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SUMMARY OF EXPERIMENTAL LAKE TREATMENTS WITH TOXAPHENE 1954-1958

By

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Toxaphene (chlorinated camphene) has been used as a fish toxicant in Michigan and other states and provinces of the United States and Canada for several years. Reports and observations on its use permit an appraisal of its value as a fish management tool. This report aims to (1) summarize the latest results of experimental treatments, (2) define uses appropriate for fishery management work in Michigan, and (3) point out areas in which further research and observations are badly needed.

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Desirable characteristics of a toxicant that would supplement or replace rotenone are: (1) a slower breakdown rate in fresh water, which would allow the toxicant to mix thoroughly throughout the basin by natural water movements; and (2) lower cost, making population control economically feasible on larger bodies of water.

Use of the newer insecticides on field crops and subsequent drainage into ponds and streams led to the discovery that some of these substances were highly toxic to fish (Lawrence, 1950; Young and Nicholson, 1951). Toxicity data for fish for most of the new organic insecticides are now available (Doudoroff, Katz, and Tarzwell, 1953; Henderson and Pickering, 1958). Compounds of the organic phosphate type are less toxic to fish than the chlorinated hydrocarbons (Henderson and Pickering, 1958) and have been rejected as fish poisons (Hayes, 1955). Of the chlorinated compounds, toxaphene (chlorinated camphene) has received the most attention. The chemical has been used for approximately ten years. It was an ingredient of a fish toxicant sold under the name of "Fish-Tox" (Tanner and Hayes, 1955). More recently, forms of the toxaphene sold for agricultural purposes have also been used as fish toxicants.

Toxaphene has the greatest toxicity to fish of any of the chlorinated hydrocarbons (except endrin) now marketed as insecticides (Henderson, Pickering and Tarzwell, 1959). These compounds are also highly toxic to aquatic invertebrates. Although extremely toxic to fish, toxaphene has a somewhat lower acute toxicity to humans than endrin, dieldrin and aldrin, and apparently has a lower chronic toxicity than other chlorinated hydrocarbons and rotenone because it is broken down by the liver (Lehman, 1948).

Treatment of lakes with toxaphene

The usual practice in treating lakes is to dilute a toxaphene emulsion 5- to 10-fold with water. The diluted chemical is then poured on the surface of the lake in the wake of an outboard motor or is pumped or sprayed on the surface or underwater. For most lakes, elaborate equipment for mixing and spraying is not required, since natural water movements can be depended upon to distribute the mixture throughout the basin.

At low temperatures and near the toxicity threshold, action of toxaphene upon fish is very slow. At temperatures below 50° F., a week to ten days may elapse before fish show distress symptoms. The die-off of fish may then continue for three weeks or more. At 70° F., most of the fish will die within a ten-day period. Among distressed fish, swimming movements are erratic and uncontrolled. Often fish will swim to shore and strand themselves. Erratic respiratory movements follow, and death is probably due to respiratory failure.

The concentrations of toxaphene used in treating various lakes (Table 1) have varied from 2 to 100 p.p.b. (parts per billion). Concentrations between 2 and 7 p.p.b. appear to affect only the small fish (Fukano and Hooper, 1958). At concentrations greater than 7 p.p.b., complete kills can be expected in the deeper lakes (Stringer and McMynn, 1958). In Michigan, partial kills have been noted in shallow lakes at concentrations as high as 15 p.p.b. Failures at concentrations as high as 50 p.p.b. have been reported in other areas (R. F. Harris, Wisconsin Department of Conservation, personal communication; Tanner and Hayes, 1955).

Complete poisoning experiments

Trout lakes.--The early work with fish toxicants in Michigan and in other northern states concerned the rehabilitation of lakes for trout. A fish toxicant containing toxaphene (Fish-Tox) was used in lakes at the Pigeon River Trout Research Station early in 1949. Certain of these lakes (Lost and South Twin) retained their toxicity for 3 to 4 years.

