The Canadian Fish Culturist

A Department of Fisheries Publication

A Bulletin of Information and Opinion
as to Fish Culture in Canada

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No. 6

Contents

Book Review:

Requests for earlier issues of the Canadian Fish Culturist continue to be received. A limited number of copies for the issue of May, 1949, remain on hand and distribution will be made on request until the supply runs out. However, no copies of earlier issues are now available.

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The Grayling (Thymallus signifer) in Northern Saskatchewan

by

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The grayling *(Thymallus signifer)* is a fine game fish and one of the few in Saskatchewan that can be taken consistently with fly tackle. Since it occurs only in the northern third of the province it has until recently been little known. Varied and conflicting reports have been heard as to its appearance, habits and game qualities. Now that air transportation has made accessible many northern waters, anglers are discovering the pleasures of grayling fishing. For these reasons, the Fisheries Branch of the Saskatchewan Department of Natural Resources has undertaken investigations of the game qualities, present distribution and fish culture possibilities of the grayling. Early observations have suggested that its range might be extended southward and tests are now in progress.

Distribution

Grayling are found in considerable numbers around the shores of our large northern lakes and in many of the tributary streams. From Lake Athabaska we have specimens and records from the north and south shores and especially from the east end. Black Lake and Sullivan Lake, both connecting with the Fond du Lac River near Stony Rapids, are known to have large numbers of grayling. In June, 1949, excellent fly fishing for grayling was found below Woodcock Falls on the Fond du Lac River, 15 miles above Stony Rapids. Specimens from Wollaston Lake have been taken mostly from the southwest but they are found in the outlet, Fond du Lac River, both above and below Hatchett Lake. They are present also in the Cochrane and Geikie Rivers and abundant in High Rock Lake, one of the headwaters of the Geikie. Reindeer Lake specimens come from Brochet at the north, Boundary and Tate Islands in the central part and Southend near the outlet. It was in the latter area that large spawning individuals were taken in May 1948 and 1949. The Reindeer Lake grayling are so large that they are often taken in the commercial gill nets of $5\frac{1}{2}$-inch stretched mesh. Cree Lake, about 120 miles west of Reindeer, also contains grayling.

The records of grayling from streams south of these four large lakes are difficult to verify. They occur in the Clearwater River which rises in Saskatchewan and flows northwest to meet the Athabaska at McMurray. Specimens have been taken at Preston Lake, near the headwaters of the Clearwater and at Portage La Loche, near the Alberta boundary. There have been persistent rumours of grayling in the Mudjatick River and other streams in the northern half of the Churchill drainage but it has not yet been possible to verify these. They are said to be found in Upper Foster Lake which is close to High Rock Lake mentioned above. They are known to occur in the Reindeer River below the Whitesand dam (nine miles south of Reindeer Lake) but we have no records of grayling taken between this point and the junction with the Churchill River. Thus grayling distribution in Saskatchewan can be said to be wide in the Athabaska drainage, general in the Reindeer Lake area and doubtful in the remainder of the Churchill drainage. It should be noted that Wollaston Lake is centrally located and drains into both the Athabaska and Reindeer systems. At the present time the outflow to Reindeer Lake through the Cochrane River is about twice that which leaves via the Fond du Lac River.

The waters in which grayling now occur appear to be much like those on other parts of the Pre-Cambrian Shield as far south as the Churchill River. It seems reasonable, therefore, to attempt the extension of its range by planting in such places as Lac la Ronge and Amisk Lake (near Flin Flon). Further encouragement may be taken from the fact that a closely related subspecies thrives in Montana.

Life History and Rate of Growth

The spawning run of grayling was observed at Rocky Falls on the Reindeer River, about five miles south from the outlet of Reindeer Lake. In 1948, spawning had begun by May 26 and was complete by May 30. In 1949 it began about May 25 and was complete by June 2. At this season Reindeer Lake was still mostly covered by ice and the temperature of the river water at the point of spawning ranged from 7·0° to 9·5°C. (44·6 to 49·1°F.). Most of the fish in spawning condition were taken in water from three to 10 feet deep, over gravel or rocky bottom, and in relatively quiet areas close to eddies or rapids. They were more abundant just above the rapids than below them. In other locations in northern Saskatchewan, grayling are reported to run into the mouths of small streams for spawning. There are no small streams near Rocky Falls and it is believed that spawning occurs on the rocky bottom of the main river.

Brown (1938a) notes that the grayling in high lakes in Montana usually spawn between May 15 and June 20. In these lakes the spawning is limited to a few days and often follows immediately after the ice goes out. The general observation is that stream populations in Montana spawn earlier (April and May) and that the spawning period extends over a longer period than that in lakes.

The run of grayling at Rocky Falls in 1948 and 1949 was made up of large individuals. They ranged from 16 inches (fork length), 2·1 pounds to 19·8 inches, 3·8 pounds. The average was about 17 inches, 2·8 pounds. Most of these fish were five and six years old with a few four and one seven years. A typical pair of spawning fish, five years old, is shown in the photograph, Figure 1. The male was 18 inches in length and weighed 2·5 pounds. The female was of the same length, 18 inches, but distended with eggs and therefore heavier, weighing three pounds. Of special interest is the marked difference in the dorsal fins. That of the male is much longer, extending back to the adipose. It is also low in front and high behind. The female dorsal is shorter, about 1·5 inches short of the adipose, and unlike that of the male it is high

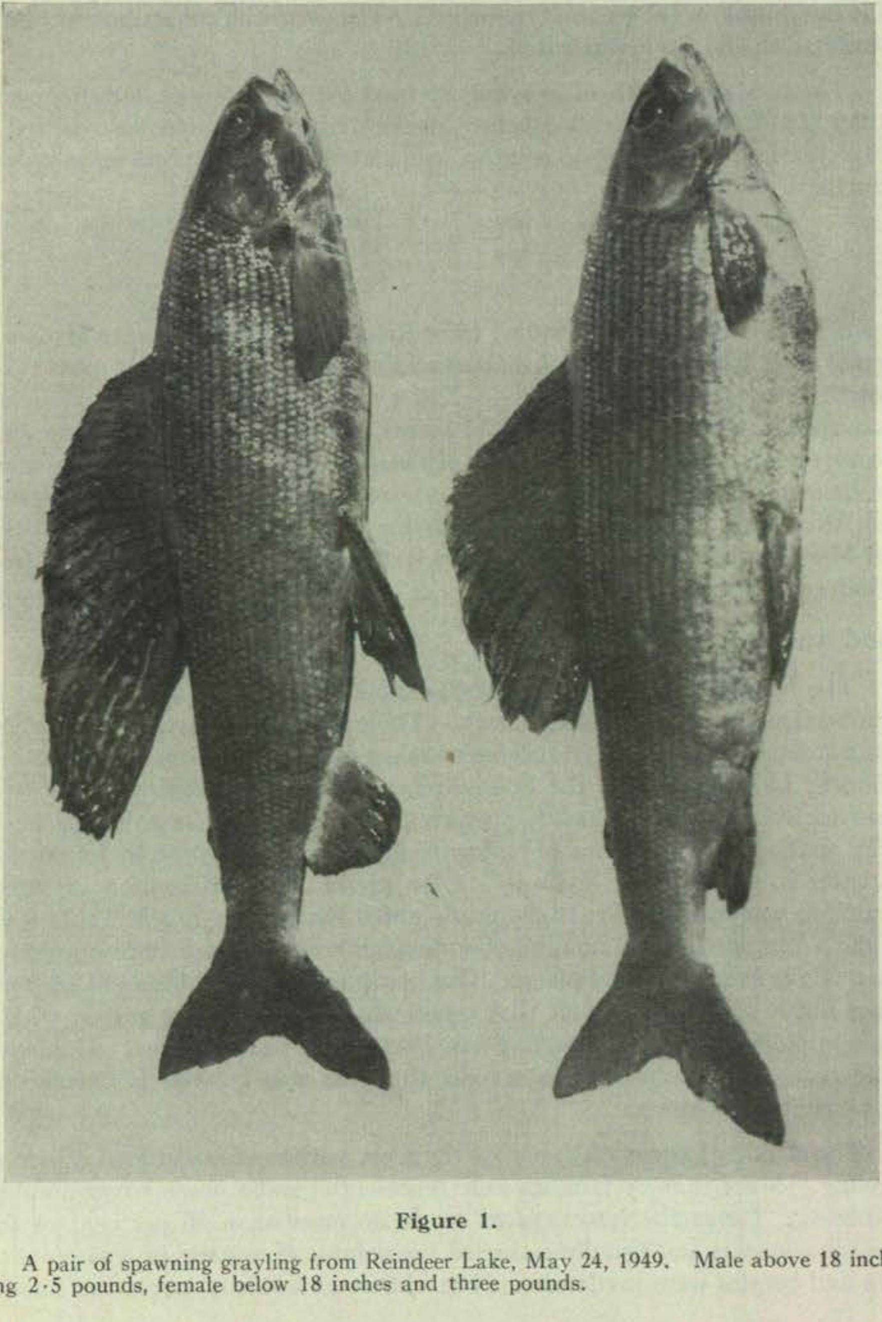

Figure 1.

A pair of spawning grayling from Reindeer Lake, May 24, 1949. Male above 18 inches long 2·5 pounds, female below 18 inches and three pounds.

in front and low behind. This sexual dimorphism was found constant in all sexually mature specimens from Reindeer and Wollaston Lakes. It was not evident in immature specimens nor in one male from Lake Athabaska, which was approaching maturity. This difference has not been recorded by Miller (1946) in grayling from Great Bear Lake nor is it mentioned in various papers which the writer has examined, although Jordan and Evermann (1896) say that the dorsal fin is "greatest in males". The geographic distribution of this character should be investigated.

The rate of growth of grayling in Lake Athabaska was determined by Miller (1946) from material supplied by the writer. His analyses resulted in the following average fork lengths, calculated at the end of each year's growth.

One year	4·4 inches	Four years	12·0 inches
Two years	7·5 inches	Five “	13·7 “
Three “	10·0 “	Six “	14·8 “

Age determinations for 26 grayling from Reindeer Lake show a rate of growth almost identical with that of Athabaska in the first two years but more rapid growth from three to six years. The average length of eight Reindeer Lake specimens five years old was 17 inches, which is two inches longer than the average for Athabaska specimens of the same age. Grayling from Wollaston Lake appear to have a growth rate intermediate between those of Reindeer and Athabaska. Great Bear Lake grayling grow more slowly (Miller 1946) and Montana lake grayling (Brown 1943) about the same rate as those from Reindeer Lake.

Food and Angling Qualities

The food of the grayling has been examined whenever samples could be obtained from northern Saskatchewan. Table I presents the results of analysis of the stomach contents of 26 specimens taken from Athabaska, Wollaston and Reindeer Lakes and from the Fond-du-Lac River. The food materials were removed from the stomachs and preserved in five per cent formalin for laboratory analysis. The volume of major food items was measured by immersion in water in a graduated cylinder. The percentage contribution of minor organisms was estimated. It should be noted that the figures in Table I are averages obtained by combining the stomach contents of several specimens taken at the same time and place. This provides a general picture of the food taken but it obscures the fact that occasional specimens were gorged with a single organism, e.g. some grayling had fed only on caddis larvae. Unidentifiable organic matter found in several stomachs was ignored in calculating the percentage volumes.

The striking feature of Table I is the great variety of insect food taken by grayling. More than 36 families were represented and a much larger number of species. Terrestrial insects often made up more than 50 per cent of the stomach contents and usually exceeded the volume of aquatic insects present. Ants and beetles were predominant but almost all kinds of terrestrial insects

Table I.

