	0.7	...	0.4	0.4	...	...	...	...	...	...	...	...	...	...
Trichoptera	1.4	1.8	...	...	...	...	...	3.3	...	...	...	...	...	...	...
Zygoptera	...	...	...	...	...	0.7	...	...	...	...	0.4	...	...	...	0.4
Libellulidae	0.7	...	0.7	...	0.7	...	...	0.3	...	...	...	...	...	...	...
Ephemeroptera	...	...	...	...	...	...	0.3	...	0.3	...	...	...	...	0.4	...
Coleoptera	...	...	...	...	...	...	...	0.3	...	...	...	...	...	...	...
Corixidae	0.4	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Sialis	0.4	...	0.4	...	0.7	...	...	...	...	...	...	...	...	...	...
Naididae	...	...	...	...	0.4	0.3	1.7	...	1.7	2.7	...	...	...	...	...
Lumbriculidae	0.4	...	...	...	...	...	0.7	...	...	...	...	...	...	...	...
Hydracarina	...	...	...	...	...	0.7	1.0	...	...	...	...	...	...	...	...
Hyalella	...	...	...	...	...	...	...	...	...	...	...	...	...	0.4	...

TABLE V

COMPARISON OF POPULATIONS OF CHAOBORUS sp. AND MIDGES OF IRWIN LAKE, ALGER COUNTY, BEFORE AND AFTER TREATMENT WITH EMULSIFIABLE ROTENONE (SEPTEMBER 12, 1951). MEAN NUMBER OF ANIMALS PER SQUARE FOOT AND 95 PERCENT CONFIDENCE LIMITS OF MEANS ARE GIVEN FOR VARIOUS DATES AND DEPTHS

Date	*Chaoborus* sp. 14-22 Feet (12 samples)		*Tendipes tuxis* 8-22 Feet (23 samples)		*Tanytarsus Jucundus* 8-13 Feet (11 samples)		Pelopiinae 8-13 Feet (11 samples)	
	Mean	Confidence limits	Mean	Confidence limits	Mean	Confidence limits	Mean	Confidence limits
Sept. 9-11, 1951	157.7	39.8 [illegible]75.5	8.4	2.3 14.4	13.8	0.0 38.0	21.1	0.6 41.6
Sept. 14-16, 1951	103.7	47.8 159.6	14.4	4.2 24.6	13.4	0.0 43.4	9.1	0.0 23.3
Oct. 17, 1951	18.0	7.2 28.8	9.2	2.6 15.8	16.4	0.0 51.0	24.4	4.1 44.6
May 14, 1952	3.0	0.6 * 8.8	1.9	0.2 * 7.1	13.4	0.0 37.5	15.0	3.7 26.1
Oct. 29, 30, 1952	51.7	19.7 83.6	1.7	0.2 * 6.7	1.5	0.1 * 6.3	24.7	5.0 44.4

* 95 percent confidence limits for Poisson frequency distribution used. For explanation, see text.

Laboratory tests on toxicity to invertebrates

All invertebrates except Daphnia and midge larvae survived 96-hour tests in emulsifiable rotenone, powdered cube, and Tide. In some tests there was high mortality of Daphnia and Tendipes in both experimental and control containers. These animals were particularly difficult to maintain in the soft water from Weber Lake and the highly colored bog water from Spruce Lake. Survival of Tendipes decorus was increased by providing detritus for case building. Table VI gives results obtained with this species in a concentration of 1.0 p.p.m. for each of the three preparations tested. A test of independence of the data of Table VI gives the following Chi square values:

Control vs. all treatments	26.64
Emulsifiable rotenone vs. cube	1.13
Emulsifiable rotenone vs. cube-Tide mixture	0.794
Cube vs. cube-Tide mixture	0.407

With 7 degrees of freedom, $X^2 90 = 12.02$. This there is no reason to suspect differences in survival rate between pairs of treatments greater than that to be expected by chance. However, the Chi square obtained by testing all treatments against the control is significant at the 95.5 per cent level, which indicates that all three preparations are toxic to midge larvae at this concentration.