Since 1954 nine trout lakes have been treated with toxaphene (Table 2). Six of these are lakes of relatively great mean depth (over 20 feet). Two lakes (Horseshoe and Green) have main basins which are quite deep but have shallow secondary basins; thus the mean depth is reduced. One treatment was made on a series of shallow, spring-fed ponds (Sylvan Pond). Sporley, Weber and Alice are soft-water lakes, while the remaining waters treated are of the hard-water type. Concentrations of toxaphene ranging from 7.5 p.p.b. to 100 p.p.b. were used. All treatments, except those of Squaw and Little Squaw lakes (7.5 and 10 p.p.b., respectively) gave complete fish kills. Many kinds of undesirable fish have been eliminated (Table 2). In Squaw and Little Squaw lakes (two lakes connected by a wide channel), minimal concentrations were used and large suckers and largemouth bass survived.

Toxicity seems to have been most persistent in the deeper lakes (Sporley, Weber, and Sand No. 1--Table 2) and least persistent in the shallow waters (Sylvan Pond, Horseshoe Lake). It now seems clear that a large excess (50-100 p.p.b.) of chemical was used in the early treatments, since subsequent treatments in the range of 10-25 p.p.b. have given complete eradication. However, one should note that a treatment with 100 p.p.b. at Horseshoe Lake, a shallow lake, did not give as long a toxic period as a much smaller dosage in deeper lakes (Sporley, Weber, Sand No. 1).

Table 1.--Lake treatments with toxaphene 1954-1958

Lakes treated with the commercial preparation, Fish-Tox, have not been included

Concentration range (p.p.b.)	Number of lakes	Location	Fish kill	Approximate duration of toxicity (months)	
				Range	Average
Nontrout lakes (mean depth less than 13 feet)					
2-7	6	Michigan	Partial	...	...
7-15	3	Michigan	Partial	...	...
	2	Michigan	Complete	2-5	3.5
16-25	7	Michigan	Complete	2-11	6.3
26-50	1	Michigan	Complete	...*	...*
51-100	4**	Michigan	Complete	2-11	8.0
	2	Iowa[1]	Complete	2-5	3.5
	1	Arizona[2]	Complete	...	<6
	1	Colorado[3]	Complete	...	7+
Trout lakes (mean depth greater than 13 feet)					
5-15	1	Michigan	Partial	...	...
	2	Michigan	Complete	...*	...*
	2	British Columbia[4]	Complete	...	9+
16-25	2	Michigan	Complete	12	12
26-50	2	Michigan	Complete	18-42*	...
	2	British Columbia[4]	Complete	...	9+
51-100	4	British Columbia[4]	Complete	...	9+

*Results incomplete, further tests required.
**Includes 2 shallow lakes subsequently planted with trout.
[1]Rose (1957, 1958). [2]Hemphill (1954).
[3]Tanner and Hayes (1955). [4]Stringer and McMynn (1958).

Since Sporley and Weber lakes are of approximately the same mean depth and were treated with the same concentration of chemical, it is difficult to explain the greater duration of toxicity at Sporley. Although the surface waters of the two lakes are transparent, the hypolimnetic water of Weber Lake is highly colored and develops a large oxygen deficit during the summer. Sporley Lake retains a high transparency throughout its depth and has a small hypolimnetic oxygen deficit. Another possible explanation is that Weber Lake was restocked with brook trout whereas recent toxicity tests on Sporley have been made with rainbow trout. Rainbow trout are now believed to be much more sensitive than brook trout to toxaphene, and the prolonged toxicity of Sporley may in part be a reflection of this difference in species susceptibility.

After approximately 27 months of toxicity, tests with large fish suggested that Sporley Lake had detoxified. Accordingly it was planted with rainbow trout in the fall of 1957. Since none of the fish of this planting were caught, it was believed that the lake had retained its toxicity. Additional testing in the summer of 1958 gave evidence that the toxicity had disappeared.

Table 2.--Trout lakes in Michigan treated with toxaphene, 1954-1958

Lake (County)	Date treated	Concentration of toxaphene (p.p.b.)	Fish present	Fish kill	Duration of toxicity (months) More than	Duration of toxicity (months) Less than
Sylvan Pond (Washtenaw)	7-8-55	100	Centrarchids Trout Mudminnow	Complete	1	2
Horseshoe (Alcona)	9-22-54	100	Centrarchids Yellow perch Northern pike	Complete	10	11
Sporley (Marquette)	8-17-55	50	Trout Cisco Suckers Yellow perch	Complete	39	?
Weber (Cheboygan)	10-22-55	50	Centrarchids Trout	Complete	12	18
Green (Antrim)	10-3-56	25	Carp Bullheads Centrarchids Trout	Complete	9	12
Sand No. 1 (Grand Traverse)	10-3-56	25	Centrarchids Trout	Complete	11	12
Little Squaw (Marquette)	4-29-58	10	Centrarchids Yellow perch Suckers Trout	Partial (?)	..	..
Alice	9-29-58	10	Trout Suckers Yellow perch	Complete (?)	?	12
Squaw (Marquette)	4-29-58	7.5	Centrarchids Yellow perch Suckers Trout	Partial	..	..

