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STATUS OF LAKE AND STREAM REHABILITATION IN THE UNITED STATES AND CANADA WITH RECOMMENDATIONS FOR MICHIGAN WATERS*

by

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Introduction

As used in this report, lake and stream rehabilitation is defined as the practice of removing all or part of a fish population and in some instances introducing one or more new species not originally present or originally present in small numbers. The objective of this procedure is to alter the structure of the fish population and thereby bring about a yield to anglers more desirable than the yield before treatment. This report will not consider alterations of fish populations brought about by introduction of new species. Successful procedures of this sort are well understood and are in wide usage. Also, it seems desirable to limit this report to fish removal through the use of chemicals. It is recognized that limited success has been

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achieved in rehabilitation through the use of seines and trap nets, etc., and by periodic drawdowns of impoundments. It should be pointed out that in shallow lakes winterkills often thin out overabundant populations. This report will deal principally with lakes. Stream rehabilitation unquestionably will reeeive more emphasis in the future. Recognizing this possibility, it is suggested that further research and development of techniques for rehabilitation of streams be carried on.

Chemicals used in rehabilitation

A variety of chemicals have, from time to time, been used to eliminate undesirable fish. In soft-water regions Titcomb (1914), Catt (1934), and others have successfully used copper sulphate as a toxicant. Cresol is a quick-acting toxicant which has found use in sampling populations of stream fishes (Embody, 1940; Wilkins, 1955). Free chlorine from HTH powder or similar compounds, and anhydrous ammonia have been suggested as fish toxicants.

Although all of the above compounds have found some use in fisheries management, fish toxicants were not used extensively until the insecticide rotenone was shown to be a practical and powerful toxicant.

Rotenone

Rotenone was first used in this country in 1934, and since this time has found wide acceptance. With the use of rotenone, the practice of eliminating undesirable fish and replacement by desired species became well established throughout the United States. Michigan has used between 3,000 and 6,000 gallons of rotenone-bearing fish toxicants each year and much higher figures are given for other states. As much as 105 tons of rotenone powder has been used in a single fish-eradication experiment. The toxicity threshold of rotenone differs slightly among fish species (Burdick, Dean and Harris, 1955), and attempts have been made to use rotenone as a species-selective chemical. It has never been widely used as a size-selective toxicant.

Although toxic to man and warm-blooded animals (132 milligrams per kilogram), rotenone has not been considered hazardous in concentrations used for fish eradication (0.025-0.050 parts per million of active ingredient). Hence it has been employed in waters used for bathing and, in some instances, in drinking water supplies. It is removed by filters used in most domestic water supply plants.

Rotenone is a relatively quick-acting toxicant. In most instances, fish die one to two hours after exposure. It appears to be subject to rapid breakdown in most lakes and ponds (Clemens and Martin, 1953). At high temperatures toxicity can be expected to last for 24 hours or less. Breakdown is so rapid that in many instances toxicity is lost before the toxicant is distributed throughout the water mass. Thus fish kills are incomplete, some of the undesirable fish remain, and retreatment is necessary. To avoid detoxification before the chemical is mixed throughout the lake, it must be well distributed with spraying equipment. Cost of rotenone varies somewhat depending on what formulation is used but in most instances does not exceed approximately $1 per acre-foot of water treated.

Rotenone, by virtue of its rapid breakdown, will probably continue for some time to be the most useful toxicant. With the Federal restrictions against the chlorinated hydrocarbons it is the only toxicant suitable for projects supported by Federal aid. Due to its rapid rate of breakdown, it is not realistic to expect that complete kills can be achieved in shallow, highly productive lakes. For such lakes the probability of survival of undesirable species is much greater than with treatments using chlorinated hydrocarbons. Large, productive, lakes reclaimed with rotenone represent a substantial expenditure and it should be recognized that reclamation may be of temporary benefit. It is recommended therefore that shallow lakes over 2,000 acre-feet in volume be treated with chlorinated hydrocarbons (Toxaphene) rather than rotenone if it is at all feasible to use the former compounds. Similarly, to minimize cost and permit maximum use of funds, rotenone should not be used for treatment of deeper, unproductive lakes (volume greater than 5,000 acre-feet) unless undue public hardship would be produced by delaying restocking for a period of one year, or unless such lakes are connected with public water supplies and health hazards would be created by the use of chlorinated hydrocarbons.

<u>Newer organic insecticides</u>

Principal needs in 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; (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 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 15 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 been used. The most popular is an emulsion which is marketed as a livestock spray (Cooper Tox).

Toxaphene

Experimental treatments of Michigan lakes with Toxaphene have been summarized in I. F. R. Report No. 1584 and uses in other states and provinces have been reviewed by Hooper (1960), Stringer and McMynn (1960), and Prevost (1960). Concentrations in the 1 to 7 parts-per-billion range appear to be useful as a size-selective toxicant since young-of-the-year of centrarchids appear to die at a lower concentration than adults (Fukano and Hooper, 1958). Size and species specificity has also been demonstrated in the case of trout by Reinert (Master's thesis, University of Michigan, 1962). Selective poisoning is not a precise procedure because of differences in individual susceptibility and because of point-to-point differences in rates of physical adsorption, diffusion and biological breakdown. The latter phenomena are probably responsible for recurring incidents in which desirable fish of a large size are killed. Until somewhat greater predictability can be achieved, the use of toxaphene as a size-selective toxicant is not recommended. Further research should be carried on to see if small dosages can be applied annually in order to eliminate successive year classes of recruits.

Michigan and a number of other states and provinces have used Toxaphene for complete eradication. A summary of pertinent information is as follows:

1. Long residual times are nearly always reported. Hence, if Toxaphene is used at a threshold concentration or above, complete kills almost always are achieved. Differences in species susceptibility have been demonstrated. Bullheads and mudminnows appear to be exceedingly resistant.

2. Lakes of low fertility and great mean depths retain toxic residues for long periods (3 to 4 years in some instances). On the other hand, detoxification is comparatively rapid in shallow, turbid lakes of high productivity. A few instances of incomplete kills have

been reported with toxaphene for the latter type of lake, even when concentrations in the range of 50-100 parts per billion have been used.

3. Detoxification time varies from lake to lake in a somewhat unpredictable manner. This appears to be due to the interaction of adsorption phenomena and chemical changes taking place at the mud-water interface. Detoxification time at the present is only roughly predictable. Assuming the threshold concentrations for the most resistant species is used, detoxification time will likely vary from 1 to 2 years for deep oligotrophic lakes to something less than 1 month for shallow, turbid lakes.

4. Most species die before accumulating enough chemical to constitute a health hazard. However, resistant species, e.g., mud-minnows and bullheads, may accumulate amounts greater than allowed by permissible food limits. Hence, it is recommended that lakes be posted at the time of treatment warning the public that dead and dying fish are not edible.