Stomach Contents of Grayling from Northern Saskatchewan (Expressed as percentage of total volume)

	Lake Athabaska		Fond-du-Lac. R.	Wollaston Lake		Reindeer Lake	
Number of Specimens	4	3	3	2	4	5	5
Length, inches	12–16 June 26 1943	11–13 Aug. 8 1945	13–15 June 20 1949	8–15 Aug. 20 1949	10–14 Aug. 12 1946	16–17 May 30 1948	17–18 May 24 1949
TERRESTRIAL INSECTS							
Orthoptera—							
Locustidae (Grasshoppers)	–	14	–	12	8	–	–
Tettigoniidae (Longhorned Grasshoppers)	–	–	3	–	6	–	–
Coleoptera—							
Carabidae (Ground beetles)	–	+	5	+	–	–	–
Silphidae (Carrion beetles)	–	–	–	2	–	–	–
Elateridae (Click beetles)	6	8	–	–	–	–	–
Buprestidae (Metallic borers)	+	–	–	–	5	–	–
Scarabaeidae (Dung beetles)	10	–	–	1	–	–	–
Cerambycidae (Long-horn beetles)	–	–	–	2	10	–	–
Chrysomelidae (Leaf beetles)	+	2	+	–	–	–	–
Curculionidae (Snout beetles)	–	6	–	–	–	–	–
Hemiptera—							
Pentatomidae (Stink bugs)	+	–	–	–	–	–	–
Aradidae (Flat bugs)	+	–	2	–	–	–	–
Miridae (Plant bugs)	–	–	–	27	–	–	–
Homoptera—							
Cicadellidae (Leaf hoppers)	–	2	–	1	–	–	–
Neuroptera—							
Sympherobiidae	–	–	–	2	–	–	–
Diptera—							
Bibionidae (March flies)	+	–	–	–	–	–	–
Rhagionidae (Snipe flies)	–	–	–	+	–	–	–
Anthomyidae	+	+	–	1	–	–	–
Muscidae (House flies)	20	–	–	2	+	–	–
Hymenoptera—							
Tenthredinidae (Sawflies)	–	2	2	–	–	–	–
Formicidae (Ants)	7	15	10	15	30	–	–
Apidae (Honey bees)	–	3	–	–	–	–	–
Ichneumonidae (Ichneumons)	+	–	–	1	–	–	–
Total Terrestrial Insects	43	52	22	56	59	0	0
AQUATIC INSECTS							
Plecoptera (Stone flies)	12	–	2	–	–	10	–
Ephemeroptera (May flies)	4	–	9	+	–	5	35
Odonata							
Zygoptera (Damsel flies)	–	–	–	3	–	–	–
Anisoptera (Dragon flies)	–	18	–	18	+	–	–
Coleoptera—							
Dytiscidae (Diving beetles)	–	+	6	–	–	–	–
Gyrinidae (Whirligig beetles)	–	–	4	–	–	–	–
Hydrophilidae (Scavenger beetles)	–	4	6	–	4	–	–
Hemiptera—							
Gerridae (Water striders)	–	–	2	–	–	–	–
Notonectidae (Back swimmers)	+	–	1	–	–	–	–
Corixidae (Water boatmen)	4	5	12	1	–	+	–
Trichoptera (Caddis flies)	6	15	21	4	–	60	55
Diptera—							
Simuliidae (Black flies)	6	–	–	4	–	–	–
Chironomidae (Midges)	–	–	5	1	2	–	–
Total Aquatic Insects	32	42	68	26	6	75	90
MISCELLANEOUS ORGANISMS							
Spiders	–	–	–	14	15	–	–
Oligochaeta (Earthworms)	3	–	–	–	–	–	–
Hirudinia (Leeches)	22	–	–	–	–	–	–
Gordiacea (Hair Worms)	–	6	–	3	8	–	–
Amphipoda (Shrimps)	–	–	–	–	12	–	+
Fish eggs (Grayling)	–	–	–	–	–	15	2
Plant marerials	–	+	10	–	–	10	8
Total Non-insect Food	25	6	10	17	35	25	10

and spiders were taken when available. Aquatic insects such as caddis, mayflies, stoneflies and dragonflies were important food items. The specimens taken at Rocky Falls in late May 1948 and 1949 had fed almost entirely on caddis larvae and mayfly nymphs. At that season, with the ice just gone from the lake, little or no terrestrial food was available. At this time also the grayling had eaten moderate numbers of their own eggs, a situation similar to that observed by Brown (1938b) in Montana lakes. Of the non-insect foods taken, spiders, leeches and hair worms predominated. Field notes on stomachs examined but not measured, indicate that amphipods and cladocerans are of considerable importance as grayling food, especially in the first and second years. Plant materials found in the stomachs have been calculated as part of the food volume but it is somewhat doubtful whether these were taken as food or by accident.

Detailed studies of the food of the grayling have been made in Montana waters by Brown (1938b) and in Ford Lake, Michigan, by Leonard (1938 and 1939). Both investigators found a great variety of insect food similar to that recorded above for Saskatchewan grayling. The habit of feeding on whatever may be available is emphasized by Leonard's observation (1938) of great differences between the morning and evening food of grayling from one location. Miller (1946) lists a varied diet for the grayling in Great Bear Lake and indicates that terrestrial insects are the principal summer food.

The omnivorous habits of the grayling and especially the wide variety of insects eaten, are directly related to its qualities as a "fly fishing" species. Tests of its angling qualities in northern Saskatchewan were made in June 1949, by N. Ferrier who visited Stony Rapids, Cree Lake and Wollaston Lake areas. He reports that a great variety of artificial flies, tied on number 10 and 12 hooks, were successful in taking grayling. Using a light seven-foot fly rod and light line he found that fish from one to two pounds provided excellent sport, comparable in his opinion to that furnished by eastern-brook or rainbow trout.

Spawning and Rearing Operations

Grayling eggs were collected in 1948 and 1949 by Mr. F. S. Mitchell of the Saskatchewan Fisheries Branch. These were taken at Rocky Falls five miles south of the outlet of Reindeer Lake. The parent stock was caught in gill nets of four and one-half inch mesh and number 90 thread. They were then transferred to wire retainers of one-inch bar mesh. The grayling were tightly gilled in the nets and suffered some damage but the location was such that traps could not be used. By clearing the nets at frequent intervals it was possible to keep alive about 80 percent of the fish caught and to use them later for spawning.

The fish were spawned by the usual technique and fertilized by the "dry" method. Most of the females produced between 4,000 and 7,000 eggs but a few of the largest yielded more than 10,000 per fish. The eggs when taken measured 10 to the inch but after several hours of "hardening" they increased to six to the inch. They were non-adhesive and heavy, sinking quickly in water. The males produced a very small quantity of milt and it was found advisable to use the milt of one male for the eggs of not more than two females.

The eggs reached the eyed stage in about 12 days after fertilization and in water of 7 to 9°C. (44·6 to 48·2°F.) Hatching required an additional 4 to 6 days in temperatures which ranged from 9 to 11°C. (48·2 to 51·8°F.). The yolk sac was absorbed in about eight days after hatching. Various workers have had difficulty in feeding the minute grayling fry. Brown (1938a) reports success with beef liver or heart ground repeatedly through a plate with 1/64-inch openings. In the absence of suitable equipment for this procedure the fry was fed for the first three days on commercial goldfish food. After this time the goldfish food was supplemented with a mixture of alfalfa meal, milk powder and soy bean meal which they ate readily for several weeks. They were later given liver prepared with an ordinary grinder but appeared to take very little of it. The fry were released on the fourth week at which time they were from 1 to 1½ inches in length.

In early June 1948, Mr. R. W. Davis, manager of the Hudson's Bay Mining and Smelting power plant at Island Falls, was given about 150 eyed eggs from which he hatched 77 grayling fry. These were fed for one month on goldfish food and later with ground beef and a weekly feeding of liver. During the summer this was supplemented by insects, molluscs and shrimps collected from the intake screens at the power plant. The fish were held in two concrete tanks each 3 x 4 x 10 feet. Each tank received a generous supply of running water. This came in from above as a jet which carried plenty of oxygen and circulated it through the water. The water temperature varied from 0·5°C. (32·9°F.) in winter to 21°C (69·8°F.) in summer. The fish were fed successfully throughout the year and when examined by the writer on May 25, 1949, they ranged from 4·5 to 7·0 inches in length and were in excellent condition. Mr. Davis hopes to expand his rearing facilities and to assist if possible in establishing grayling in the Island Falls area.

Distribution

In the 1948 operation 400,000 grayling eggs were taken. A first shipment of these was taken by plane to Island Falls where 75,000 eyed eggs were placed in Flanagan Lake and the remainder to Flin Flon where 75,000 were planted in Amisk (Beaver) Lake. At the same time six adult grayling were released in Flanagan Lake. The second lot of 250,000 eyed eggs was taken to Lac la Ronge and planted near the outlet of the lake. Eight adult fish, four males and four females, were also released in Lac la Ronge.

The 1949 operations were hampered by severe weather conditions but approximately 200,000 eggs were taken. Some of these were taken to Lac la Ronge where a small hatchery had been set up. Sixty-thousand fry were hatched and 56,000 of these were released in Lac la Ronge near the hatchery site. Four thousand were fed for about five weeks then transferred to the Montreal River (outlet of Lac la Ronge) where they were released below the

Nistowiak Falls. A further lot of nine adult grayling 15 to 18 inches long had been released in Lac la Ronge near the mouth of the Montreal River when the eggs were brought in by plane.

It is, of course, too early to predict the result of these transfers of grayling southward within the Churchill River drainage. Progress to date has been satisfactory and no unfavourable conditions have been encountered.

Acknowledgement

The writer is indebted to the Saskatchewan Department of Natural Resources for the opportunity to participate in the grayling work. He wishes to commend Fisheries Officer F. S. Mitchell for his excellent work in the field, much of it carried on under difficult conditions.

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National Parks Creel Census

by

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The idea of recording angling catches is at least several hundred years old, even on this continent, since many historical accounts record catches made by explorers.

The idea of recording the number of fish caught from water areas as a measure of the productivity of the areas for fish is also well over a hundred years old. Salmon angling clubs in many parts of the United Kingdom and on some of the more famous rivers of Quebec and the Maritime provinces have records of complete catches extending over many years.

These early attempts to collect information dealt with either single individuals or the membership of clubs or other rather limited organizations.

One of the first attempts to collect angling statistics regarding the catch of large numbers of anglers from extensive water areas was the collection of data regarding the length, weight and number of fish taken from the waters of the Maligne System in Jasper National Park, beginning in 1933. Angling in the area was first permitted in that year. The information regarding the catch of each angler was recorded by a person duly authorized to collect such information. At that time a part of the regulations governing angling in National Parks required that each angler make a return regarding his catch before leaving the area. The regulation is still in effect with minor modifications.

A considerable volume of data was collected in this manner and an analysis of these data has indicated that one unit of the system, Beaver Lake, is probably the most productive body of water of which we are aware in any National Park in Canada. This lake, with an area of only 90 acres and a depth of only about six feet produced, during the period 1933-1947 a total of 18,500 pounds or over nine tons of Eastern Brook Trout or an average of 13·7 pounds of trout per acre per year for a period of 15 years. Angling in the area has not been so heavy since 1942 with the result that the apparent productivity, as indicated by catch statistics has fallen.