Non-trout lakes.--Complete poisoning was attempted on 12 warm-water lakes with average depths of less than 10 feet (Table 3). Most of these lakes are unstratified but some may develop a thermocline. Ten are hard-water lakes but two (McCarthy, Shelser) have soft water (Table 4). Concentrations of toxaphene from 10 to 100 p.p.b. were used. Complete eradication of fish resulted from all treatments at concentrations above 15 p.p.b. with the possible exception of the Lake Erie Marshes.

Table 3.--Twelve non-trout lakes in Michigan treated with toxaphene 1954-1958 (complete poisoning attempted)

Lake (County)	Date treated	Concentration of toxaphene (p.p.b.)	Fish present	Fish kill	Duration of toxicity (months) More than	Duration of toxicity (months) Less than
McCarthy (Lake)	8-4-54	100	Centrarchids Bullheads	Complete	9	10
Walton (Marquette)	10-18-55	100	Yellow perch Suckers	Complete	?	?
Lake Erie Marsh (Monroe)	1958	30	Carp Walleye	Uncertain	?	?
Shelser (Leelanau)	7-3-56	25	Centrarchids Bullheads	Complete	0	2
Spring (Ogemaw) (Second treatment)	7-10-58	25	Yellow perch Centrarchids Bullheads	Complete	..	..
Tyler (Jackson)	9-19-56	25	Centrarchids Bullheads Yellow perch	Complete	0	7
Dollar (Grand Traverse)	May 1957	20	Centrarchids Yellow perch Suckers	Complete	0	4
Sand No. 4 (Grand Traverse)	10-2-56	20	Centrarchids Yellow perch	Complete	10	11
Sand No. 5 (Grand Traverse)	10-2-56	20	Centrarchids Yellow perch	Complete	7	9
Sand No. 3 (Grand Traverse) (Second treatment)	4-17-57	20	Golden shiner	Complete	0	5
Devil's Wash Basin (Ogemaw)	Nov. 1957	15	Bullheads Mudminnow	Complete	0	..
Spring (Ogemaw) (First treatment)	6-9-58	15	Yellow perch Centrarchids Bullheads	Partial	..	..
Sand No. 2 (Grand Traverse)	10-1-56	10	Centrarchids Yellow perch	Complete	0	2
Sand No. 3 (Grand Traverse) (First treatment)	10-1-56	10	Centrarchids	Partial	..	..

Table 4.--Limnological features of Michigan lakes treated with toxaphene, 1954-1958

Lake	Area (acres)	Mean depth (feet)	Secchi disk reading (feet)	Methyl orange alkalinity (p.p.m.)	Condition of thermocline[1]	Submergent vegetation
Alice	45.1	22.0	17	18	P	None
Devil's Wash Basin	1.5	6.8	5	117	T	Abundant
Dixon	80.0	13.0	26	111	A	Sparse
Dollar	37.0	9.5	..	25	A	Abundant
Erie (Marsh)[2]	1,024.0	3.0	0.5-1.3	62	A	Sparse
Fish	18.0	13.0	9	39	P	Moderate
Gerry	28.0	11.0	15	47	P	Abundant
Green	30.0	13.0	22	122	P	Sparse
Horseshoe	12.3	7.7	10	82	P	Moderate
House	4.0	7.4	8	125	T	Common
Loon	17.0	6.7	5	100	A	Abundant
Little Squaw	39.0	16.0	..	...	P	Sparse
McCarthy	10.0	8.8	6	6	A	None
Roots	15.6	4.6	9	...	A	Sparse
Sand No. 1	14.2	22.0	20	75	P	Sparse
Sand No. 2	17.3	11.0	..	71	T	Sparse
Sand No. 3	14.9	5.7	13**	55	A	Sparse
Sand No. 4	11.3	9.1	14	85	T	Sparse
Sand No. 5	21.5	5.3	13**	...	A	Sparse
Shelser	10.6	9.3	..	3	...	Abundant
Sporley	76.0	22.0	11	19	P	Sparse
Spring	73.0	6.0	9	82	A	Abundant
Squaw	230.0	28.0	11	108	P	Sparse
Sylvan Pond	2.3	2.3	..	195	A	Moderate
Tyler	5.8	9.5	4	195	T	Abundant
Walton	15.0*	9.0*	..	...	...	Moderate
Weber	31.0	20.0	15	4	P	None