Endrin

All of the chlorinated hydrocarbons are potentially good fish toxicants. Toxaphene is much preferred over others because of the favorable cost factor and because it has a greater toxicity on an active ingredient basis than any other available compound, with the exception of Endrin. Although more toxic than Toxaphene, commercial preparations of Endrin are more expensive and hence have found little acceptance.

A single Endrin treatment in Michigan (North Twin Lake, Grand Traverse County) appeared to be only partially successful. At a concentration of 8 ppb suckers and perch were eliminated but the killifish (Fundulus) survived. In view of the low tolerance levels in food products discussed below, the use of Endrin is not recommended.

Health hazards associated with use of insecticides as fish toxicants

The three insecticides used in fisheries management are Toxaphene, rotenone and Endrin. According to an amendment published in the federal register on June 5, 1963 the following residue tolerances are permitted for the above named compounds:

1. Seven parts per million of Toxaphene residue is permitted on fruits, vegetables, and the fat of meat from cattle, hogs and sheep. Five parts per million residue is permitted on barley, oats, rice and wheat, while only three parts per million is allowed on bananas of which a residue of not more than 0.3 part per million shall be in the pulp after the peel is removed and discarded.

2. Rotenone is exempt from tolerance limits due to its rapid decomposition brought about by the enzymes in most living tissues of plants and animals. Rotenone, however, cannot be applied during or after harvest.

3. The tolerance for Endrin on sugar crops, cabbage, eggplants, etc., is zero. Zero, however is defined as that concentration which is not detectable by the official standard method of analysis.

State laws in Michigan do not differ from Federal laws regarding pesticide residues. With regards to Toxaphene, Dr. Muehlberger, Chief of the Toxicology Section of the Michigan Department of Health has stated that a concentration of 20 parts per billion of toxaphene in water (concentration used in fish eradication) would not constitute a health hazard to humans or animals.

The main health hazard associated with pesticides arises from their tendency to concentrate within tissues of plants and animals. This buildup varies considerably as is shown by the fact that on certain foods there is a lower residue tolerance limit. Certain species of fish and animals build up residue levels higher than others.

When a New Mexico lake was treated with Toxaphene (0.02 ppm) the concentration buildup in trout was as follows (Kallman, Cope and Navarre, 1962):

6 hrs. after treatment trout contained	0.43 ppm
12 hrs. thereafter trout contained	1.8 ppm
48 hrs. thereafter trout contained	5.4 ppm
61 hrs. thereafter trout contained	4.2 ppm
72 hrs. thereafter trout contained	3.4 ppm

The concentration of Toxaphene in these trout before treatment ranged from 0.06-0.12 ppm. The buildup in trout seems to have terminated due to the fact that most of the trout died at a concentration of 5.4 ppm.

In comparison to the trout, the bullheads contained 0.37-0.44 ppm Toxaphene before treatment and the residue buildup in this species was as follows:

6 hrs. after treatment	0.51 ppm Toxaphene
12 hrs. after treatment	3.9 ppm
72 hrs. after treatment	4.2 ppm
96 hrs. after treatment	9.2 ppm
120 hrs. after treatment	12.0 ppm

After 195 days these fish still contained 0.8 to 1.2 ppm Toxaphene. It is evident that certain species continue to concentrate pesticides in their tissues far longer than others.

Toxaphene has been found in trout from lakes never treated with this chemical in concentrations ranging from 0.06 - 0.12 ppm. Most of the pesticides are found in the mud and vegetation of untreated waters in concentrations ranging from 0.08-0.8 ppm.

When waters are treated with Toxaphene the buildup is rapid for one day after treatment. With a treatment of 0.02 ppm, surface water at the end of one day contained 0.003 ppm while the mud and vegetation contained 8 and 16 ppm respectively. At the end of one week only a trace could be found in the water (surface) while the vegetation still contained 5.9 ppm. After 12 months the vegetation contained 0.6 ppm. One month after aerial spraying Endrin was found in concentrations of 0.02-1.0 ppm in fish tissue. The 24 hr. TLm for Endrin is 2.0 ppb (0.002 ppm) while the level for Toxaphene is 11.5 ppb (Katz, 1961).

The evaluation and analysis of pesticides is a difficult and sometimes costly procedure. Lengthy extraction and cleanup procedures are often necessary to detect pesticides present in trace amounts. Although detection is possible with standard paper chromatographic procedures, pesticides are best analyzed by gas chromatography and subsequent infra-red spectrophotometric analysis. Such equipment, although costing as much as $10-15, 000, sharply reduces the time necessary to evaluate pesticides and greatly increases the accuracy of results.

In view of present interest in environmental contamination by pesticides, it is important that excessive use of compounds resistant to breakdown, such as Toxaphene, be minimized. No lake which is part of a domestic water supply should be treated with Toxaphene. It is recommended that the use of Toxaphene be restricted to the following types of reclamation projects:

1. Shallow, warm-water lakes with volume greater than 2, 000 acre-feet, when it can be anticipated that repeated treatments (due to reintroduction of undesirable species) will be necessary. The use of Toxaphene in such cases is justified on an economic basis, e.g., it would be too costly to make repeated treatments with rotenone.

2. Large, deep, oligotrophic lakes of volume greater than 5, 000 acre-feet in which undue hardship would not be created by elimination of fishing for periods of 12 to 18 months.

3. Other lakes suitable for reclamation in which rotenone has been shown to be ineffective even when used at high concentration levels.

Survey of literature on rehabilitation practices in other states and Canada

Attempts have been made to reclaim virtually every type of lake from acid bogs in Nova Scotia (Smith, 1938), to alkaline potholes in Florida (Huish, 1958), to cold mountain lakes of the Pacific coast (Stringer and McMynn, 1960). For many of the large hydroelectric impoundments, total reclamation is too costly and only partial poisoning is feasible (Tarzwell, 1942).

It was recognized early in rehabilitation work that small lakes with neither inlet nor outlet were not only cheaper to reclaim, but also slower to become recontaminated. In the last decade, however, rehabilitation has been attempted on an entire lake and stream system in the Adirondacks (Zilliox and Pfeiffer, 1960) and on a few salmonoid streams of the Smoky Mountains and Pacific coast (Lennon and Parker, 1959; Berry and Larkin, 1954; Pintler and Johnson, 1958). No literature has been found on rehabilitation of warm-water streams.

The need for reclamation is usually indicated by: (1) the presence of warm-water species in trout waters, (2) stunting, (3) abundance of carp, bullheads, shad, gar pike, minnows or other "trash" fish. Even pike and trout have been considered undesirable in certain waters (Lennon and Parker, 1959; Wales, 1947; Miller, 1950).

Total versus partial kills

Much effort has been expended in testing new toxicants and techniques which will produce complete kills. Partial or selective poisoning to remove only undesired components of a population has also received considerable attention and has the advantage of being less wasteful of game fish.

When a substantial trout population already exists in a lake, partial poisoning with rotenone during thermal stratification has been successfully accomplished with little loss of trout (Greenbank, 1941; Tompkins and Mullan, 1958; Hayes and Livingstone, 1955). Unfortunately, the kill of undesired species was invariably incomplete.