Also in the early '30's certain areas in the U.S. began to experiment with the collection of angling catch statistics over large areas frequented by the general public.

The Vermont test-water studies (Lord 1946) were among the earliest efforts in this direction. In this operation, certain water areas were designated each year by the State legislature as "test-waters". All anglers fishing in such waters were required by law to file catch returns with special wardens who patrolled the areas. The test-waters were changed each year and in this manner information for a considerable number of areas for one-year periods was obtained.

First Creel Census Operations

One of the first creel census operations in Canada conducted in the manner now widely used throughout Canada and the United States, was that begun in Algonquin Provincial Park in Ontario in 1936, by the Ontario Fisheries Research Laboratory (Fry 1939). This was one of the first creel census operations in which emphasis was placed on the collection of data regarding individual sizes of fish caught, methods of angling and most important, time required to take fish (fishing effort). This census was begun, and is being continued, as a basic tool in the management of the game fish populations of the area. Changes in open and close seasons, angling regulations of several types, stocking schedules and other management operations are based, in large measure, on the information collected through the creel census each year supplemented by special studies conducted by fisheries investigators in areas where insufficient or inconclusive information is secured through the creel census.

Since its introduction in 1936 in Algonquin Park, the creel census system has been extended to other Provincial Parks in Ontario by the Ontario Fisheries Research Laboratory.

Creel census operations of a similar type were begun in Prince Albert National Park, Saskatchewan in 1940 and extended to five other parks in 1941. Since then other extensions of the work have been made and in 1948 creel census data were collected from 11 National Parks. These data were collected for the most part through the voluntary completion, by the anglers, of special creel census cards provided for the purpose. In some areas, where a more complete census is desirable, fisheries officers have been employed to assist in the collection of creel census data from anglers. Park wardens and other park personnel also assist greatly in inducing anglers to complete creel census cards.

A publicity campaign, begun in 1946 and expanded in 1947, in which reports on the results of the creel census operations in various parks were supplied to anglers who expressed an interest in the work has resulted in a considerable increase in the number of creel census returns. This is particularly true of certain areas. The distribution of "Anglers Guides", providing information on angling regulations, means of access to angling areas, suggestions regarding lures and other information useful to anglers, in nine National Parks has also helped to increase the volume of creel census returns.

During 1948, a total of 6,070 creel census cards were completed and returned, reporting the capture by 7,968 anglers, of 29,542 fish from 117 lakes and 68 streams in 11 National Parks. An analysis of this information, and its correlation with previous data from the same areas, enables the Dominion Wildlife Service to evaluate the success of fisheries management procedures used in the National Parks. This also enables the Service to modify these procedures where necessary in order to ensure the most satisfactory and effective use by anglers of each water area.

Use of Creel Census Cards

The creel census cards at present in use in the National Parks are the result of a series of modifications based on eight years experience and are designed to secure, in the simplest possible manner, data regarding the species of fish caught, their lengths, their numbers, the type of lure used in the capture, the time of day, and most important, the time, in hours or minutes, required for the capture. With this information available on a card from which the information can be conveniently extracted, the analysis of the data is greatly simplified.

It is possible, for instance, to plot a histogram showing the frequency of capture of fish of different sizes from any lake. If this indicates that too large a proportion of the angling catch consists of immature fish, then steps may be taken, by changing the regulations, to protect the desired portion of the fish population.

If the fishing effort, or number of hours required to capture a fish, becomes progressively greater for a given species of fish during succeeding years, this may be an indication of the imminent depletion of this species and steps may then be taken to check such depletion by whatever means may be most suitable, before it has reached serious proportions.

There has not, except in the case of the Maligne system in Jasper Park, been an attempt to collect creel census data for the total catch of fish taken by anglers from National Park waters. Indeed in many cases it is extremely difficult, for several reasons, to arrive at a satisfactory estimate of the percentage of National Park anglers who have, in the past, completed creel census cards. Until 1948, angling in the Mountain National Parks was conducted under license but free fishing privileges were granted to motorists and their families who purchased park seasonal motor vehicle permits. Since the proportion of motorists who availed themselves of the free angling privilege was not known, so the total number of anglers operating was not known.

A recent revision of the regulations, governing angling in National Parks, has abolished the free fishing privilege accorded to motorists with the result that in 1948, for the first time, the total number of licensed anglers in the mountain Parks was known. This information in conjunction with the creel census information collected from the same areas permitted the calculation, for the first time, of the total drain on the fish resources of the areas.

Distribution of fish and other management operations in the parks have been based, as far as possible, on the data available from the creel census together with those obtained by special studies of specific problems. This basis has proven quite satisfactory in a general way. The data obtained this year on total angling catch will, I believe, permit further refinements in the management programme with still more favourable results.

Beginning in 1948 in connection with and largely dependent on the creel census organization, is a programme of marking fish, by tagging and fin-clipping in order that their history from release to capture by anglers, may be studied. This programme, though only begun, has already given some interesting information regarding movement of lake trout in a large lake. The major importance of this programme lies in its bearing on hatchery operation. We do not know what contribution fish planted from hatcheries into certain water areas, make to the angling catch from those areas. We are relying on the returns of tagged and marked fish, through the creel census by licensed anglers, to give us the answers to these questions. It is quite probable that a different answer will be obtained from each water area investigated. In any event, until we have the answers, we cannot be sure that we are using our hatchery facilities and other management tools to the greatest advantage.

The development of means of recording and using angling catch statistics for the improvement of angling has extended over a long period of time and is still undergoing refinement. However, we now feel that we have the means at hand, through the National Parks Creel Census, of directing our fisheries management operations toward the production of angling which will satisfy increasing numbers of anglers.

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A Population Estimate Based on Catch-Effort Statistics

by

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Ontario Fish and Wildlife Division

The Department of Lands and Forests of the Province of Ontario has for some years been conducting a programme of removing smallmouth black bass *(Micropterus dolomieu)* from waters in the province where these are exceptionally abundant, but slow growing, and transporting them to waters where angling has given a low yield. The present paper concerns itself with an effort to estimate the standing crop of fish in one such harvested lake (O'Reilly Lake) on the basis of catch-effort data.

O'Reilly Lake is a small body of water of 100 acres in area lying near the edge of the Pre-Cambrian Shield in Olden township of Frontenac County. The water is quite clear, and there is no visible inlet or outlet. Springs occur occasionally along the shore. The shoreline is about 80 per cent rock with scattered areas of marsh and sand beach. The lake is surrounded by rolling, rocky farm land. Angling is limited to a few boats a week, there being no public road to the lake.

The work was begun on August 1, 1949, and fishing was continued for 18 days. During that time, 1,893 bass were removed from O'Reilly Lake for planting elsewhere in that district.

In accordance with our usual method, trap nets were set in the lake, and catches recorded from day to day. It was found that a net set in a likely looking spot would fish well, for a few days, when catches would drop off sharply. The net was then moved, in some cases only about 200 yards, and high catches would again be reported. The entire impression was one of exploitation of a series of local populations, usually in sheltered bays. The setting of the trap net is limited to rather shallow water (up to 10 feet) and no effort at exploitation of these areas where shore water was over this depth was made.

In addition to smallmouth bass, sunfish *(Lepomis gibbosus)*, suckers *(Catostomus commersonii)*, pike (*Esox lucius*), and bull head catfish *(Ameiurus nebulosus)* were encountered in the lake.

In order that the fishing effort might be reduced to standard units, trap nets were used, with 100-feet leads, of 2½-inch mesh and six-foot cribs of two-inch mesh. These nets are of the usual commercial type, made up for work of this nature. Nets of the same size were selected for purposes of standardization. They were lifted every day and moved when fishing began to drop off. Such nets retained no fish of less than six inches fork length, and the following discussion therefore refers only to fish of greater size than this. For the purpose of calculation, one unit of effort is taken as one trap net set for 24 hours, and the unit of catch is one fish. The time unit is one day.

Measured and Scale Samples Retained

Of the 1,893 fish taken in the trap nets, 156 were measured and scale samples were retained. This sample was believed to be fairly random, and measurements were taken to the nearest half inch. The mean of this sample was 8·84 ± 1·52 inches and the range was six inches to 14·5 inches. Distribution about the mean was normal except that the lower tail was cut off at six inches, the lower limit of effectiveness of the trap net.

The method of population estimation used here was described by De Lury (1947). It is based on the belief that the number of fish taken from a population by successive units of effort is governed by the total population available, and hence the population may be estimated on the basis of the observed catch per unit of effort.

De Lury bases his calculation on three assumptions.

(1) The population is closed. The effects of migration and natural mortality are negligible. An endeavour was made, by fishing intensively for the shortest possible period, to satisfy this requirement. Undoubtedly, a certain number of individuals entered the size group dealt with during the 18 days of netting, and some natural mortality and angling mortality occurred, but it is believed that this is negligible in comparison with the total of 1,893 fish removed.

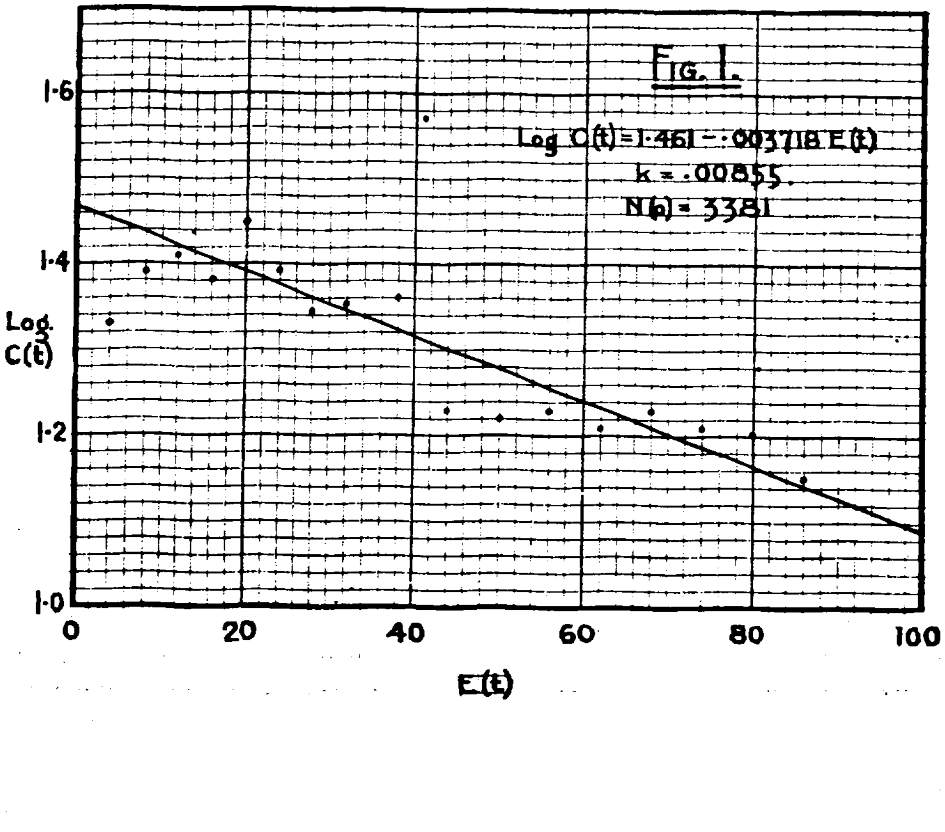

FIG. 1.