[1] P = Thermocline and hypolimnion present in summer.
T = Thermocline present in summer but little or no hypolimnion.
A = Thermocline absent, lake unstratified.

[2] Data supplied by Prof. P. I. Tack, Dept. Fish and Wildlife, Michigan State University.

* Area and volume estimated.

**Disk visible to the bottom.

Here carp may have re-entered the marshes from the main lake or may have survived in an untreated bay. Nearly all species survived the first treatment of Spring Lake at 15 p.p.b., but the second treatment at 25 p.p.b. killed all fish. At Sand Lake No. 3, a 10 p.p.b.-treatment left a few large golden shiners, and these were eliminated by a second application at 20 p.p.b.

It appears that the shallow lakes do not retain toxicity as long as the deep (trout) waters (Table 3). All of these (shallow) lakes detoxified in less than one year, even when concentrations as large as 100 p.p.b. were used. In these lakes, as in the trout lakes, toxicity appeared most persistent in the deeper and more transparent waters. Toxicity lasted longer in Sand No. 4, mean depth 9.1 feet, than in Sand No. 5, mean depth 5.3 feet (both lakes treated with 20 p.p.b.). In Sand Lake No. 2, mean depth 11.0 feet, complete kill was achieved at 10 p.p.b., while only a partial kill was obtained in Sand Lake No. 3, which has a mean depth of 5.7 feet. Thus both average depth and transparency must be taken into account in determining critical concentration level for a lake treatment.

Selective poisoning experiments

Selective poisoning of smaller fish was attempted in six lakes (Table 5). Concentrations, calculated only for the water volume of the epilimnion, ranged between 2 and 7 p.p.b.

At a concentration of 2 p.p.b. (Roots Lake), only young-of-the-year largemouth bass about 1 to 2 inches long were killed. Treatments at 5 p.p.b. resulted in selective kills, although the results were somewhat variable from lake to lake. At House Lake most of the fish less than 4 inches long and a few of the larger fish succumbed. In Fish Lake nearly all of the bluntnose minnows and small bluegills were killed, along with a fair number of 6- to 8-inch bluegills and a few 6- to 9-inch largemouth bass. Most of the fish killed in Loon Lake were 5 inches or shorter, although a few larger black crappies and bluegills were noted.

In Dixon Lake fish of a larger size were affected. Checks conducted 11 days after the treatment indicated a heavy kill of yellow perch up to 7 inches in length plus a surprising number of 10- to 17-inch white suckers and 18- to 24-inch walleyes. At that time largemouth bass, pumpkinseed, yellow perch, white suckers, northern pike and walleyes were caught in gill nets. In subsequent netting only 9 common shiners were taken. Two circumstances may have influenced the results on this lake. First, the lake level was considerably below that shown on the map, but volumes were calculated from the map with no adjustment for the lowered lake level. Second, Dixon Lake was more transparent than the other lakes treated at 5 p.p.b. If transparency increases the efficiency of toxaphene, as experiments to date indicate, then identical concentrations of the chemical might be expected to affect larger fish to a greater extent in a transparent lake than in a turbid lake.

At 7 p.p.b. (Gerry Lake), the kill was chiefly small green sunfish, pumpkinseeds and bluegills plus a few 2- to 5-inch yellow perch, 6- to 7-inch bluegills and a few rock bass in the 6- to 9-inch group.

The concentration of 5 p.p.b. seems to be in the proper range for selectively poisoning small, stunted fish. Obviously lake conditions make this level too high in some instances and too low in others. Further test treatments are needed to better relate limnological conditions with activity of the chemical, particularly in the range of 2 to 5 p.p.b.