Selective reclamation is a potential tool in warm-water lake management. Alabama, which intensively manages 18 lakes for sport angling, uses selective shoreline poisoning with rotenone quite successfully to maintain a balanced population of largemouth bass, bluegills, and redear (Hooper and Crance, 1960). Riel (1964) used selective poisoning of perch eggs to thin a perch population. Carp populations have been selectively poisoned after the fish were trapped in restricted areas of the lake (Tarzwell, 1942; Wales, 1942; Buck et al., 1960). Southern states have selectively killed gizzard shad with 1 ppm rotenone (Hulsey and Stevenson, 1959; Sandoz, 1959; Huish, 1958). White perch and carp are more susceptible to copper sulphate than pike or bass but apparently these differences in sensitivity have not been utilized (Belding, 1927). Sodium hydroxide pellets have been dropped on nests to reduce sunfish populations (Jackson, 1956). Chemicals which are species-specific such as TFM, the selective lampricide, are urgently needed.

Success of treatments

Fish eradication is usually incomplete even under the best conditions. Clemens and Martin (1953) achieved a complete kill in only 2 out of 18 ponds treated with relatively high concentrations of rotenone. Zilliox and Pfeiffer (1956) claimed complete kill in 8 of 14 trout ponds. Toxaphene, which detoxifies slowly, gives a complete kill more often than rotenone (Hooper and Fukano, 1960; Stringer and McMynn, 1958; Zilliox and Pfeiffer, 1960).

Generally a complete kill is more likely in a trout lake than in a stream or warm-water lake. Best results are achieved in lakes that are relatively acidic, cold, deep, clear, weedless, unstratified, with neither inlet nor outlet and which do not have muskrat and beaver tunnels capable of hiding fish and fish eggs (Zilliox and Pfeiffer, 1960; Hooper and Fukano, 1960; Prevost, 1960; Stringer and McMynn, 1960). Obviously precautions should be taken to prevent immigration of undesired species into the newly treated lake by the construction of barriers on inlets and outlets (Zilliox and Pfeiffer, 1960).

Species reintroduced

Many species have been introduced in rehabilitated waters. The success of any particular species depends on its suitability to the water in question.

Many kinds of trouts and the kokanee (Webster and Flick, 1960) have been planted, although brook or rainbow trout are preferred. Brook trout do better than rainbows in small streams of the Smoky Mountains

(Lennon and Parker, 1959), in waters of pH less than 6.2 (Zilliox and Pfeiffer, 1960), and in those spring-fed lakes where brook trout will spawn naturally (Wales and Borgeson, 1961; Foye, 1956). The brook trout is very popular in Canada (Prevost, 1960), but rainbows, with the advantage of greater longevity, are more often preferred (Wales and Borgeson, 1961). Lake and brown trout are considered to be too difficult to catch and too predacious (Wales and Borgeson, 1961).

Warm-water lakes have been restocked with fish which anglers desire rather than with combinations which are apt to form stable populations. Perhaps an exception is Alabama, which successfully manages largemouth, bluegill, and redear populations in public fishing lakes (Hooper and Crance, 1960). No references on management of mono-specific, warm-water populations were found.

Success of rehabilitation

Success of rehabilitation depends upon the completeness of kill, precautions taken to prevent reintroduction of undesirables, choice of species to be restocked, and subsequent management. In the last two areas, warm-water rehabilitation is particularly deficient. Initial growth rate of fish in reclaimed lakes is frequently good and such waters often provide good to excellent fishing for at least two years--especially trout lakes and streams (Wales and Borgeson, 1961; Foye, 1956; Smith, 1938; Lennon and Parker, 1959; and others).

Trout lake reclamation has been more successful than reclamation of either streams or warm-water lakes. This is probably due not only to the greater likelihood of a complete kill, and the reduced capacity of warm-water species to repopulate cold waters, but also to the opportunity presented for management of the population through maintenance stocking. Trout waters, both lake and stream, almost always provide the best angling when the kill is complete and no other species is introduced by immigration or by the bait angler (Zilliox and Pfeiffer, 1960; Vestal, 1942a and 1942b; and others). When the kill is incomplete (whether total or partial kill was sought), the quality of trout angling may be expected to decline as the population of undesired fishes increases. This may take as little as 2 to 5 years (Zilliox, 1954; Smith, 1941; Mullan, 1959). Usually only trout are introduced when other species are eliminated but Foye (1956) found that the addition of the alewife helped a brown trout population.

It is even difficult to achieve and maintain stream rehabilitation because of incomplete kills and high rates of immigration (Boccardy and Cooper, 1961). Returns must be substantial and immediate for such a project to be feasible. Lennon and Parker (1959) considered the rehabilitation of two streams in the Smoky Mountains successful.

Information on the success of warm-water lake rehabilitation is sparse. As mentioned earlier, Hooper and Crance (1960) used selective poisoning to maintain population balance. Riel (1964) improved angling for at least a few years by selective poisoning of perch. Others (Sandoz, 1959; Zilliox and Pfeiffer, 1960; Miller, 1950) were unable to manage warm-water species with toxicants.

Results of a nation-wide questionnaire on

status of rehabilitations

In order to assess, on a nationwide basis, the degree of acceptance and value assigned to reclamation procedures, letters were sent to fisheries agencies of 22 states in March, 1964. The following questions were asked:

(1) Do you personally consider this (rehabilitation) a satisfactory method of fish management?

(2) What proportion of the time and/or budget of your management section is devoted to rehabilitation with chemicals?

(3) What proportion of your rehabilitation treatments have been successful? How many complete failures?

(4) What has been your experience with public reaction to lake and stream rehabilitation (complete kills followed by re-stocking)?

(5) What kinds of fish, if any, do you stock to supply interim fishing while a new population is getting established?

(6) Do you feel that the knowledge of population dynamics is now adequate to successfully manage a renovated body of water on a sustained basis in your state?

(7) How often do you have to repeat a partial thinning treatment in order to provide consistent "satisfactory" fishing?

(8) In your experience have you found one time of year preferable to another for a chemical treatment? Why?