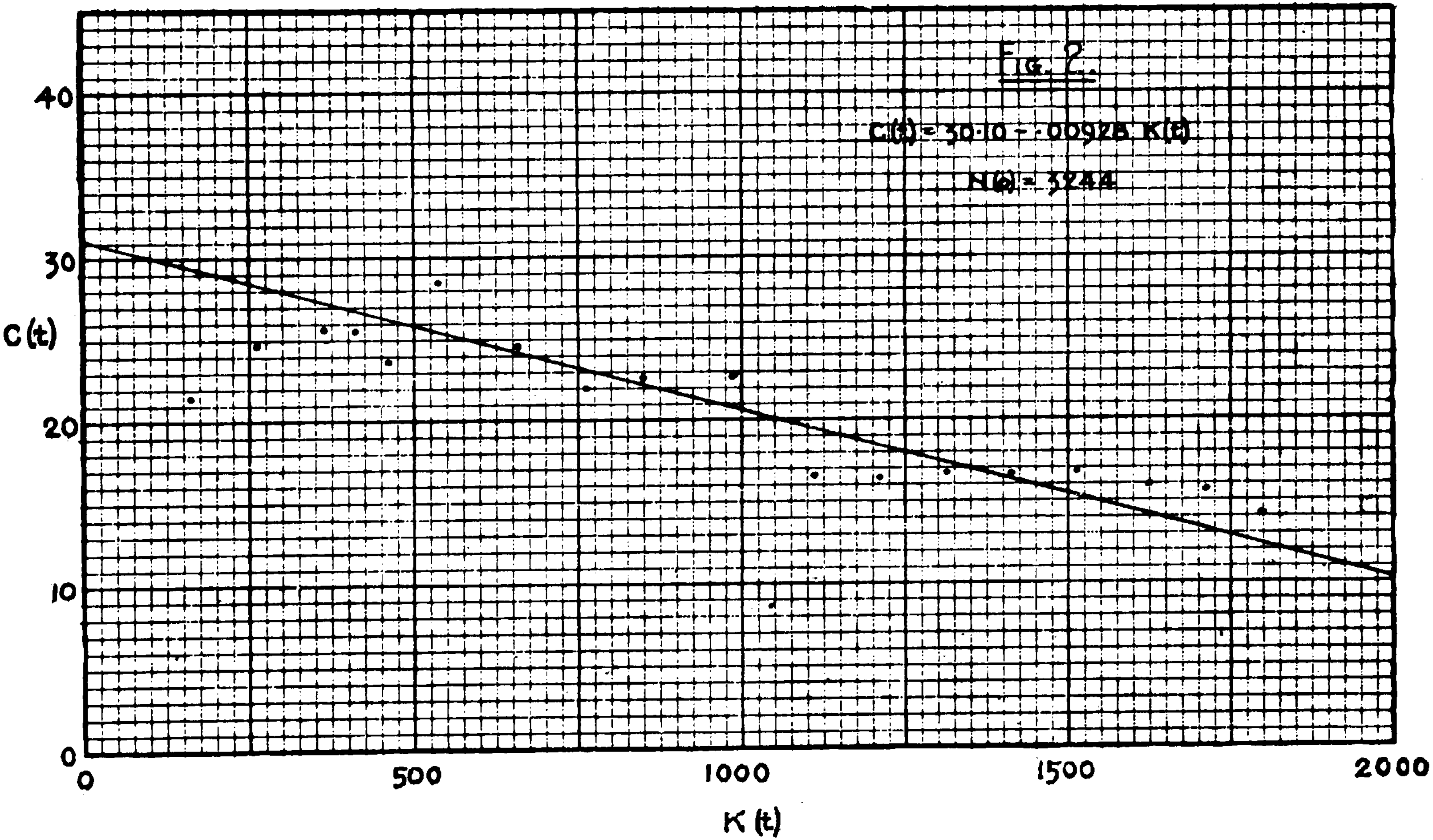

FIG. 2.

(2) That the units of effort do not compete with one another. It is believed that the nets were set in such a way that no two were competing during a given time interval.

(3) That catchability, defined as the proportion of the total population remaining in the lake taken by one unit of effort, is constant. While it is expected that day to day variations such as a decreased catch after a cool night, will occur, this assumption implies the absence of trend in catchability during the sampling period. The assumption is justified to some extent by observation since a straight line relationship in Figs. 1 and 2 is admissible.

In Table I, column one refers to time interval, and column two, c(t), to catch per unit time. Column three indicates effort per unit time and column four indicates catch per unit effort or c(t) / e(t). Columns five and six refer to cumulative catch K(t), and cumulative effort, E(t), up to the time interval concerned, i.e. at t−1, and log C(t) is self explanatory. These symbols are taken from De Lury (1947).

TABLE I.

Catch—Effort Data of the O'Reilly Lake Bass Fishing

1 Time Interval t	2 Catch Per Unit Time c(t)	3 Effort Per Unit Time e(t)	4 $C(t)=\frac{C(t)}{e(t)}$	5 Cumulative Catch K(t)	6 Cumulative Effort E(t)	7 log C(t)
1	167	4	41·75	0	0	1·623
2	86	4	21·5	167	4	1·33
3	98	4	24·5	253	8	1·39
4	102	4	25·5	351	12	1·41
5	95	4	23·75	453	16	1·38
6	114	4	28·5	548	20	1·45
7	98	4	24·5	662	24	1·39
8	88	4	22·0	760	28	1·34
9	133	6	22·2	848	32	1·35
10	137	6	22·8	981	38	1·36
11	101	6	16·8	1118	44	1·23
12	99	6	16·5	1219	50	1·22
13	101	6	16·8	1318	56	1·23
14	98	6	16·4	1419	62	1·21
15	101	6	16·8	1517	68	1·23
16	97	6	16·2	1618	74	1·21
17	94	6	15·7	1715	80	1·20
18	84	6	14·0	1809	86	1·15
				1893	92	

If the three assumptions indicated above are admissible, De Lury has shown that log C(t) = log [k N (o)] − k log e E(t), where k is the proportion of the remaining population captured by one unit of effort, which is constant by assumption (3) above, and N (o) is the number of fish present at time o , or at the beginning of the experiment.

Values of Log C(t) are plotted against E(t) in Fig. I. As will be seen by examining this figure, a straight line relationship is permissible throughout the range, and a straight line was drawn through these points by the method of least squares, the equation for this line being $\text{Log } C(t) = 1{\cdot}461 - {\cdot}003718\, E(t)$. k log e may then be equated to ·003718, and k = ·00855. If log [k N (o)] is then equated to 1·415, N(o) is computed to be 3381. On this basis, a figure of about 3,400 fish of the size group dealt with is estimated for the population at the beginning of the fishing effort.

From the equation $\log C(t) = \log [k\, N(o)] - k \log e\, E(t)$, the equation $C(t) = k\, N(o) - k\, K(t)$ may be derived.

As a check upon the above results, C(t) was plotted against K(t) (Fig. 2). A line was drawn through the points from K(t) = O to K(t) = 2000, by the method of least squares and the equation $C(t) = 30{\cdot}10 - {\cdot}00928\, K(t)$ is derived. The intercept on the x axis then gives the total of fish in the lake at the beginning of the experiment, since this indicates the limit of catch when C(t) = O. This figure is 3244, giving a figure in some agreement with the previous estimation at the beginning of the experiment.

O'Reilly lake has an area of about 100 acres measured by planimeter on topographic map $31 \frac{c}{10}$ (Tichborne). On the basis of these calculations, a standing crop of about 30 bass of six inches and over per acre is indicated. Such a figure is of little value, since it is obvious that not all the area of the lake is occupied by fish.

While the figure for total population is of theoretical value only without supporting evidence such as might be provided by a tagging programme, it is interesting to note that on this basis, well over half the fish in the lake were removed before catches began to fall off markedly. It is hoped that it will be possible to conduct a similar experiment in conjunction with a properly designed tagging experiment during the summer of 1950, since it would be most desirable from the practical point of view if cropping limits could be set on lakes used in this harvesting programme. Important data on recruitment might also be derived if the programme were conducted over a series of years.

The author wishes to express his gratitude to Dr. D. B. De Lury of the Ontario Research Foundation and Dr. F. E. J. Fry of the University of Toronto for a critical reading of the manuscript and to Mr. J. S. Hazzard of the Ontario Department of Lands and Forests for his work in setting and lifting the nets and recording the catch.

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Artificial Hybridization of Eastern Brook Trout and Lake Trout

by

J. E. Stenton

Warden, Lake Minnewanka District, Banff National Park

In the fall of 1946, a successful attempt was made to cross Eastern Brook Trout, *Salvelinus fontinalis*, and the Lake Trout, *Cristivomer namaycush*. In this first attempt a female Brook trout and a male Lake Trout were used; these eggs hatched successfully, but it was noted that a few specimens had deformed caudal fins, and all of them died. The balance, unfortunately, were all lost when chlorine was introduced into the Banff water supply.

In the fall of 1947 another attempt, on a larger scale, was made to hybridize the species. In this second trial the species concerned were crossed both ways, that is, a female Lake Trout to a male Brook Trout and vice versa. The stripping was carried out by the dry method and fertilization was successful in both cases. The Lake Trout used in this experiment were netted from Lake Minnewanka, and the Eastern Brook Trout were taken from the Third Vermilion lake and transported to Lake Minnewanka, a distance of 11 miles.

In view of the difficulty with the water at the Banff Hatchery at this time, temporary troughs were set up in the rock tunnel, under the main dirt dam at Lake Minnewanka. This tunnel was used to supply water to the old power house, prior to the construction of the present dam. After the flow of water was closed off from this tunnel, the Calgary Power Company installed a wood stage pipe, two feet in diameter, inside the tunnel, with a gate valve at both ends of the line. The top end of the tunnel was then sealed with a heavy slab of concrete; this work was carried out prior to raising the level of the lake. The water now charging this wood stave pipe, and which was used in the temporary troughs, is drawn from the lake at a depth of approximately 55 feet below the present surface of the lake. Thus the water had a constant temperature which slowly declined as the winter advanced.

The water temperature, when the eggs were first introduced on October 22, was 46°F., and the air temperature in the tunnel was 50°F. These temperatures declined slowly until a minimum water temperature of 38°F. and an air temperature of 40°F. were reached on December 18, following which they remained steady through the balance of the winter. It was quite obvious that the water governed the air temperature as it remained just two degrees warmer than the water. The tunnel was in total darkness and all work was carried out with the aid of flashlights.

During the early part of November the eggs went unchecked for a period of five days. Upon returning it was found that the fungus *Saprolegnia* had attached and covered all of the eggs, and approximately 75 per cent were dead. It was also noted that a heavy cover of dead plankton was present in all baskets and covered the bottoms of the troughs. It is suspected that this was the major cause of the rapid spread of fungus on what appeared to be healthy strong eggs. A great deal of work was necessary to try and save the remaining live eggs as they were still in the tender stage. However, success crowned the efforts and it was possible to bring a number of the remaining eggs through to the hatching stage. These eggs were moved from the tunnel to the Banff Hatchery on January 24 and remained there during the balance of the incubation period.

The change from the tunnel to the hatchery resulted in another slight drop in the water temperature.

The Lake Trout—Brook Trout hybrids reached the eyed stage on December 18, 57 days after being placed in the tunnel; hatching was completed at the Banff Hatchery by March 21, 151 days from the time of fertilization. The water temperature averaged 39°F. during the period. Approximately the same number of days were required to hatch the straight lake trout eggs. The Brook Trout-Lake Trout hybrids hatched approximately 10 days earlier and the straight Brook Trout at about the same time.