Table 5.--Selective poisoning treatments with toxaphene on Michigan lakes, 1957-1958

Lake (County)	Date treated	Concentration of toxaphene (p.p.b.)	Fish present	Observed fish kill: Species	Size range (inches)	Abundance
Gerry (Benzie)	8-12-58	7	Bluegill	Bluegill	2-5	Many
			Pumpkinseed	Pumpkinseed	2-5	Many
			Green sunfish	Green sunfish	2-5	Many
			Yellow perch	Yellow perch	2-5	Few
			Rock bass	Rock bass	6-9	Few
			Smallmouth bass	Bluegill	6-7	Few
			Northern pike			
House (Gladwin)	7-25-57	5	Bluegill	Bluegill	1-4	Many
			Pumpkinseed	Pumpkinseed	1-4	Few
			Largemouth bass	Bluegill	5-6	Very few
			Rock bass			
			Yellow perch			
			Carp			
Dixon (Otsego)	8-14-58	5	Yellow perch	Yellow perch	1-5	Many
			Walleye	Yellow perch	6-7	Many
			White sucker	Walleye	18-24	Few
			Pumpkinseed	Rock bass	1-6	Very few
			Largemouth bass	Largemouth bass	1-2	Very few
			Rock bass	White sucker	1-2	Few
			Northern pike	White sucker	10-17	Many
			Bullheads			
Fish (Grand Traverse)	8-16-58	5	Bluegill	Bluegill	1-5	Many
			Largemouth bass	Bluegill	6-8	Many
			Yellow perch	Yellow perch	6-8	Very few
			Bluntnose minnow	Largemouth bass	6-9	Very few
				Bluntnose minnow	1-3	Many
Loon (Ogemaw)	8-29-58	5	Pumpkinseed	Pumpkinseed	2-3	Many
			Bullheads	Bluegill	3-4	Many
			Bluegill	Bluegill	4-7	Few
			Largemouth bass	Largemouth bass	2-3	Many
			Rock bass	Rock bass	2-3	Few
			Black crappie	Black crappie	6-9	Very few
Roots (Grand Traverse)	7-23-57	2	Bluegill	Largemouth bass	1-2	Few
			Largemouth bass			
			Carp			

Factors influencing toxicity of treated waters

The kill of fish achieved with a given dosage of toxaphene depends upon (1) concentration applied, (2) the rate of dispersion of the chemical through the water mass, (3) the rate of dissipation or breakdown of the chemical, and (4) the rate of flushing, or rate of water movement through the lake. The variability in results experienced in trials using identical concentrations (Table 1) are probably due to factors (2) and (3). Incomplete kills may result from poor dispersion of the chemical in weedy and protected bays and backwaters, or from rapid chemical breakdown so that the chemical loses its potency before penetrating all parts of the basin.

Factors influencing the breakdown of toxaphene in treated waters have been discussed by Hooper and Grzenda (1957). Toxicity is lost most rapidly in the presence of light, high temperature and high oxygen, and more rapidly in water with high alkalinity than in soft water. In the laboratory, detoxification of water appears to come from the micro-organisms attached to the sides of the containing vessel and to other substrates that may be introduced. Sterilization inhibits the detoxifying action of substrates. The slow disappearance of the chemical from lakes of great mean depth is perhaps due to the high ratio of water volume to area of bottom substrate. In a deep trout lake, several years may be required to bring enough water in contact with the bottom to detoxify the lake. Breakdown appears to be rapid in highly turbid lakes, and Rose (1958) has suggested that lakes may be detoxified by artificially creating turbid water. Very likely, turbid waters lose their toxicity through the action of micro-organisms suspended in the water or attached to non-living particulate matter.

Effect on aquatic invertebrates

Although there is an abundance of data on the toxicity of chlorinated hydrocarbons to terrestrial invertebrates, not much is known about the toxicity of these compounds to aquatic animals other than fish. Streams receiving run-off water containing toxaphene, DDT, BHC (benzene hexachloride), or aldrin lost most of their bottom fauna (Hooper and Hester, 1955). The 24-hour TL_m[1] of toxaphene for aquatic sow bugs (*Asellus*), scuds (*Gammarus*), *Daphnia* and mayflies (*Ephemera*) appears to be greater than that for fish (Hooper and Grzenda, 1957). This is substantiated by reports that bottom fauna and plankton re-appear in lakes that have been treated with toxaphene before the lakes can be stocked with fish (Tanner and Hayes, 1955; Hooper and Grzenda, 1957).