Table 1.--Summary of replies to questionnaire on rehabilitation practices in 18 states

(Refer to text for details of questions asked)

Locality	Is reclamation a satisfactory method of management	Budget proportion	Time proportion	% Successful	Number of failures	Public reaction	Interim stocking	Is knowledge of population dynamics adequate	Partial thinning	Time of chemical treatment
MIDWEST										
Indiana	Yes	8-10	--	75	2	ok if explained	None	No	Not tried	Oct-Nov
Missouri	Yes	5	8	all but 2		enthusiastic	None	No	Testing annual treatments	Aug
Minnesota	qualified yes	5	3	90 trout 65 warm-water		very good	rainbow or brook trout	50% for trout lakes	Not done	early fall
Wisconsin	Yes	1.5	1.5	80	0	excellent	rainbows	good for trout lakes; incomplete for warm-water lakes	?	mid-summer
Illinois	Yes	?	8	95	6	very good	None	lacking	biennially	early fall
Iowa	Yes	5	?	100	0	good	adult bullhead, chan. cat, crappie	incomplete	Not done	winter-toxaphene; summer and fall-rotenone
EAST										
New York	Yes (trout ponds)	5	5	nearly all successful		very good	yrl. brook trout	adequate for trout lakes	Not done	Fall
SOUTH										
Florida	Yes	?	25	80-85	< 2	good	None	No	annually or biennially for gizzard shad	late fall

(continued)

Table 1.--continued

Locality	Is reclamation a satisfactory method of management	Budget proportion	Time proportion	% Successful	Number of failures	Public reaction	Interim stocking	Is knowledge of population dynamics adequate	Partial thinning	Time of chemical treatment
SOUTH, continued										
Alabama	qualified yes	small portion		?	?	ok	none	fairly good for small lakes	any time	fall
Tennessee	Farm pond renovation only									
Kentucky	yes	1	2	few failures in pond and stream		not very good	none	qualified yes	?	early fall
Virginia	qualified yes	<2	?	selective kills --good; streams --poor		?	none	yes	frequently	early fall
WEST										
Arizona	yes - up to 100 acres	variable (0-25%)		majority	?	most favor it	trout for high use areas	?	not tried	late summer and fall
Texas	fair	6	33	no complete kills		over-sold	none	no	?	?
Colorado	ok for small waters	<3	?	75	0	generally good	none	fair on trout no-warmwater	not done	early fall
California	yes	6	?	90	few	favorable most of time	trout in trout lakes only	many gaps	not done	fall
Utah	qualified yes	1	1	nearly all	0	good	none	no	5-10 yrs	?
Washington	yes (trout lakes)	2	?	100	0	some objections	none	?	unsatisfactory	fall

Table 2.--Supplementary information from questionnaire

A. Characteristics of population and habitats on which reclamation attempted

MIDWEST

Indiana - Hasn't been used very much. Warm water population involved.

Missouri - Lakes and ponds, no stream work; mostly centrarchids and/or carp problems.

Minnesota - Small, relatively shallow lakes having sunfish, perch and pike--were removed for trout management. Bullhead removed in warm-water lakes.

Wisconsin - Renovate lakes for trout lakes; eliminate crowded warm-water population. Also trout stream renovation.

Illinois - Small lakes and ponds.

EAST

New York - Almost entirely confined to pond and lake reclamation for trout. Eliminate yellow perch and other warm-water species. Mostly ponds less than 50 acres. Few from 100-461 acres.

Massachusetts - Selective kills of sunfish in bass-sunfish (bluegill ?) ponds; also treated epilimnion to reduce warm-water species in trout lakes. Partial controls also.

SOUTH

Florida - Isolated lakes and ponds. Selective removal of shad and total elimination of populations.

Alabama - Small ponds and lakes-- usually advice furnished to owners. Thin out over-crowded bluegill ponds and lakes. Partial poisoning annually is successful in state-owned lakes.

Tennessee - Farm pond renovation. One reservoir treated to remove rough fish.

Kentucky - Total eradication in small impoundments (less than 50 acres); selective removal of shad, carp, and/or buffalo in large impoundments. Pond renovation done by owner. Stream rehabilitation--poor success. Four annual shad treatments produced good bass and crappie fishing for about 6 years.

Virginia - Selective kills of shad, carp, catfish, golden shiners. Feeder streams to new public fishing lakes. Lakes with too many bluegills and/or crappie.

Table 2. --continued

WEST

Arizona - Trout and warm-water lakes--up to 100 acres in size--also streams.

Texas - Selective shad kills; pre-impoundment treatments; complete eradication. Problem lakes involve one or more gizzard shad, drum, carp, etc., stunted bluegill, yellow bullheads, chubsucker, suckers, golden shiner.

Colorado - Small lakes or ponds. Rough fish elimination.

California - Bullheads in trout waters; rough fish control in new and older reservoirs. Squawfish and carp problems; thin out bluegill and bullhead populations. Pre-impoundment treatment of drainage. 17 streams have been treated but re-invasion was rapid.

Washington - Eliminate fish in lakes to be used for salmon rearing; eliminate warm-water fish from trout lakes.

Oklahoma - Partial controls tried for carp, bullheads and bluegills.

Idaho - carp spawning in shallow water were treated successfully.

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B. Species re-introduced

MIDWEST

Indiana - Fingerling warm-water species.

Missouri - Largemouth bass, channel cat, bluegill fingerlings--100:50:500/A. bluegill--250, redear--250. Lakes closed for 2 summers following stocking.

Minnesota - Catchable size rainbow or brook trout in special cases. Usually fingerling or sublegal trout planted.

Wisconsin - Rainbows for interim fishing; bass fingerlings; 3 or 4 species planted in warm-water lakes.

Illinois - One planting of fingerlings (spp. ?); allow 2 years for fishery to develop.

EAST

New York - Yearling brook trout in spring followed by fall fingerling plants.

SOUTH

Alabama - Bluegills, redear, bass. Experimented with *Tilapia*.

Tennessee - Bass and bluegills.

Table 2.--concluded.

SOUTH, continued

Kentucky - Bass fingerlings (smallmouth bass ?) in streams; ponds--probably bass and bluegills.

Virginia - Marginal trout waters - catchable size trout; ponds--probably bass and bluegills.

WEST

Arizona - Fingerling trout or warm-water species; catchable trout in areas of high fishing pressure.

Texas - Largemouth bass fry, channel cat fingerlings, adult redear--200:50:10/A., largemouth bass fingerlings in new lakes and fry.

Colorado - Fingerlings--usually trout.

California - Catchable trout when use is heavy; new reservoirs--fingerling trout or fry and fingerling of warm-water species.

Washington - Mostly 2-inch fingerling trout (Spp. ?); 7-inch trout in some small lakes that require repeated treatments.

Replies from 18 states have been summarized in Table 1 and supplementary information taken from the questionnaire is given in Table 2. In general, the responses indicated that:

(1) Rehabilitation is a widely accepted method used in management.

(2) A relatively high rate of successful projects is indicated (65 to 100 percent). Many states considered a project successful if fishing improved only for one year.

(3) Public acceptance is, in general, favorable, but nearly all agencies stressed the need for adequate "education" of the public prior to renovation.

(4) Partial thinning must be undertaken on a continuing basis. Many states do not favor this approach.

(5) In northern states most rehabilitation has been for the purpose of introducing trout. Very few states provide interim fishing while a new population is becoming established.

(6) Stream reclamation projects have, in general, had limited success. Re-invasion of undesirable species is rapid.

(7) Our knowledge of population dynamics is inadequate, particularly for warm-water lakes.