All of the Brook Trout-Lake Trout hybrids died, but a number of the Lake Trout-Brook Trout hybrids are progressing satisfactorily at the Banff Hatchery.

The final results of this cross are, as yet, uncertain. The fish may prove to be sterile, and reproduction will not occur.

Water temperatures recorded in the tunnel were as follows:—

October 22	46°F.	Air	50°F.
November 3	44°F.	Air	46°F.
November 11	42°F.	Air	44°F.
November 19	40°F.	Air	42°F.
December 6	38°F.	Air	40°F.

Water temperature of 38°F. and air temperature of 40°F. continued throughout the balance of the winter.

The fish that were hatched in the spring of 1947 are now, at 21 months of age, ranging from 12 to 14 inches in length and are very active, rising readily for flies caste on the surface of their pool. Unfortunately none of the true fry of the parent species were retained to act as a control on the growth rate.

In general appearance the hybrids favour the lake trout, but the vermiculations of the brook trout are evident on closer examination and a row of pale yellow spots is apparent just above the lateral line. The back is a pale green colour and the under section is white with no apparent colour markings.

These species were crossed again in the fall of 1947 and showed much the same conditions as earlier work with a good percentage of the Lake trout (female) and the Brook trout (male) hatching normally. On the other hand where the sexes were reversed a fairly large number hatched with a deformed caudal fin. All died. The balance are doing nicely at the Banff Hatchery. In the case of the deformed caudal fins it is estimated that the cross resulted in a much larger embryo and the Brook trout egg was not large enough to permit normal development of this appendage.

Recognition of Trout in Alberta

by

Richard B. Miller

Associate Professor of Zoology, University of Alberta

The trout of Alberta waters are not easy to identify. For rainbows and cutthroats, particularly, a rather elaborate series of measurements to determine relative sizes of body parts is necessary for absolute identification. However, it is possible to distinguish trout species fairly well using a colour characteristics and, in the following key, this method is used. One anatomical character has been retained; this is the nature of the teeth (vomerine teeth) borne on the vomer bone in the roof of the mouth. This is illustrated in the accompanying figure. (A similar figure was used originally by Professor J. R. Dymond).

Descriptive Key to Alberta Trout

GROUP A. Chars.

Lake trout, eastern brook, Dolly Varden.

Vomer bone with teeth toward front only; spots on body pale in colour ranging from yellow to red; leading edges of paired fins white; no rainbow stripe and no black spotting; fall spawning.

(1) Lake trout *(Cristivomer namaycush):*

Except at spawning time (September-November), this trout never has bright colours; it is dull grey or greenish; the spots are very pale, sometimes almost grey and occur on both back and sides; the tail has a deep fork; found across Canada in deep lakes; now established in Ghost River reservoir; a slow growing fish which will not stand heavy fishing.

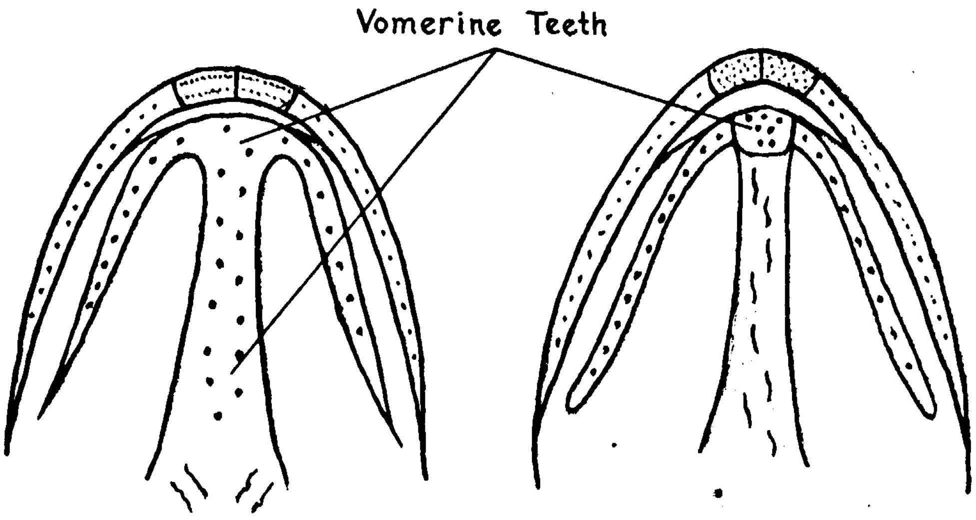
(2) Eastern brook *(Salvelinus fontinalis)*

Colours usually bright, sides with red spots surrounded by blue borders; back with dark wavy marks ("worm tracks"); tail either square or only slightly forked.

Native of eastern Canada as far west as Nelson River in Manitoba, introduced widely in Alberta and established in Maligne, Raven, Sheep, Highwood and Elbow Rivers.

(3) Dolly Varden *(Salvelinus alpinus)*

Colours duller than eastern brook; back uniformly dark; spots on sides yellow to orange or pink, without blue borders; tail forked but not so deeply as lake trout. The uniform dark back distinguishes it easily from lake trout; native to whole of east slope drainage.



ROOFS OF MOUTHS

TROUT - Left (B) CHAR - Right (A)

GROUP B. Trout

(Cutthroat, rainbow, brown or Loch Leven, rainbow-cutthroat hybrid)

Vomer bone with teeth on its whole length; black spotted on sides.

(1) Brown or Loch Leven trout *(Salmo trutta)*

Tail fin without spots; red spots on sides mixed with the black ones; these red spots often have blue borders; presence of black spots, and vomerine teeth distinguish it from eastern brook; no rainbow stripe.

Native of Europe, now widespread in slow North American trout streams; in Alberta found in Bow from Calgary up and in upper Red Deer tributaries.

(2) Cutthroat trout *(Salmo clarkii)*

Creases beneath lower jaw bright scarlet (cutthroat mark). The cutthroat mark is sometimes pale or even absent; rainbow stripe often present; on some, the sides and belly are pale but on many, the lower sides and belly are pink; this pink colour becomes stronger when the fish dies and begins to dry out.

Native to Saskatchewan drainage; absent in Athabasca.

(3) Rainbow trout *(Salmo gairdnerii)*

No cutthroat mark; rainbow stripe from cheeks to tail, along middle of each side; the red or pink colour does not extend to lower sides and belly as in cutthroat.

Widely planted in Alberta; established in a few lakes. A small variety (probably Dymond's subspecies *whitehousei*) is native to the Athabasca drainage. The rainbow has largely failed to survive in the streams of the Saskatchewan drainage; it has crossed extensively with the native Cutthroat in these waters.

(4) Rainbow-cutthroat hybrid *(S. clarkii X S. gairdnerii)*

This fish is best known in the Bow River below Calgary where it has been extensively studied by W. M. Gilmour. It is locally called "Steelhead". The colour is generally silvery; the rainbow stripe is present on small fish but faint or absent on fish of a pound or more. Sometimes a cutthroat mark is present which may be yellow, orange or red; it varies in length from a mere spot to the full length characteristic of the cutthroat trout. On a hook they behave like rainbow, leaping frequently. Mr. Gilmour observed spawning and the fish is self-maintaining.

Experimental Use of Fertilizer

Review by

M. W. Smith

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Experimental use of fertilizer in the production of fish-food organisms and fish. By Robert C. Ball. Michigan State College, Agricultural Experiment Station. Technical Bull. 210. pp. 1-28, 1949.

As a co-operative effort, the Institute for Fisheries Research of the Michigan Department of Conservation and the Michigan State College have undertaken investigations to determine the effectiveness of fertilizing representative Michigan waters for increased fish production. Although much has been learned in the southern United States upon the principles of fertilizing ponds, the author states: "Because of the many physical, chemical and climatological differences existing between the southern and northern regions, it was believed that the recommendations for fertilizing southern ponds would not be applicable to those in Michigan." However, the similarity of many aquatic environments in southern Canada to those in Michigan prompts a definite interest upon the part of Canadian investigators in the Michigan program.

This paper presents results upon the fertilization of a number of ponds (0·46 to 7·1 acres) at Wolf Lake, Drayton Plains and Hastings Fish Hatcheries. At each location, paired ponds, selected for similarity in character, were employed for each particular experiment, one being fertilized while the other remained unfertilized and served as a control. The experiments ran for one summer.

Most of the fertilized ponds received barnyard manure in early spring at the rate of one ton per 1½ acres, then all were treated, about 60 days later beginning on June 18, 1946, with a commercial fertilizer of the formula 10-6-4 ($N-P_2O_5-K_2O$), at a rate of 33⅓ lbs. per acre per week until August 26, 1946. Results disclosed that weekly or fortnightly applications at the above rate produced no better effects than applications of 100 lbs. every 3-week interval.

The production of plankton, bottom organisms, tadpoles was decidedly greater in the fertilized water. Improvements in production of minnows (creek chub and white sucker) for bait and of the largemouth black bass and bluegills did not keep step in a consistent manner with the greater production of fish foods. In certain instances survival of the fish was too low to capitalize fully upon the productive capacity of the fertilized water, while in others "volunteer" fish, such as the brook stickleback in abundance, introduced a disturbing factor. Divergence in the series of biological events in the ponds which appeared similar at the outset of the experiments in physical, chemical and biological features gave varied results, difficult of evaluation.

The results in this paper with respect to fish production demonstrate that even in small ponds which may be subjected to considerable control much experimentation is apparently needed before criteria can be established for increased fish yields through fertilization. The reviewer feels, however, that with the number of ponds at the author's disposal (21 were used) better design of experimentation could have been set up so that much of the variation that occurred could have been accounted for and the effects of the fertilizer more clearly demonstrated.

OTTAWA
EDMOND CLOUTIER, C.M.G., B.A., L.Ph.,
KING'S PRINTER AND CONTROLLER OF STATIONERY
1950

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A Department of Fisheries Publication

A Bulletin of Information and Opinion as to Fish Culture in Canada

July 1950

No. 7

Contents

Requests for earlier issues of The Canadian Fish Culturist continue to be received. A limited number of copies of issue No. 5, May, 1949, and issue No. 6, March, 1950, remain on hand and distribution will be made on request until the supply runs out. No copies of earlier issues are now available.

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July 1950 No. 7

The Square Lake Experiment:

An Attempt to Control Triaenophorus crassus by Poisoning Pike

by

Richard B. Miller

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The tapeworm, *Triaenophorus crassus* Forel, is an intestinal parasite of the pike, *Esox lucius* L. Its first intermediate host is the copepod, *Cyclops bicuspidatus* Claus, and its second intermediate host any one of a variety of salmonoid fishes, but most particularly, the coregonines. Of the coregonine fishes the ciscoes are by far the most heavily infested, but widespread infestation of the whitefish, *Coregonus clupeaformis* Mitchill, has made the parasite one of great economic importance in the freshwater fishing industry. Details of the life history have been published by Miller (1943a, 1943b, and 1945a).

For some years the control of this parasite has been a subject of conference and research. Miller (1945b) has published a list of possible control methods. The most obvious of these, control of the terminal host, the pike, is the subject of the present paper.