It is clear that a major portion of bottom fauna is eliminated when lakes are treated with a concentration of 100 p.p.b. of toxaphene. This dosage eliminated midges from a Colorado reservoir (Cushing and Olive, 1957), and with the decline in midges, the oligochaete population increased. These authors believed that their toxaphene treatment was more destructive to bottom fauna than would result from rotenone application. In two Michigan lakes treated with 100 p.p.b. of toxaphene, most of the invertebrates, except mollusks and oligochaetes, were killed. Following such reductions the bottom fauna re-appears promptly. Most

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[1] The median tolerance limit, designated as TL_m is that concentration of the substance at which 50 percent of the test animals used are able to survive for a specified period of time under the conditions of the experiment.

groups of invertebrates killed in an Alabama stream in 1950 had re-appeared by 1953 (Hooper and Hester, 1955). Both Michigan and Colorado lakes mentioned above were repopulated within 9 to 11 months, although the Michigan lakes had a reduced number of species.

At a concentration less than 100 p.p.b. of toxaphene, there is less convincing evidence of damage to bottom fauna. Rose (1958) noted large increases in midge populations in an Iowa lake following a dosage of 100 p.p.b. This build-up of midges presumably was due to release of the midge population from predation by bullheads. In Little Squaw Lake, a Michigan lake treated with a concentration of 10 p.p.b., the bottom fauna was nearly as abundant 14 days after application of toxaphene as before treatment (Table 6). The small decrease in numbers was due to the emergence of midges. Similar results were noted in treating a second Michigan lake (Sand Lake No. 2) at a concentration of 10 p.p.b. Stringer and McMynn (1958) found that midges were eliminated from lakes treated at 100 p.p.b. but survived in lakes treated with concentrations ranging between 10 and 70 p.p.b. Of the other invertebrates sampled by these authors, the only ones eliminated at concentrations of 10 p.p.b. were amphipods (*Gammarus* and *Hyalella*). The higher concentrations in earlier experiments (100 p.p.b.) must now be considered overdosages for most, if not all, lakes. Hence, it would appear that the effects of toxaphene upon the bottom fauna are minor when it is used in the proper concentration range.

Table 6.--Bottom fauna at a littoral station in Little Squaw Lake, Marquette County, Michigan, before and after treatment with toxaphene at 10 parts per billion

(4 Ekman samples in each collection)

Type of organism	Number per one-quarter square foot			
	Before treatment (April 29, 1958)		After treatment (May 13, 1958)	
	Mean	Standard error	Mean	Standard error
Glyptotendipes sp.	45	5.5	35	3.4
Other Diptera	6.7	1.9	6.5	1.5
Ephemeroptera	...	...	...*	...*
Trichoptera	...	...	...*	...*
Total weight (mg. per 1/4 $ft.^2$)	192	30	128	10

*Less than 1 per 1/4 $ft.^2$

Health hazards in the use of chlorinated insecticides

Judging from existing toxicity data, it does not appear that important hazards will arise from the addition of toxaphene (in a quantity required for fish eradication) to waters not used as drinking water supplies. Even overdosages would not appear to be dangerous. Hemphill (1954) calculated that a cow would have to drink

18,000 gallons of water (100 p.p.b. of toxaphene) per day to receive a toxic dose. Since in most cases treatments will require less than 25 p.p.b., it would seem that there is little chance that man would ever receive an acute dose (60 mg. per kg.). Toxicity data suggest that, as it is used in lake treatments, toxaphene is less hazardous than rotenone. Toxicity of toxaphene to fish (96-hour TL_m, Henderson and Pickering, 1958) is 4 p.p.b. as compared to 11 p.p.b. for rotenone. Thus toxaphene is nearly three times as toxic as rotenone and can be used in concentrations one-third as great. Comparable Oral LD_{50} values for rats in mg. per kg. body weight are 90 for toxaphene as compared to 132 for rotenone (Henderson and Pickering, 1958). Thus it would appear that rotenone is about 50 percent less toxic to mammals than toxaphene, but must be used in concentrations three times as great to kill fish.