Lake rehabilitation in Michigan

Summary of projects 1934-1963

Ball (1948b) summarized the early period (1934-1942) of rehabilitation with rotenone. He reported that 32 lakes were treated with rotenone to remove or reduce unwanted populations. An attempt to recover the entire fish population was made on 18 of the lakes. All the lakes were less than 22 acres in area and the majority had an undesirable fish population when they were treated. The standing crop of fish removed ranged from 10 to 194 pounds per acre. The average was 58 pounds of which 18 pounds were legal-sized sport fishes. Six of the nine lakes in which the kill apparently was complete were subsequently stocked with trout. The lakes were soon repopulated with warm-water species. Three remained free of other fish for a number of years.

Few, if any, lakes were treated during the last years of World War II, 1943-1945. During the post-war period, 1947-1954, forty-five lakes and ponds were treated with rotenone. This included 42 (719 acres) lakes in Regions I and II, and three lakes in Region III (17 acres) (Scott, 1961). Trout were planted in all of these lakes except for one 7-acre warm-water lake in Region I. Powdered or emulsifiable rotenone was used for all treatment except for 11 in which Toxaphene (Fish-Tox) was used.

Increased emphasis upon warm-water fish management beginning in 1956 together with the stepped-up trout reclamation resulted in an increase in the number of lake and stream rehabilitation projects carried out each year. From 1955 through 1958 the average number of lakes treated each year was 21, whereas the average number treated each year from 1959 through 1963 was 32 (Scott, 1961).

Table 3 gives a breakdown of the location by region, area, and type for 243 lake and stream reclamation projects carried out between January 1955 and December 1963. Partial poisoning for the control of pan fish was attempted on 18 lakes. Attempts at complete removal of pan fish were made on 46 lakes. Thirty lakes and impoundments were treated for removal of rough fish. Also, 143 trout lakes and ponds (many of them Special Regulation Trout Ponds) were treated. Six rough-fish lakes were stocked with trout after treatment. In 21 of the warm-water lake treatments (complete kills), rainbow trout were also stocked the first year to furnish fishing while the warm-water fish populations were becoming established.

The 243 lakes rehabilitated during this period had a total area of 10,511 acres. Of this total, 2,087 acres were in Region I, 2,589 acres in Region II, and 5,835 acres in Region III. About 220 miles of trout and warm-water streams were treated in attempts to reduce or eliminate rough fish and establish trout or desirable warm-water fish (Scott, 1962). Further treatment and evaluation details on some of the warm-water lakes treated from 1956 through 1959 will be found in the appendix of this report.

Evaluation of rehabilitation 1955-1963

In March, 1964, all district fisheries supervisors were sent a questionnaire listing all lakes in their district which had been treated with rotenone since 1955. The supervisors were asked to comment upon the

Table 3.--Number and total acreage of lakes, and miles of streams treated with rotenone by the Lake and Stream Improvement Section, 1955-1963

Region	Number of lakes and/or ponds: Pan fish control (warm-water) – Partial	Pan fish control (warm-water) – Complete	Rough fish control – Warm water	Rough fish control – Trout water	Trout lakes and ponds	Warm-water lakes	Lakes having interim trout stocking	Area of lakes treated (acres)	Streams treated (miles)
I	0	2	0	0	59	61	0	2,087	30
II	1	27	0	2	54	84	14	2,589	0
III	17	17	30	4	30	98	7	5,835	190
Total	18	46	30	6	143	243	21	10,511	220
Total warm-water		94							
Total trout				149					
Total rough fish			36						

degree and duration of benefit from these rehabilitation projects, the amount of evaluation made of the results, the amount of local assistance received, and the reasons, if any, for failure. The ten questionnaires returned indicated that nearly all trout stockings in lakes have been rather carefully evaluated; however nearly 50 percent of the warm-water lake treatments in Region III have not been evaluated. Most evaluations were based upon somewhat subjective estimates of angler returns--some were based upon seine hauls and test netting. Table 4 gives the number of lakes treated and kind of trout planted (including grayling and splake) for lakes from which information was received. Information on the number of warm-water lakes treated and evaluated is included in Table 5 and the supervisors' opinions of the degree and average duration of benefit from rehabilitation where known is given.

Seventy-five percent of the trout lakes rehabilitated in Region I provided either good or fair angling and the average duration of benefit was 3.6 years. Most lakes were managed for brook trout, followed by rainbow trout, and combination brook trout and rainbow trout lakes. The longest period of success was realized in the combination brook-rainbow trout lakes (5.2 years for six lakes).

Only seven trout-lake treatment evaluations were reported from Region II--four brook trout and three rainbow trout lakes. The average percentage of treatments considered good or fair after treatment was 71 and the average duration of the success was 2.7 years.

In Region III, evaluations were reported for 13 lakes treated for trout during this period. This includes three brook trout lakes, five

Table 4.--Number of lakes treated with rotenone, stocked with various species of trout, and the degree and average duration of benefit from rehabilitation for the period 1955-1963. Data obtained from questionnaires sent to District Fisheries Supervisors. (Lakes not evaluated are not included.)

Region	Degree of success	Species of trout							Sub-total (degree of success)				Percentage good or fair	Average duration (years)
		Brook	Rainbow	Brown	Brook Rainbow	Brook Brown Rainbow	Grayling	Splake	Good	Fair	Poor	All		
I	Good	11	6	1	5	-	-	1	24	-	-	-	--	---
	Fair	3	-	-	-	-	-	-	-	3	-	-	--	---
	Poor	5	1	1	1	-	1	-	-	-	9	-	--	---
Subtotal		19	7	2	6	-	1	1	-	-	-	36	75	---
Average duration		3.4	3.7	2.0	5.2	-	0.0	3.0	-	-	-	-	--	3.6
II*	Good	1	1	-	-	-	-	-	2	-	-	-	--	---
	Fair	2	1	-	-	-	-	-	-	3	-	-	--	---
	Poor	1	1	-	-	-	-	-	-	-	2	-	--	---
Subtotal		4	3	-	-	-	-	-	-	-	-	7	71	---
Average duration		3.0	2.3	-	-	-	-	-	-	-	-	-	--	2.7
III	Good	2	1	-	1	2	-	-	6	-	-	-	--	---
	Fair	1	3	-	2	-	-	-	-	6	-	-	--	---
	Poor	-	1	-	-	-	-	-	-	-	1	-	--	---
Subtotal		3	5	-	3	2	-	-	-	-	-	13	92	---
Average duration		2.3	2.2	-	4.0	4.0	-	-	-	-	-	-	--	3.2
Total	Good	14	8	1	6	2	-	1	32	-	-	-	--	---
	Fair	6	4	-	2	-	-	-	-	12	-	-	--	---
	Poor	6	3	1	1	-	1	-	-	-	12	-	--	---
Total		26	15	2	9	2	1	1	-	-	-	56	--	---
Percentage good or fair		77	80	50	89	100	0	100	-	-	-	-	79	---
Average duration		3.2	2.9	2.0	4.8	4.0	0.0	3.0	-	-	-	-	--	3.4

* Data from 3 of the 5 districts.

Table 5.--Success of warm-water lake rehabilitation for period 1955-1963. Data from questionnaires returned by 10 District Fisheries Supervisors.