Various attempts to effect a control by other methods have been made; Miller and Watkins (1946) tried, without success, to kill larval tapeworms (coracidia) by acidifying a lake. This experiment failed because of the enormous buffer reserve in the bottom mud of the lake. Miller (1948a) has reported on the Alberta Government's experiment at Lesser Slave Lake, where tullibee reduction has proven to be at least partly effective in controlling *Triaenophorus crassus.*

The present experiment at Square Lake, Alberta, was based on the fundamental fact that pike move inshore to shallow water to spawn, often concentrating in relatively small areas. It seemed possible, then, that pike could be killed by rotenone poisoning at this time of year with very little disturbance of other species of fish. Also, and of considerable economic significance, the area of lake to be treated would be very much reduced. (This method of differential poisoning was suggested by Greenbank (1941) in lakes which stratified thermally.) The Alberta Government Fisheries Branch agreed to finance such an experiment and, in 1946, a suitable lake was sought. The lake must have an infested coregonine population and yet be small enough to keep costs at a reasonable level. Square Lake, with an area of 2·5 square miles, and a heavily infested cisco population (*Leucichthys tullibee* Richardson), was finally chosen.

The research plan was quite simple:—

(1) A large sample of tullibee was to be obtained, the number of cysts of *Triaenophorus* in each fish counted, and the age of each fish determined from its scales.

(2) The spawning grounds and time of spawning of the pike were to be ascertained. Then, at the proper time, rotenone was to be distributed to kill the pike. Just before the poisoning a number of marked pike were to be released to enable a calculation of total numbers of pike and the mortality caused by the poisoning.

(3) In the late summer of the year of poisoning a second sample of tullibee was to be examined. Since it has been shown (Miller 1945) that tullibee acquire their cysts in July, the infestation of each age group of the second sample, by comparison with the first, would at once indicate the effectiveness of the poisoning.

(4) If desirable, it was planned to repeat the experiment in successive springs.

(5) General information on the lake was to be obtained to as great an extent as the main programme allowed time.

This plan, with minor modifications, has been carried out for three springs, 1947–8–9. The results have shown the method to be uneconomic; no further work will be done. In this paper the account of the experiment is broken into a section on the general characters of Square Lake, a section on the poisoning of the pike, including a discussion of recoveries of marked fish, the effect on *Triaenophorus* infestation of tullibee and a section on costs.

Description of Square Lake

Square Lake lies in Township 68 Range 12–13, West of the 4th meridian. It has an area of approximately 2·5 square miles. The surrounding country is rolling and well-covered with second growth poplar and spruce scrub; extensive muskegs occupy the lower lying areas. A single inlet functions in spring and early summer; it drains a hay meadow of about two sections in extent. The outlet, Square Creek, drains into the Owl River and thence into Lac La Biche. Up until the spring of 1948 this outlet had not functioned for ten or more years. In 1948 a flood re-opened the outlet and it was still flowing in August, 1949. Most of the lake is ringed with bullrushes; lakeward of these are less abundant patches of pond lilies, while still deeper are abundant beds of submerged aquatics.

Morphometry

The shape and contours of the lake are shown on the map, Figure 1. The main body of the lake is roughly square; the shore is very regular, the shore line high and sandy. The southern shore is broken by two bays, Gregoire Bay, where camp headquarters were established, and Touton Bay. These two bays were shallow and muddy and proved to be the principal pike spawning areas.

The contours shown on the map are based on an extensive series of soundings made from a boat and located by running at constant speed on a straight line and sounding at regular time intervals. It is a surprisingly deep lake, well over 100 feet for a fair proportion of its area. The slope of the basin is abrupt; no extensive shallows occur.

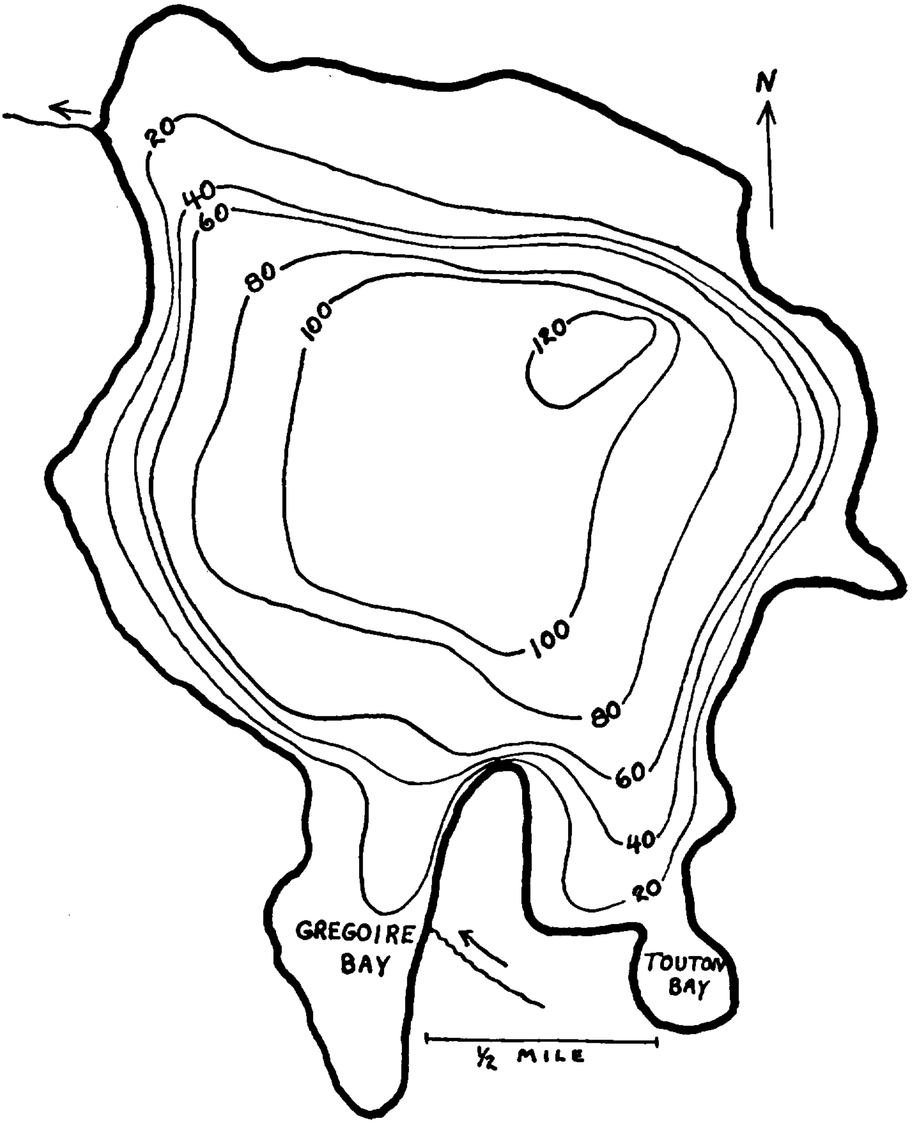

Figure 1

Shape and Contours of Square Lake, Alberta

Physical and Chemical Data

The ice cover left the lake on May 13 in 1947 and 1948 and on May 7 in 1949. The dates of freeze-ups are not exactly known, but the month of freeze-up is November.

Observations of temperature change with depth were made with a GM reversing thermometer at various times throughout the open season. These are summarized in the following table:

TABLE I

Temperature Data from Square Lake (°C.)

Depth (feet)	July 25–26, 1947	Aug. 29, 1948	May 9, 1949	Aug. 6, 1949
0	22·1	15·5	6·4	21·4
3	22·1		4·8	
7	22·0			
10	21·5	14·6	4·5	20·0
12	20·9			
15	19·0			
16·5	17·8			
18	15·0			
21	12·8	14·5		18·4
24	11·0		4·3	
30	10·0	14·5		12·8
36	8·4			
39	7·6	12·0		
42	7·5			
45	7·2	7·8		
51	6·6		4·2	
60	6·0	5·8		
80	6·0		4·0	
100	5·5	4·6		8·3

The data in Table I show that summer thermal stratification occurs in Square Lake. The epilimnion eventually extends down for some 30 or 40 feet. The deepest parts of the hypolimnion are warmed only slightly; the highest temperature observed was 8·3° C. at 100 feet in August, 1949.

The thermal stratification is accompanied by stratification of dissolved oxygen. Measurements of quantities of oxygen follow:

TABLE II

Dissolved oxygen at different depths in Square Lake

(cc./litre, uncorrected for altitude and barometric pressure)

Depth	July 25–26, 1947	May 13, 1948	[1]Aug. 29, 1948	May 5, 1949	Aug. 6, 1949
0	7·6		7·3		
20	5·2				5·9
30	3·2	4·3	6·8		3·5
62	2·9				
80	1·5	4·1		5·8	2·1
102	0·7	0·9	1·0 [1]45′—2·9		0·5

Some of the data in Table II give interesting information. For example, on May 13, 1948, there was very little oxygen at 100 feet; on the same day the temperature at this depth was 3·2° C.; this means that the spring-turnover had not yet occurred (the ice cover left the same day) and the low oxygen was a result of winter stagnation. These data also show that severe summer stagnation occurred in each of the three years of observation; in July and August the hypolimnion contained too little oxygen to support fish. (This fact probably explains the failure to survive of rainbow trout, planted in the fall of 1947.)

The summer depletion of oxygen in the hypolimnion is probably accompanied by an accumulation of carbon dioxide. This is suggested by pH determinations, made with an Hellige comparator, in July, 1947. Surface pH was 8·2; it was 7·2 at 60 feet and 6·9 at 100 feet.

Transparency, as measured with a Secchi disc, was observed from time to time. It was generally low, and even in the spring, on the day of break-up, was only five feet.

Plankton

Hauls were made each spring and again in the summers using a net of number 20 silk bolting cloth having a mouth diameter of 25 cm. In general, the plankton is moderately rich. Bottom to surface hauls yielded a settled volume of 2·7–4·3 cc., in the spring and early summer. In August the quantity increased enormously because of a bloom of the blue-green alga, *Aphanizomenon*. The zooplankters were identified by Dr. J. E. Moore. He found,—

- Copepoda
  - *Cyclops bicuspidatus*—abundant
  - *Cyclops viridis*—common
  - *Diaptomus* sp.—abundant

- Cladocera
  - *Daphnia longispina*—abundant
  - *Bosmina obtusirostris*—rare
  - *Chydorus sphaericus*—rare
  - *Alona guttata*—rare
  - *Diaphanisoma leuchtenbergianum*—rare
  - *Leptodora kindtii*—rare

- Rotifera
  - *Anurea*—abundant
  - *Nothalca*—abundant

- Protozoa
  - *Ceratium*—abundant

Phytoplankters were not common; *Anabaena* and *Aphanizomenon* became plentiful in late summer, and a few filamentous greens were usually present.

Bottom Fauna

Dredgings were taken with a six-inch Ekman dredge. A series of ten dredgings, taken in July, 1947, will serve to define the bottom fauna. These are summarized in Table III.

TABLE III

Ten dredgings from Square Lake on July 26, 1947

Depth (feet)	Midge larvae	Midge pupae	Leeches	Oligochaetes	Gastropods	Sphaeriids	Vol. (cc./ sq. foot)
10......	127[1]	3	6[2]	0	9[3]	1	1·2
31......	22[4]	3	0	11[5]	0	10	7·2
40......	11[1]	0	0	5[6]	0	2	0·8
50......	26[4]	0	0	2[6]	0	11	4·8
59......	4[1]	0	0	0	0	0	0
69......	1[1]	0	0	0	0	0	0
79......	11[1]	0	0	2[6]	0	0	0·8
107......	1[1]	0	0	0	0	0	0

1. *Tanytarsus* sp.
2. *Glossiphonia stagnalis*
3. 1 *Physa*, 3 species *Planorbis*
4. *Chironomus chironomus* sp. and *Tanytarsus*
5. *Lumbriculus* sp.
6. *Limnodrilus* sp.