Discussion

It is surprising that so many Michigan lakes treated with emulsifiable rotenone and Fishtox remained toxic for long periods. Most reports on the use of these products in other states and Canada have

TABLE VI

NUMBER OF TENDIPES DECORUS SURVIVING TREATMENT WITH VARIOUS ROTENONE PREPARATIONS

Time in hours	Control	Liquid Noxfish, 1.0 p.p.m.	Powdered cube root, 1.0 p.p.m. and Tide 0.05 p.p.m.	Powdered cube root, 1.0 p.p.m.
0	20	20	11	20
2	20	20	11	20
5	20	20	11	20
16	20	19	9	17
26	20	17	8	14
32	20	17	8	14
44	18	6	5	8
96	15	1	0	2

been favorable on length of time required for detoxification (Solman, 1950; Smith, 1950). It has been reported that Fishtox dissipates itself within 30 days. The unfavorable reports on the use of this product have been that even when used at high concentrations (up to 2.0 p.p.m.) it did not assure a complete kill (Krumholz, 1950; Smith, 1950, quoting Alderdice, 1949, and Anthony, 1949, and Smith, 1949). The fact that the water of Lost Lake was still highly toxic to fish after 33 months, even though the qualitative test for rotenone was negative, suggests that special dispersing agents acting alone or synergistically rather than rotenone were responsible for extended toxicity. Other factors possibly responsible for the persistent toxicity of the Pigeon River lakes are: (1) the high concentration of poison used (although higher concentrations that have been employed elsewhere have not given such unfavorable results), and (2) certain unusual morphometric characteristics. All of these lakes are deep and have large volume in relation to their surface area. This condition tends to minimize water circulation in the basin so that there is a proportionately large volume of stagnant water during summer stratification. Also, the ratio of water volume to mud surface is high in such lakes. If dissipation of toxic substances depends upon exchange of materials between mud and water, which apparently was true in the case of Lost Lake, then these lakes would be expected to remain toxic longer than those having a high ratio of mud surface to water and having a more complete circulation of water in the basin.

The 11 Michigan lakes that have remained toxic longer than one month have an alkalinity range of from 3.0 to 198 p.p.m. Such a broad range suggests that water hardness cannot be used to predict the time necessary for detoxification. Comparison of tests run in very soft water of Weber Lake with tests in which water from Whitmore and Spruce lakes was used, indicated to the contrary that survival of fish may be greater in soft water than in hard water when emulsifiable rotenone is used. Considering only lakes treated with emulsifiable rotenone, one lake of the four that remained toxic longer than one month has a high alkalinity (Section 4 Lake). A second lake, Holland Lake, has a low alkalinity (18-23 p.p.m.). The other two lakes have been of very low alkalinity (less than 10 p.p.m.). Of the lakes treated with emulsifiable rotenone in which the toxicity has not persisted, one has a high alkalinity (192 p.p.m.), two are of moderate alkalinity (32-45 p.p.m.), and one is of low alkalinity (11 p.p.m.). It is perhaps significant that only one of these three lakes (Lake Nineteen) is landlocked, the others having outlets. On the other hand, only one of the lakes with persistent toxicity (Tank Lake) has an outlet, and it is intermittent. Unquestionably the presence or absence of inflowing and outflowing streams is important in determining how long a lake will retain toxicity. Since the landlocked lakes of a given area ordinarily are lower in alkalinity than drainage lakes (Juday, Birge, and Meloche, 1935), perhaps reported persistent toxicities in lakes of low alkalinity are as much due to the lack of water movement through the basin as to any inherent characteristic of the water.

Only two of the lakes treated with emulsifiable rotenone retained their toxicity longer than eight months. Most of these treated in late summer were suited for stocking the succeeding spring. Retention of toxicity over winter may even be an advantage in that it insures a complete kill of fish since the water is thoroughly mixed at the time of the fall overturn. Although apparently a high mortality of invertebrates occurred in Section 4 Lake where emulsifiable rotenone at a concentration of 1.7 p.p.m. was used, there was no such mass die-off of fish-food organisms in Irvin Lake with 0.55 p.p.m. The only bottom animal in Irvin Lake that was seriously affected was the free-swimming phantom midge which is also killed by powdered rotenone compounds. Furthermore, laboratory tests gave no indication that emulsifiable rotenone was more toxic than powdered cube to the more important groups of bottom organisms at a concentration of 1 p.p.m.

Although emulsifiable rotenone apparently can be used effectively without its causing major biological changes, every effort should be made to avoid such disasterous results as were obtained with Fishtox in the Pigeon River Area lakes. Manufacturers cannot be relied upon to anticipate the wide variety of physical and chemical conditions in lakes that might influence the toxicity of their products. Fishery workers should be cautioned against the use of products for which the manufacturer does not provide a complete chemical analysis so that effects of all ingredients can be tested on fish and fish-food organisms.