(Lakes not evaluated are not included.)

Degree of success	Warm-water lakes treated		Average duration of success (years)
	Number	Percent of total	
Good	12	40.0	4.7 (Good and Fair)
Fair	10	33.3	
Poor	8	26.7	0.5
Total	30	100.0	4.0

rainbow lakes, three combination brook-rainbow lakes, and two lakes with all three species of trout present. The percent considered to be good or fair after treatment was 92 and the average duration of benefit from the treatments was 3.2 years. Therefore, of a statewide total of 56 trout lakes and ponds, 79 percent were considered good or fair following treatment and the average duration of benefits was 3.4 years. The total number of lakes reported for various species was 26 for brook trout, 15 for rainbow trout, 2 brown trout, 9 combination brook and rainbow, 2 combination brook, brown and rainbow, 1 grayling and 1 splake lake. The highest average duration of success (4.8 years) was for the combination of brook and rainbow trout.

Of the 30 lakes treated for warm-water fish management, 73 percent were considered good or fair following the treatment and the average duration of success of the treatment was 4.7 years for the good and fair success category, and 0.5 for poor success. There were 10 lakes for which no evaluation of results was available.

Reason for failure

Reason for failure of the treatments and management operations following treatment were compiled for all the trout lakes. The most common cause given for failure was re-establishment of trash fish following treatment (25 lakes). Trash fish included suckers (2 lakes), perch (1 lake), and other warm-water species (3 lakes). Reports from other lakes did not specify which species of fish became re-established. The second highest cause of failure was incomplete kills (17 lakes); at 7 of the lakes a combination of incomplete kill and reinfestation of trash fish was listed as the cause. Various other minor reasons for failure included poor stocking, insufficient brood stock, poor growth, promiscuous stocking by anglers, and reversion to private control. Reasons for failure of warm-water lakes were substantially the same as for trout lakes.

Partial bluegill control with rotenone,
1956-1959

In approximately 25 percent of the lakes inventoried in Michigan by routine surveys, bluegills were found to be growing slowly. Many of these lakes seemed completely overrun with bluegills which seldom attained a length as great as 6 inches in 6 or 7 years. In 1956, it was decided that control of bluegills with rotenone in some of these lakes should be attempted. The plan decided upon was for the Lake and Stream Improvement Section to remove from 50 to 90 percent of the bluegills from the selected lakes. Analysis of the results were made by biologists of the Hastings station of the Institute for Fisheries Research.[1]

From 60 lakes, which growth-rate records indicated as having slow-growing bluegills, five were selected for work during 1956. These five lakes were considered poor fishing lakes by the public. The lakes selected were: Saddle Lake, Van Buren County; East and West Turk lakes, Montcalm County; Lower Scott Lake, Allegan County; and Island Lake,

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[1] See Appendix for details.

Livingston County. The cost of treating the lakes in 1956 was about eight dollars to ten dollars per acre. A large part of the cost was for personnel to pick up the dead fish.

In 1957, six additional lakes were selected for study. These were: Murphy Lake, Tuscola County; Woodland Lake, Livingston County; Bass Lake, Kent County; Townline Lake, Montcalm County; Mill Lake, Washtenaw County; and Leidy Lake, Tuscola County. In 1958, Eagle Lake, Kalamazoo County, Grass Lake, Oakland County, and Stone Lake, Cass County were treated for the first time, and Saddle Lake was treated for the second time.

Restocking and management of lakes after treatment

The management practices undertaken on lakes treated with rotenone between 1956 and 1959 are given in Tables 6 and 7. Several predators were restocked in an effort to control pan fish and carp populations. Pike marshes were controlled artificially at several of these lakes to increase pike populations, and restrictive regulations were put on some lakes to keep anglers from harvesting pike before they could function as predators. Two lakes (Townline and Woodland) received partial shoreline treatments after the original treatment to offset the success of bluegill reproduction. One lake association (Townline) attempted to control bluegill reproduction by treating nests with copper sulphate crystals to kill eggs and fry. A winterkill on Grass Lake and a summer mortality on Stone Lake reduced these populations.

Table 6.--A summary of treatments, and fish plantings made in 15 warm-water lakes on which partial or total rehabilitation was attempted, 1956-1959[1]

Lake and county	Date of original treatment	Subsequent treatments		Fish stocked after treatment (number per acre)[2]				
		Date	Type	Pike	Musky	Largemouth bass	Bluegill	Rainbow
Beadle, Calhoun	10/58	--		.8A	-	45F	-	-
Saddle, Van Buren	7/56	1958	Complete	-	-	9F	-	-
Lower Scott, Allegan	8/56	--		2A, 37F	-	9F	-	-
Woodland, Livingston	6/57	1958	Partial (shoreline)	4F	-	43F	-	-
Grass, Oakland	10/58	1962	Complete (winterkill)	1A, 4F	-	87F	-	-
Island, Livingston	9/56	--		.1A	-	-	-	-
Murphy, Tuscola	5/57	--		-	24F	-	-	-
Townline, Montcalm	6/57	1958	Partial (shoreline)	518F	-	45F	-	-
		1961-62	Copper sulphate	(marsh)				
Bass, Kent	6/57	--		2F	-	5F	-	-
East Turk, Montcalm	8/56	--		.6A	-	8F	-	-
West Turk, Montcalm	8/56	---		.9A	-	12F	-	-
Mill, Washtenaw	6/57	--		59F	-	-	-	-
Leidy, St. Joseph	9/57	--		59F	-	100F	11A	-
Saddle, Van Buren	6/58	--		.6A	-	64F	68F	17A
Eagle, Kalamazoo	8/58	--		4A, 6F	-	22F	-	4A
Stone, Cass	10/59	1962	Partial (summerkill)	7A	-	55F[3]	103F	28A

[1] For estimated percentage kill see Table 8.

[2] A = Adult
F = Fingerling

[3] Fingerling smallmouth bass also stocked (30 per acre).

Table 7.--Summary of management procedures used, predator abundance (pike and musky), and fishing success for 15 lakes on which partial or total rehabilitation attempted, 1956-1959[1]