From Table III it is obvious that the severe stagnation at hypolimnial depths has reduced the bottom organisms in the deep water to a very small population of midge larvae. In shallower water the fauna is moderately rich.

Down to depths of 20 feet the bottom is fairly firm and carpeted with aquatic plants of which *Lemna trisulca* was most common. In deeper water the bottom consisted of a very fine, black muck which became gelatinous and redolent of anaerobic decomposition at depths of 60–70 feet and greater.

Fish

The following were found,—

**Leucichthys tullibee* Richardson; very abundant
Catostomus commersonnii (Lacépède)—very abundant
Notropis hudsonius (Clinton)—very abundant
Esox lucius Linnaeus—very abundant.
Lota lota maculosa (Le Sueur)—common
Perca flavescens (Mitchill)—abundant
Poecilichthys exilis (Girard)—rare

The Poisoning of the Pike Spawning Areas

The pike were found to congregate in three areas at spawning time (late April to mid-May). These were a small strip along the north shore, Touton Bay and Gregoire Bay. The last area received the greatest numbers; from

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**In the spring of 1947 in a narrow strip of open water between ice and shore, the spawn of this species was found in submerged windrows stretched along approximately a half mile of sand beach. The windrows were as much as four feet wide and several inches deep. It was possible to fill a quart sealer with pure eggs by one scooping motion.*

here many pike ascended the inlet to spawn in a hay meadow. It was decided to distribute most of the poison in Gregoire Bay and give smaller doses to the other two areas and to the hay meadow.

Preliminary Marking Experiment

Each spring, before poisoning, pike were caught with gill-nets, marked by clipping a fin and released. The gill-nets were set in the narrow strip of open water between the ice and the shore. They were 'run' throughout the day so that the fish could be removed and liberated while still in good condition.

In 1947, from May 6–14, 436 pike were marked. Those caught in Gregoire Bay were marked by clipping off the left pectoral fin (with tinsnips); recaptures of marked fish were identified by clipping off the left pelvic fin. Fish caught in Touton Bay were marked by clipping the left pelvic and those caught on the north shore were marked by clipping the right pelvic fin. Recaptures of marked fish soon revealed that. the same fish frequented all three areas (Miller, 1948b). This suggested that concentrating on the main spawning area, Gregoire Bay, might enable us to attack all the pike.

In 1948, from May 7–10, 162 pike were marked by clipping off the right pectoral fin. Those caught in Touton Bay were deprived of their right pelvic fins. Recaptured fish were not marked. No fish were marked on the north shore.

In 1949, from April 26–29, 330 pike were marked by clipping the left pelvic fin. The same mark was used in all localities. Recaptured fish were not marked. Recaptures of 1947 and 1948 marked fish were killed. Spring came a full week earlier in this year, and, as the run-off was not great, it was possible to install a trap in the inlet creek. Here 68 of the fish which were marked were captured.

Application of Poison

In 1947 and 1948 the poison used was Atox, a C.I.L. preparation containing approximately 0·5 per cent rotenone. Because of this small rotenone concentration a preliminary test of toxicity was made using pike in two 148 gallon tanks.

From observations made on these tanks it was concluded that 1 p.p.m. was ineffective, 2 p.p.m. were lethal in about six hours and 5 p.p.m. were lethal in about two hours. (The average temperature throughout the experiment was approximately 4° C.) In poisoning the pike spawning areas the objective was set at a concentration of at least 2 p.p.m. of Atox, and the necessary calculations were made to determine the quantities required.

Aquarium experiments by Leonard (1939) found that 0·5 p.p.m. of derris powder with 5 per cent rotenone content was required to kill all species of fish; subsequent work in the field by many workers has confirmed this figure. It represents a rotenone concentration of 0·025 p.p.m. Atox at 2 p.p.m. represents a rotenone concentration of 0·01 p.p.m. While this quantity proved effective in killing pike it was noticed that common suckers were only slightly affected.

The Atox was distributed in the lake by towing burlap bags filled with it behind a boat powered with an outboard motor. Similar bags were dragged along the shore, in shallow water, by men walking. In these ways the following amounts were distributed:

1947,	inlet creek,	30 lb.	on May 10
	Touton Bay,	200 lb.	on May 11.
		200 lb.	on May 13.
		150 lb.	on May 15.
	Gregoire Bay,	1000 lb.	on May 13.
		500 lb.	on May 14.
		700 lb.	on May 15.
	North Shore,	200 lb.	on May 16.
		2980 lb.	
1948.	Hay meadow	50 lb.	on May 6.
		150 lb.	on May 7.
		200 lb.	on May 8.
	Touton Bay	400 lb.	on May 12.
	Gregoire Bay	500 lb.	on May 11.
		500 lb.	on May 12.
		500 lb.	on May 13.
		2300 lb.	

The flood in the spring of 1948 resulted in a large body of water covering the hay meadow from which the inlet creek rises. A large concentration of pike here dictated the increased poisoning.

In 1949 a supply of Fish Tox was obtained. It was distributed in the same way as the Atox as follows:

Hay meadow and inlet creek,	31 lb.	on April 28.
	30 lb.	on April 29.
Touton Bay,	181 lb.	on April 29.
Gregoire Bay,	510 lb.	on April 30.
	510 lb.	on May 2.
	360 lb.	on May 7.
	330 lb.	on May 9.
Outlet Creek,	60 lb.	on May 1.
	2012 lb.	

In addition to the Fish Tox, Atox, (left over from 1948,) was applied as follows:

Touton Bay,	300 lb.	on May 6.
	200 lb.	on May 9.

Recovery of Poisoned Fish

Pike began surfacing within one to two and one-half hours following application of poison (Atox and Fish Tox). They swam at the surface with their bodies inclined so that the snout broke water but the rest of the fish was submerged. Fish so affected had not necessarily received a lethal dose; if their random swimming carried them out of the poisoned area many, perhaps most, recovered.

While Leonard (1939) reported that fish affected to the point of equilibrium loss would not recover, Vestal (1942), Smith (1940) and Krumholtz (1948) have recorded ample evidence to indicate that such fish will recover when transferred to fresh water.

In 1948, it was observed that fish actually fled from the poison. Thus the hay meadow was poisoned on May 8. On May 9 a search for dead fish turned up 50. These were all in or near the outlet of the meadow, whereas, during the poisoning they were scattered to its most remote parts. Furthermore, a search revealed another 95 scattered along two or three miles of the creek running from the meadow to the lake. Only three fish could be found, dead or alive, in the meadow itself. Obviously, the pike had been driven out by the Atox; an unknown, but probably large number regained the lake and remained alive.

Fish which remained in the treated areas and succumbed to the poison were very difficult to recover. The majority, in their death agonies, had plunged head foremost into the bottom mud, with such force that the head and forepart of the body half way to the dorsal fin were buried. These fish remained there, even after decomposition had begun. As the transparency was only about five feet, many, probably most, of such fish were not found. Of the small minority of pike which died floating at the surface, herring gulls took a large share. Practically all yearling pike disappeared in this way as the gulls seized them soon after they first surfaced and before they were dead.

As a consequence of these facts, the recoveries of poisoned pike were very small and disappointing. They were,—

In 1947, 21 of the 436 marked pike were recovered.

In 1948, 11 of the 162 marked pike were recovered.

In 1949, 48 of the 330 marked pike were recovered.

Ball (1948) poisoned a small lake in Michigan in which marked trout and bluegills had been liberated. He tried to effect a complete kill but recovered only 58·9 per cent of the marked bluegills and 44·7 per cent of the trout.

Since the number of fish killed but not recovered is unknown and, possibly, large, no confidence may be placed in calculations of total population or of total mortality based on returns of poisoned, marked fish. It was necessary, therefore, to supplement these data with returns of marked fish taken in gill-nets each year.

The poison affected only a few fishes other than the pike. Common suckers were taken in the gill-nets in small numbers with the pike. Not more than a half dozen of these were found dead following poisoning. No other large fishes were present on the pike spawning areas; a few perch were killed on the fringes of the operation. Small fishes were variously affected. Spot-tailed minnows were killed in very large numbers but Iowa darters and young burbots were little affected. The young burbots were seen 'belly-up' on the bottom but they eventually recovered.

Mortality Calculations

During the time that gill-nets were being operated to catch pike for marking, a number of marked fish were recaptured. During and after poisoning gill-nets were set and further recaptures of marked fish were made. These recoveries of marked fish may be added to the returns of poisoning and used to make estimates of the total population of pike. The estimates were made using a Schnabel-type formula as explained by Ricker (Ricker 1948; Schnabel 1938). The following populations were calculated.

Population in spring of 1947—1456
Population in spring of 1948—1076
Population in spring of 1949—3190

These somewhat alarming figures suggest that the control campaign, while it disposed of about a quarter of the fish in 1947 led, in 1948, to an increase of nearly 300 per cent! This paradox is easily explained; the spring flood in 1948, as mentioned earlier, opened the outlet of Square Lake to Owl Creek. This outlet remained open all summer, and, although it was screened vandals broke the screening out. An enormous influx of new pike must have taken place.

Having established the numbers of pike present at the beginning of each year's operations it is now desirable to determine the mortality that occurred each year. In the previous section it was explained that returns of marked poisoned fish were too small to be reliable in calculations. Consequently no estimate of mortality due to poisoning alone is available. Instead the returns of marked fish during the year of marking and in subsequent years must be used. Such estimates give total mortality—a compound of poisoning, netting and natural mortality. Natural mortality in pike is low so that most of the mortality must be due to the poisoning and netting operations. There are several ways of using the data to calculate mortalities. These serve as checks upon one another and strengthen the validity of the data.

(I.) Mortalities estimated from returns in 1949 of fish marked in 1947, 1948 and 1949.

In 1949 there were 1527 fish killed that were in the same size range ('net') as fish marked. Of these 1527 fish, 24 had been marked in 1947, 25 in 1948 and 88 in 1949. The total of 1949 marked fish known to be at large before killing began was 328.

Then, if R represents recaptures of marked fish and N represents total marked fish at large,

$$\frac{R\ '49}{N\ '49} = \frac{R\ '48}{N\ '48} = \frac{R\ '47}{N\ '47}, \text{ or}$$

$$\frac{88}{328} = \frac{25}{N\ '48} = \frac{24}{N\ '47}$$

By solving this equation we find,—

N '48 = 93 (number of 1948 marked fish alive in 1949)
N '47 = 89.

In 1948, 162 fish were marked. The survival to 1949 was, therefore, $\frac{93}{162} = 0{\cdot}58$, and, by subtraction, the mortality from 1948–1949 was 0·42 or 42%.

In 1947, 436 fish were marked. The survival of 1947 fish to 1949 was, therefore, $\frac{89}{436} = 0{\cdot}20$, and the mortality 0·80 or 80%. We have shown that mortality from 1948–1949 was 42%. Therefore, of this 80% mortality from 1947–1949, 80 − 42 or 38% occurred from 1947–1948.

Summarizing, we have,—

Mortality 1947–48 = 38%
Mortality 1948–49 = 42%.

(II.) Mortality from 1947–1948 calculated from the formula $S = \frac{R_2M}{NQ}$.

Ricker (1948) has explained the use of this formula where S = survival, R_2 = returns in year 2 of fish marked in year 1, N = total marked in year 1, Q = returns of fish marked in year 2, and M = total fish marked in year 2. In 1948 these quantities were:

R_2 = 91
N = 436
Q = 50
M = 162

Therefore, survival from 1947–48 $= \frac{91 \times 162}{50 \times 436} = 0{\cdot}67$

Mortality = 0·33 = 33%.