Henderson, Pickering and Tarzwell (1959) indicate that in hard water endrin is about four times more toxic to fathead minnows than is toxaphene, but endrin possesses an acute toxicity to mammals five times greater than toxaphene. This would indicate that toxaphene is somewhat safer than endrin from the standpoint of danger to humans.

A clearance from health authorities should be obtained before drinking water supplies are treated with any of the chlorinated hydrocarbons. Also, care should be exercised in handling concentrated material, since only a small quantity of undiluted chemical is required for a toxic dose to man (approximately 4 grams of toxaphene). Empty drums and containers should be thoroughly rinsed at the completion of a job. It is well to exclude bathers from a treatment area until the chemical has had opportunity to mix with the lake water.

Fish killed by toxaphene have been eaten by the authors and other members of the Institute for Fisheries Research staff and have not been found to be off flavor. The amount of chemical absorbed by the fish at the time of death must be very small and there is little chance of ingesting a dangerous dosage from the fish flesh.

Suggested usages of toxaphene and rotenone

These two toxicants have different properties and will, to a certain extent, supplement one another as toxicants in the management of fresh-water fisheries. The contrasting characteristics of toxaphene and rotenone are outlined in Table 7. Since toxaphene acts slowly, it is hardly suitable for situations wherein a quick kill or quick immobilization of the fish is required. Rotenone and cresol would be much more effective in such situations. Hence toxaphene would have little use in stream treatments unless provisions could be made for bleeding the chemical into the current for several days. This might be accomplished by treating a headwater lake but usually toxaphene will be difficult to use in such situations. Rotenone seldom produces complete kills in shallow, warm-water lakes containing an abundance of vegetation, because it breaks down too rapidly (Clemens and Martin, 1953). Breakdown of toxaphene, on the other hand, is slow and should prove highly effective on such waters. Although toxaphene would be preferred for treatment of large lakes because of its low cost, it cannot as yet be recommended for deep, oligotrophic lakes because of its persistent toxicity. Further study is needed to provide ways of stimulating its breakdown in such water. With treatments at a low concentration, around 10 p.p.b., fertilization and the production of plankton might prove effective for detoxification.

Table 7.--Comparison of properties of rotenone and toxaphene emulsions when used for fish eradication in Michigan waters

	Toxicity range (p.p.b. active ingredient)	Contact time (70° F.)	Detoxification time (70° F.)	Situations favorable	Situations unfavorable
Rotenone emulsion	25-50 (500-1000)*	Moderate (1-3 hours)	Low, variable (24 hours +)	Streams, small lakes, partial poisoning	Where wind dispersion required
Toxaphene emulsion	10-50 (13-67)*	High (1-3 days)	High, variable (3 weeks +)	Where wind dispersion required, large lakes	Streams, partial poisoning

* Concentration of the emulsified chemical. (e.g. 25 p.p.b. in terms of active ingredient is equivalent to 500 p.p.b. or 0.5 p.p.m. of an emulsion containing 5% rotenone)

Season for lake treatments with toxaphene

Dosage required to kill fish increases as the temperature decreases (Hooper and Grzenda, 1957). Also the time the fish must be exposed to gain a lethal dose of toxaphene increases as temperature decreases. With temperature just above freezing and at concentration of 15 p.p.b., fish mortality extended for nearly three weeks in Devil's Wash Basin. On the other hand, at temperatures in the 70°-80° F. range and with concentration of 25 p.p.b., die-off continued for only three or four days in Tyler Lake.

There seems to be little or no detoxification of lake water under the ice. In every instance in which a lake was known to be toxic when the ice formed in the fall, it was still toxic the next spring. Thus it would appear that the winter season cannot be used as a period for detoxification.

There is circumstantial evidence that detoxification is most rapid in the spring and early summer. Lakes treated at this season (Shelser, Spring, Dollar) seem to have lost their toxicity rapidly. Perhaps the spring circulation and plankton bloom assist breakdown and loss of the chemical. Some detoxification may also occur in the early fall (Sand Lake No. 2). In most instances treatments have been made in the late fall when temperatures were low.