Lake and county	Special regulations for pike		Pike march management		Pike abundance		Creel census (year)	Report of fishing success	
	Year	Type	Year	Success	Number per acre seined	Population estimate (number per acre)		Year	Quality
Beadle, Calhoun	--		--	--	0.4	--	--	--	Poor
Saddle, VanBuren	--		--	--	0.0	--	1957	--	Good
Lower Scott, Allegan	1957-60	Closed to fishing	--	--	1.0	--	--	--	Poor
Woodland, Livingston	--		--	--	0.6	--	--	1958-60	Good
Grass, Oakland	--		1959	Poor	7.6	--	--	--	?
Island, Livingston	--		1958-59	Poor	4.2	--	--	--	Fair
Murphy, Tuscola	1960-64	No spearing	--	--	6.4	--	--	--	Good
Townline, Montcalm	1958-62	Closed to fishing							
	1963	27" size limit	1958-				1959-	1959	Good
	1963	No spearing	63	Good	11.0	--	62	1962	Poor
Bass, Kent	--		--	--	0.7	--	--	--	Poor
E. Turk, Montcalm	1957-63	Closed to fishing	--	--	28.3	83(1958)	1958-59	1957	Good
	1964	No spearing					1962	1958-62	Poor
W. Turk, Montcalm	1957-63	Closed to fishing	--	--	53.2	91(1958)	1958-59	1957	Good
	1964	No spearing					1962	1958-62	Poor
Mill, Washtenaw	--		--	--	2.2	--	--	1958-60	Good
Leidy, St. Joseph	--		--	--	9.4	--	--	1962	Excellent
								1960	Good
Saddle, VanBuren	--		--	--	0.7	--	1958	1958-60	Good
								1960	Poor
Eagle, Kalamazoo	--		1959	Good	8.7	--	--	1959-60	Poor
Stone, Cass	1961-62	Closed to fishing	--	--	0.9	--	--	--	Good

[1] For estimated percentage kill, see Table 8.

Most of the lakes treated between 1956 and 1959 received plantings of largemouth bass and pike. Bass were stocked to replace fish killed by treatments. Northern pike were stocked if adequate spawning areas were present. Adult pike were planted if available, otherwise fingerlings were used. At Murphy Lake, Tuscola County, muskellunge were stocked instead of northern pike because the habitat seemed suitable for this species. At lakes with high levels of kill, especially those at 100 percent, efforts were made to establish a small number of fingerling or adult pan fish after the predators were established. Three of these lakes received plantings of from 4 to 28 rainbow trout per acre to furnish interim fishing before the establishment of the warm-water fish.

At four lakes treated in 1956 and 1957 (Lower Scott Lake, Townline, and East and West Turk lakes) pike fishing was prohibited to protect pike stocked in the lakes until they had spawned. This protection was continued for several years in an effort to build up the population. Protection was continued until 1960 at Lower Scott, until 1962 at Townline Lake, and until 1963 at the Turk lakes. Beginning in 1963 at Townline Lake the size limit for pike was set at 27 inches and fishing was allowed only during the summer season. At the Turk lakes pike fishing will be open in 1964 but spearing will not be allowed. Spearing was closed at Murphy Lake, Tuscola County, in 1960 and remains closed to this time in order to protect the planted muskies from winter harvest. Stone Lake, Cass County, was closed to all types of pike fishing from 1961 to 1962.

Increase in bluegill growth

Table 8 gives the average annual bluegill growth increment for each of the 15 lakes treated with rotenone between 1956 and 1959, both before the treatment and for various numbers of years after the treatment depending upon the duration of growth improvement. The average bluegill growth increment is an empirical index derived by summing quotients of the length of each bluegill divided by the number of growing seasons it had lived. In other words, if a bluegill was 5.0 inches long and had completed five growing seasons, its average annual growth increment would be 1.0 inch. Average annual growth increments for various years after treatment were measured from scales taken from fish captured by seining. Only the last year's growth was determined by back calculation from scales. This avoided inaccuracies in growth increments arising from calculation of an extended growth history from scales, and also avoided the calculation of the body-scale relationship for each lake.

The growth rate at Beadle Lake, Calhoun County, after removal of less than 20 percent of the population in 1958, was only 4 percent greater in 1959 than before treatment (Table 8). This growth increment is of doubtful statistical significance. At four lakes (Saddle, Lower Scott, Woodland, and Grass) at which from 20 to 40 percent of the fish were removed, the growth increment the year following treatment averaged 20 percent above the pre-treatment value. At Island, Murphy, and Townline lakes, where between 40 and 60 percent of the fish were removed, the average increase in the growth increment the year following treatment was

Table 8.--Average annual growth increment of bluegills before and after treatment with rotenone and the duration of bluegill growth improvement after various levels of population reduction for 15 lakes treated 1956-1959

Estimated percentage of kill	Lake and county	Average bluegill growth increment per year (inches)								Duration of growth improvement	
		Before treat-ment	Years after treatment						Percent-age first year		
			1	2	3	4	5	6		Years	Average
20	Beadle, Calhoun	0.98	1.02	1.02	0.98	--	--	--	4	0	0
20-40	Saddle, VanBuren	1.26	1.49	(Re-treated in 1958)					18	1	1.2
	Lower Scott, Allegan	1.16	1.38	1.16	1.16	--	--	--	19	1	
	Woodland, Livingston	1.25	1.57	1.59	1.20	--	--	--	26	2	
	Grass, Oakland	1.04	1.24	1.07	0.71	--	--	--	19	1	
	Average	1.18	1.42	1.27	1.02	--	--	--	20	-	
40-60	Island, Livingston	1.17	2.10	1.33	0.84	--	--	--	79	2	2.2
	Murphy, Tuscola[1]	1.24	1.77	1.54	1.32	1.09	--	--	43	3	
	Townline, Montcalm	1.00	1.97	1.55	1.01	1.11	0.96	--	97	2	
	Average	1.14	1.95	1.47	1.06	--	--	--	73	-	
60-80	Bass, Kent	0.88	2.20	1.45	0.85	--	--	--	150	2	
80-95	East Turk, Montcalm	0.95	2.93	2.98	1.88	1.88	1.41	1.00	208	5	3.4
	West Turk, Montcalm	0.97	2.99	3.06	1.29	1.50	1.30	0.96	208	5	
	Mill, Washtenaw	1.41	3.11	1.61	2.21	1.46	1.19	--	121	3	
	Average	1.11	3.01	2.55	1.79	1.61	1.30	--	179	-	
100	Leidy, St. Joseph[1]	1.69	3.65	3.04	1.79	1.70	--	--	116	3	
	Saddle, VanBuren	1.26	3.22	2.35	1.49	1.00	--	--	156	3	
	Eagle, Kalamazoo	1.03	2.97	1.87	1.27	--	--	--	188	3	
	Stone, Cass[1]	1.63	4.51[2]	--	1.43	2.93[3]	--	--	177	2	
	Average	1.40	3.59	2.42	1.50	--	--	--	159	-	
	Overall average	1.18	2.59	1.83	1.30	--	--	--	126		2.5

[1] Treated because of heavy carp population.

[2] Second years growth; first year only 0's present.

[3] Heavy natural summer kill in August, 1962.

73 percent over the growth rate prior to treatment. At Bass Lake which had a kill estimated to be somewhat over 60 percent, the growth rate improvement was 150 percent. At East and West Turk lakes and Mill Lake between 80 and 95 percent of the fish population was removed. These lakes showed an average of 179 percent improvement in growth following treatment, compared to the pre-treatment rate. Mill Lake bluegills showed the greatest average increase in length (3.1 inches in 1957). Growth rate improvement of bluegills in the four lakes (Leidy, Saddle, Eagle, and Stone) in which the entire population was eliminated was 159 percent the first year after treatment. The year following treatment the average length of bluegills in these lakes had increased from 3.0 to 4.5 inches. The average percentage improvement in growth of fish in these lakes was lower than in lakes treated at the 80 to 95 percent level because the pre-treatment growth rate in many of these lakes was higher than in the 80 to 95 percent group. The greatest average increase in length was 4.5 inches in Stone Lake, Cass County.