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Summary

1. Of 73 Michigan lakes treated with various fish poisons, 11 remained toxic to fish for over one month.

2. Lakes in which detoxification has been slow have chiefly been those poisoned with either an emulsifiable form of rotenone or a trade product, containing rotenone, called Fishtox. Toxicity has persisted for over one month in only one of 56 lakes treated with powdered rotenone compounds.

3. Five lakes that were treated with Fishtox remained toxic for over 18 months, and apparently caused far more extensive mortality of bottom-dwelling invertebrates than occurs when powdered forms of rotenone are used.

4. Lakes treated with emulsifiable rotenones have been toxic for as long as 9 months. In one lake in which a high concentration (1.7 p.p.m.) of this poison was used, there apparently was a great loss of bottom invertebrates.

5. A study of the bottom fauna of Irvin Lake, a lake that was given a 0.55 p.p.m. application of emulsifiable rotenone, showed a significant die-off of only one form (Chaoborus).

6. In laboratory tests, the emulsifiable product killed bluegills in less time than either powdered cube root or a mixture of cube and the detergent Tide.

7. Bluegills survived longer in water from a lake of low alkalinity treated with emulsifiable rotenone than in water from lakes of high alkalinity.

8. A variety of aquatic invertebrates survived laboratory tests in which a concentration of 1 p.p.m. was used for each the emulsified product, cube, and a mixture of cube and Tide. The midge Tendipes decorus was the only bottom invertebrate tested that was killed. There was no apparent difference in effect of the three compounds to this species.

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Appendix

Michigan lakes treated with rotenone from 1942 through 1953*/

Lake**/	County	Town, Range, & Section	Years treated
Irwin	Alger	44N, 19W, 12	1951
Hike	Alger	44,45N, 19W, 2,3,35	1952
Rock	Alger	45N, 19W, 34,35	1952
Trueman (Hemlock)	Alger	45N, 19W, 10	1948
Bellaire Pond	Antrim	30N, 7W, 20	1949
Green	Antrim	29N, 7W, 26,27	1948
Roland	Baraga	51N, 31W, 12,13	1953
Hemlock	Cheboygan	33N, 1W, 34	1950
Weber	Cheboygan	34N, 3W, 31	1948
Dukes	Chippewa	45N, 1W, 28	1947
O'Niel	Dickinson	44N, 28W, 7	1953
Hilltop	Gogebic	44N, 39W, 6	1949
Sand	Grand Traverse	27N, 9W, 23	1953
Clear (Kratt)	Houghton	51N, 36W, 3,4,9,10	1952
Deadman	Iron	41N, 32W, 5,8	1953
Portage Creek Pond	Jackson	2S, 2E, 8	1950, 1953
Lost	Luce	47N, 12W, 21,22	1948
Musgrove	Luce	47N, 12W, 22	1948
Peanut	Luce	47N, 11W, 30	1948
Tank	Luce	49N, 11,12W, 31,36	1950
Young	Luce	47N, 11W, 29	1948
Blair (E. Voelker) Pond	Marquette	46N, 27W, 22	1946, 1951
Island	Marquette	45N, 30W, 14	1948
Perch	Marquette	45,46N, 30W, 4,33	1949
Rock	Marquette	47N, 27W, 8	1952
Section 14	Marquette	45N, 30W, 14	1952
Sporley	Marquette	45,46N, 24W, 5,31,32	1947
Sucker	Montmorency	31N, 4E, 29	1948
Sand	Newaygo	11N, 13W, 19	1949
Nero	Ogemaw	24N, 3E, 5,6	1947
Center	Osceola	20N, 9W, 21,22	1947
Lost	Otsego	32N, 1W, 2,3	1950
North Twin	Otsego	32N, 1W, 10	1948, 1950
West Lost	Otsego	32N, 1W, 3	1948, 1950
Bear Den	Presque Isle	33N, 2E, 32	1948, 1950
Ashford	Schoolcraft	43N, 16W, 3,10	1948
Dutch Fred	Schoolcraft	47N, 13W, 18	1949
Nineteen (Bear)	Schoolcraft	44N, 18W, 27,34	1953
Sylvan Ponds (3)	Washtenaw	2S, 3E, 6	1952

*/This list does not include the several lakes that were treated prior to 1943 and that were retreated since then. For a list of the lakes poisoned up to 1943, see Ball's publication of 1948, "A Summary of Experiments in Michigan Lakes on the Elimination of Fish Populations with Rotenone, 1934-1942".

**/See Table I for the lakes treated with rotenone-bearing substances other than the powdered form; Weber Lake (Table I), Blair Pond and North Twin, West Lost, and Bear Den lakes (first treatment), and all the other lakes were treated with powdered rotenone.