Late fall treatments immediately before the lake freezes have the advantage of killing the fish under the ice so that fish decomposition and the resulting odor are not apt to create a public nuisance. On the other hand, since little detoxification occurs under the ice, fall treatments have little advantage over spring treatments as far as detoxification time is concerned; therefore an early spring treatment (at the beginning of the spring overturn) would be most desirable when a lake can provide some winter fishing prior to treatment. Shallow lakes treated immediately after ice breakup can, in most instances, be restocked the early part of the summer. In any event, for a complete poisoning, it is recommended that treatments be made at the beginning of the spring overturn (as soon as the ice cover disappears) so that this period can be used for detoxification.

Recommended dosages of toxaphene for Michigan lakes

Suggested toxaphene dosages for various categories of Michigan lakes in which a complete elimination of fish life is desired are given in Table 8. Transparency, mean depth, and stratification are three lake features believed to be most important in determining the amount of chemical which should be used and length of time the chemical will remain in the lake water. The schedule of concentrations is admittedly somewhat subjective. It was arrived at by a limited number of experiments on Michigan lakes, interpretation of the results of experiments in other states, and by applying the knowledge gained from laboratory experiments. Adjustments in dosage schedule will most certainly have to be made after toxaphene has been used on a greater variety of lakes. It is emphasized that dosage rates are tentative for the deeper trout lakes. More research is required before an adequate treatment program can be well established for these waters.

Since the lake area indirectly influences the persistence of toxicity, these recommendations apply only to lakes between 20 and 200 acres surface area. For larger lakes, the dosages can probably be increased slightly because of the more rapid circulation of toxaphene in the basin. Conversely, the limited circulation of small lakes means that the chemical will disappear somewhat more slowly and a lighter dosage should be used.

Estimated detoxification time for various categories of lakes are as follows (it is assumed that lakes will be treated immediately following the disappearance of ice in the spring):

Shallow, unstratified lakes of moderate to high turbidity	Less than 3 months from time of treatment
All categories of lakes except trout lakes of great depth and high transparency	Less than 6 months after treatment
Transparent trout lakes	One year after time of treatment

The amount and cost of Agricultural Cooper-Tox #6 to treat 100 acre-feet of water at various concentrations are given in Table 9.

Table 8.--Recommended concentrations of toxaphene for various types of lakes

Concentration range (p.p.b. of toxaphene)	Lake type
30-50	Unstratified, shallow and highly turbid warm-water lakes. Secchi disk reading often less than 3 feet.
20-30	Unstratified, shallow warm-water lakes of moderate transparency and high productivity. Secchi disk readings usually 3-6 feet.
15-20	Stratified lakes of moderate depth (mean depth less than 20 feet) and moderate to low transparency. Secchi disk readings usually 6-9 feet.
10-15	Stratified lakes of great depth (mean depth greater than 20 feet) and moderate to high transparency. Secchi disk readings usually 9-20 feet.
7.5-10*	Stratified lakes of great depth and high transparency (Secchi disk usually greater than 20 feet), and low productivity.

* Lakes of this category have not been adequately studied.

Table 9.--Amount and cost of Agricultural Cooper-Tox #6 (emulsifiable concentrate containing 6 lb. Tech. toxaphene per gallon) to treat 100 acre-feet at various concentrations

Concentration (parts per billion)	Gallons per 100 acre-feet	Cost per 100 acre-feet at $3.00 per gallon	Number of 100-acre-foot units treated by one gallon
1	0.0453	$0.14	22.08
2	0.0906	0.27	11.04
3	0.1359	0.41	7.36
4	0.1812	0.54	5.52
5	0.2265	0.68	4.42
6	0.2718	0.82	3.68
7	0.3171	0.95	3.15
8	0.3624	1.09	2.76
9	0.4077	1.22	2.45
10	0.4530	1.36	2.21
11	0.4983	1.49	2.01
12	0.5436	1.63	1.84
13	0.5889	1.77	1.70
14	0.6342	1.90	1.58
15	0.6795	2.04	1.47
16	0.7248	2.17	1.38
17	0.7701	2.31	1.30
18	0.8154	2.45	1.23
19	0.8607	2.58	1.16
20	0.9060	2.72	1.10
25	1.1325	3.40	0.88
30	1.3590	4.08	0.74
35	1.5855	4.76	0.63
40	1.8120	5.44	0.55
45	2.0385	6.12	0.49
50	2.2650	6.80	0.44

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