Relationship between percentage of bluegills removed and duration of growth increment

No significant improvement in the growth rate in bluegills collected from Beadle Lake, Calhoun County (less than 20 percent removed), could be detected for 3 years after the treatment; therefore the duration of growth improvement was considered as 0 years. Growth rate improvement was detected for only one year in fish from lakes having a 20 to 40 percent kill, except for Woodland Lake in which improvement lasted for two years. Growth improvement at Saddle Lake might have continued longer than one year but the lake was re-treated at the 100 percent level during the second year.

Two of the lakes with a 40 to 60 percent kill (Island and Townline lakes) maintained improved growth for 2 years. A third lake (Murphy) showed improvement for about 3 years. Bluegills were not abundant at Murphy Lake at the time of treatment and have not increased in numbers significantly since the treatment. Bass Lake, Kent County (60 percent of bluegills removed), showed an improvement in growth rate for 2 years following treatment.

Of the lakes in the 80 to 95 percent reduction category, Mill Lake maintained an improvement for 3 years and the Turk lakes showed better growth for 5 years. The longer period of better growth in Turk lakes appeared to be due to predation. A large year class of northern pike appeared immediately after treatment and apparently controlled the bluegill population for several years. Good natural reproduction of pike at the Turk lakes did not continue after 1957. As the population of pike steadily dwindled, the bluegill population increased correspondingly. By 1961 in West Turk and by 1962 in East Turk bluegills were extremely abundant and were growing slowly. All the lakes which had a 100 percent removal maintained improved growth for 3 years following treatment, except Stone Lake, Cass County, which showed an improvement for only 2 years.

Thus there seems to be evidence that length of time during which growth rate improvement can be detected is correlated with the percentage of stunted pan fish removed. Very roughly one year improvement was detected when one-third of the fish population was removed, two years improvement was noted when two-thirds of the fish population was removed and some improvement was detected for three years when all or nearly all of the bluegills were removed. It should be pointed out that this is a tentative rule of thumb and is supported only by semi-quantitative estimates of population removal. Clearly, many factors are involved and more data are needed to validate this relationship.

Conclusions and recommendations regarding lake rehabilitation practices in Michigan

It is clear from the above discussions that lake rehabilitation cannot be considered a permanent or even a semi-permanent management procedure. Evidence from Michigan and other states indicates that re-population by undesirable species is relatively rapid. In lakes in which stunted pan fish had been eliminated, after a period of about 3 years, growth rate is again reduced to pre-treatment level.

In planning a future rehabilitation program, the committee (authors) advises that the benefits of such a program may last for only 3 or 4 years. In Michigan the average has been 3.6 years. The committee considers a rehabilitation project to be successful if it can provide better fishing for at least 3 years for each year it is out of production following treatment. Using this criterion of success, the committee anticipates that by using the best existing methods there should be at least a 75-percent success for rehabilitation projects. It is felt that a rehabilitation program is desirable and should be continued. However, since treatments must be repeated, it is obvious that this leads to a continuing program and the number of lakes rehabilitated must be determined by long-range budgetary considerations.

Trout lake rehabilitation is a sound management tool in situations where angling pressure is moderate to heavy and where chances of contamination are low. Increased emphasis should be given to the planting of rainbow trout. Partial poisoning of two-story lakes is generally not recommended except under conditions of intensive management. Trout stream reclamation should be undertaken only where fishing pressure is heavy and stringent precautions are taken to achieve a good kill and prevent recontamination.

Much more research in the areas of population dynamics and species interactions is required before total reclamation of warm-waters will give predictable results. Selective poisoning may be of some value when properly executed. However, because of the high reproductive potential of warm-water fish, it is essential that ecological pressure of some sort be directed against the undesired species or they probably will increase to former abundance. Such pressure may be exerted by means of frequent poisoning, or by the encouragement of predators and competitors.

There should be increased emphasis given to the reclamation of warm-water lakes. Certain warm-water lakes may be selected for management on an intensive basis. In these lakes the fish populations must be carefully analyzed and controlled and all existing management techniques must be employed in order to provide a maximum angler yield. This might include artificial cropping, pike marsh management, lake fertilization, and maintenance plantings of species not reproducing in the lake. A limited number of such intensive management lakes might be desirable to demonstrate to the public the benefits of lake rehabilitation. Not over two such lakes for the three existing regions are recommended. It is further recommended that the program not be attempted unless the Department can furnish adequate man power and competent biologists to carefully observe population changes and apply appropriate management techniques at the correct time. It is felt that the experience gained by management personnel in such manipulations will be a desirable by-product.

<u>Species and species combinations suitable for introductions following treatment</u>

A. Centrarchids

1. Bass-bluegill combination.

It is recommended that initial stocking be a combination of brood stock bass and fingerlings. Evidence of bass reproduction should appear before bluegills are introduced. Timing should be such that bluegills do not reproduce until one year following successful bass reproduction.

2. Bass alone or bass and forage minnows.

Largemouth and/or smallmouth bass may be stocked as fingerlings. Choice of these two species depends upon spawning facilities and physical characteristics in the lake. Golden shiners or fathead minnows may be stocked one year after the introduction of fingerling bass.

B. Walleyes

Although there is little evidence in the literature to support this recommendation, it is believed that walleye fry might be successful in rehabilitated lakes. It is suggested that this be tried on an experimental basis.

C. Pike-perch combination

A combination of northern pike and yellow perch is recommended if a manageable pike marsh exists. Adult perch should be introduced first. Adult pike can then be planted in the marsh after there is evidence of perch reproduction.

D. Muskellunge-perch combination

A muskellunge-perch combination is suggested for lakes in which muskellunge will reproduce or are being stocked on a maintenance basis. Adult perch should be introduced first and muskellunge planted after there is evidence of perch reproduction. Where there is no natural reproduction of muskellunge, a maintenance stocking should be made every 2 or 3 years.

E. Muskellunge-sucker combination

As in the above case the predator should not be introduced until there is evidence that the suckers are reproducing.

F. Trout

The existing policy is satisfactory except that rehabilitated lakes might be more successful if more emphasis were given to rainbow trout. A combination of rainbow and brook trout might be tried in a greater number of lakes.

Suggested research

1. Selective toxicants and selective treatments--It is recommended that further research be carried out to develop both size-selective and species-selective toxicants. It is further recommended that further effort be made to use existing toxicants on a selective basis.

2. It is recommended that research be directed toward obtaining strains of fish of low fertility and/or devising techniques for sterilization of existing strains.

3. It is felt that increased emphasis should be given to the study of population dynamics of species and species combinations that might be used in lake rehabilitation. Only through such studies can improvements be made in predicting success and in increasing yield to anglers.

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