(III.) Mortality from 1947–48 calculated from the ratio of 1947 to 1948 marked fish in a catch in 1948.

In 1948 a catch of 477 fish contained 50 fish marked in 1948 and 91 marked in 1947. Let x equal the number of fish marked in 1947 that survived to 1948. Then

$$\frac{91}{50} = \frac{x}{\text{number marked in 1948}}$$

$$= \frac{x}{162}$$

$$x = 295.$$

Of 436 fish marked in 1947, 295 survived to 1948. The mortality must be, $\frac{141}{436} = 0{\cdot}32 = 32\%$.

(IV.) Mortality from 1948–49 calculated from the ratio of 1947 marked fish caught in 1948 (R_2) to those caught in 1949 (R_3).

In 1948, 91 (R_2) fish marked in 1947 were caught; in 1949, 39 (R_3) fish marked in 1947 were caught. Survival will be $\frac{39}{91} = 0{\cdot}43$

Mortality from 1948–1949 equals 0·57 = 57%.

(V.) Summary of mortality calculations, 1947–48, 1948–49.

From I, mortality 1947–48 = 38%
II, mortality 1947–8 = 33%
III, mortality 1947–8 = 32%
Average = 34%

From I, mortality 1948–9 = 42%
IV, mortality 1948–9 = 57%
Average = 50%

The various calculations provide quite reassuring checks on one another and enable reasonably reliable averages to be calculated.

(VI.) Comparison of apparent and real mortalities and the derivation of a value for real mortality caused in 1949.

Since there have been no returns of 1949 marked fish except those during the poisoning the mortality cannot be calculated by the methods used for the 1947 and 1948 operations. An estimate can be made in another way:

The mortality calculated for 1947 was 34% (Section V). During operations in 1947, 61 marked fish were recovered out of a total of 436 marked. The apparent mortality was, therefore, $\frac{61}{436} = 0{\cdot}14 = 14\%$. The real (calculated) mortality has been calculated at 34% or 2·4 times the apparent mortality.

The mortality calculated for 1948 was 50% (Section V). During operations in 1948, 16 marked fish out of a total of 162 marked fish were recovered. The apparent mortality was $\frac{16}{162} = 0{\cdot}10 = 10\%$. The real (calculated) mortality was 5 times greater.

During operations in 1949, 90 marked fish out of a total of 330 marked fish were killed. This is an apparent mortality of 27%. Reasoning from the average of the relation between apparent and real mortality in 1947 and 1948, this mortality represents less than one-third of the real mortality. The real. mortality must have been about 86%.

The populations and the observed and calculated kills may now be set down as follows,—

Date	Population of pike	Observed kill	Calculated kill
1947	1,456	225	495 (34%)
1948	1,076	430	538 (50%)
1949	3,190	1,617	2,740 (86%)

The much more effective kill in 1949 was due to the use of the Fish Tox. That this large kill really occurred is substantiated, to some degree, by fishing operations carried out in August, 1949. From the fifth to the eighth of this month a total of 950 yards of gill-nets was set in pike waters; only 23 were caught, or 2·4 pike per 100 yards of net. In August, 1948, 300 yards caught 14 pike or 4·7 per 100 yards of net.

Effect of Pike Reduction on the Infestation of Tullibee

Throughout the experiment a detailed analysis of the infestation of the tullibee has been made. The first samples were taken in November, 1946, and served to establish the degree of infestation of each year class of tullibee before any operations began. Another sample in May, 1947, would also show no effects of treatment. These samples totalled 402 fish. After the first poisoning 473 tullibee were examined in July and October, 1947, and May, 1948, to measure its effect. The effect of the second poisoning was noted by examination of 312 tullibee in August, 1948, and May, 1949. The final sample, taken to assess the results of the third poisoning, was taken in August, 1949. It consisted of 500 fish. Altogether, 1687 tullibee have been weighed and measured and cut up for cyst counts; and scale samples of each have been used to determine ages. All these observations are summarized in Table IV.

A study of Table IV shows that total infestation has decreased from the original level in November, 1946. The decrease, from 10·8 cysts per fish to 6·57 cysts per fish, is approximately 39 per cent. The reduction occurrred in two main steps; the first followed the first poisoning and the second followed the third poisoning. There was no significant change in infestation following the second poisoning. This is due, possibly, to the fresh influx of pike in 1948. The breakdown of the infestation into age groups of tullibee shows that the reduction in numbers of worms has been consistent, i.e., except for a sample of 112 fish in May, 1949, the worminess of each age group has decreased each year. This proves that the observed decreases in total worminess are not due to variation in the age composition of the samples, but are real decreases.

TABLE IV

Record of tullibee infestation in Square Lake throughout the experiment. Age groups with small numbers are omitted in detailed analysis but included in the average for all ages. Figures give cysts per 100 fish. Figures in brackets give number of fish of each age cut.

Date	Number fish cut	Ages and cysts/100 fish						Averages, all ages
		3	4	5	6	7	8	
November 1946	302	668(81)	1,053(180)	1,291(34)	—	—	—	970
May 1947	100	—	1,180(30)	1,201(46)	1,301(19)	—	—	1,200
Combined	—	—	—	—	—	—	—	1,080
FIRST POISONING—Calculated pike reduction of 34%								
July 1947	200	653(42)	925(51)	1,066(62)	954(30)	—	—	890
October 1947	201	592(41)	845(113)	950(45)	—	—	—	820
May 1948	72	—	580(15)	885(43)	1,090(14)	—	—	860
Combined	—	—	—	—	—	—	—	856
SECOND POISONING—Calculated pike reduction of 50%								
August 1948	200	525(41)	728(50)	730(56)	1,005(41)	1,135(11)	—	760
May 1949	112	1,255(35)	1,139(66)	1,370(10)	—	—	—	1,190
Combined	—	—	—	—	—	—	—	890
THIRD POISONING—Calculated pike reduction of 86%								
August 1949	500	413(22)	486(64)	630(139)	700(135)	790(95)	770(24)	657
	1,687							

Costs of the Experiment

Mr. H. B. Watkins, Superintendent of Fisheries for the Department of Lands and Forests, Province of Alberta, has prepared a rough estimate of the costs borne by his department in financing the experiment. Only a rough estimate is possible since several of the men who assisted with field work were Provincial Fishery employees who worked partly at their ordinary duties and partly on the experiment. Nor has any attempt been made to estimate the deterioration of provincial vehicles used to take equipment and personnel to and from Square Lake over very primitive 'bush' trails. The estimate, with these limitations, is as follows,—

1946	November	2 men, wages, 4 days	48.00
		Truck, 400 miles	40.00
		4 days' expenses	36.00
1947	May 5–16	5 men, wages, 12 days	360.00
		Expenses, 12 days	270.00
		2,980 pounds Atox	491.70
	July	3 men, wages, 4 days	72.00
		4 days' expenses	140.00
	October	2 men, wages, 3 days	36.00
		Expenses, 3 days	28.00
		Truck, outboards	210.00
1948	May 5–14	5 men, wages, 10 days	300.00
		10 days' expenses	250.00
		2,300 pounds Atox	322.00
		Trucks, outboards	75.00
	August	2 men, wages, 3 days	36.00
		Expenses, 3 days	30.00
		Truck	60.00
1949	April 25–May 12.	5 men, wages, 18 days	540.00
		Expenses, 18 days	450.00
		2,012 pounds Fish Tox	804.80
		500 pounds Atox	70.00
		Trucks, outboards	95.00
	August	5 men, wages, 5 days	150.00
		5 men, expenses	50.00
		Trucks, outboards	60.00
			$5,024.50

Conclusions

Since the primary object of the experiment was to determine the practicability of reducing *Triaenophorus* infestation by poisoning pike, the reduction achieved must be assessed in terms of cost. A total reduction in worminess of 39 per cent was caused, presumably, by pike control efforts which cost at least $5,024.50. The size of the lake was 2·5 square miles and its pike population only a few thousands. In the face of these facts it is perfectly obvious that the method is not practical. Application of the method to lakes of only ten or 20 square miles would bring the costs to prohibitive levels and on large lakes the costs would be astronomical. The author believes that this conclusion would still be valid if a fresh influx of pike in 1948 had not occurred. This influx did not cause an increased worminess; it merely stopped the decrease, or negated one year's operations. If we assume that one-third of the money spent (one year of three) was wasted, the remaining two-thirds is still a large enough sum to make the conclusion justified.

A second conclusion arises out of the 1948 influx of pike. Despite precautions to prevent it, pike will repopulate depleted areas very rapidly. They live in all waters from small muskeg lakes to the largest of cold, clear waters; they are virtually everywhere. Any lake with an outlet must be screened, or, some time, pike will enter. It is next to impossible to keep screens intact; most lakes are in thinly settled areas where transportation facilities are poor. It is difficult, therefore, to make regular inspections of screens. High water and/or vandalism soon render them ineffective.

The experiment was completely financed by the Alberta Department of Lands and Forests, Fishery Branch. The Fishery Branch also provided personnel, boats and engines, fishing gear, camping equipment and transportation. I am particularly indebted to Hon. N. E. Tanner, Minister of Lands and Forests, to Mr. E. S. Heustis, Fish and Game Commissioner and to Mr. H. B. Watkins, Superintendent of Fisheries, whose support made the necessary funds available. I am also indebted to these gentlemen for permission to publish.

I should also like to express my appreciation of the services of several Fishery Branch employees who assisted with the field work.

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An Experiment in Aquatic Weed Control

by

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The Fish and Wildlife Division of the Ontario Department of Lands and Forests receives many requests for advice on the removal of aquatic weed growth in privately owned trout ponds. In order to work out a standard technique, an experiment was set up to demonstrate the relative efficiency of two control agents in the Glen Major Ponds, Ontario. These ponds are at present owned by the Glen Major Trout Club, and were described by Ricker, (1932). The ponds lie in a wooded valley among moraine hills on the border between Pickering and Uxbridge Townships, Ontario County. There are three ponds in a linear series with earthen dams between. They are of considerable age, the upper pond being originally a mill pond, and form the headwater of Duffin Creek.

The ponds have always had a considerable bottom cover of Chara, and in recent years, an introduction of Elodea (Anacharis) has occurred in the two lower ponds. This plant has spread extensively in both ponds, in certain areas reaching the surface in a solid mat, and impeding fishing to a considerable extent. We were concerned with the removal of this growth from the lower ponds.

Since it was important that the fish population be preserved as much as possible, materials were sought which would be non-lethal to fish. It was decided that a formulation of 2,4-D should be used in the lower pond on the basis of the results described by Surber (1949) and Speirs (1948). Benechlor 3.C, believed to be Ortho-dichlorbenzene was chosen for the second pond, in the belief that a technique of application could be worked out which would minimize fish mortality.

Techniques Used in Two Ponds

POND No. 1

The lowest of the series of three, Pond No. 1 has an area of 3·3 acres. The bottom was covered with Chara except for a wide clear channel down the centre, and the lower portion of the pond is heavily grown with Anacharis. A triangular area one-half acre in extent was marked out in the south-easterly corner of the pond bounded by bank on two sides and by the clear channel for the most part on the third side. In this area the growth of Anacharis was heavy. Average depth of water was three feet.

On August 25, a formulation was applied to this portion of the pond, made up as follows:

46% Isopropyl ester of 2,4-dichlorophenoxyacetic acid
40% Base oil
14% Emulsifiers and sequestring agents

This had an acid equivalent of four pounds per imperial gallon. The formulation is water emulsifiable and the isopropyl ester was used because it forms a milky cloud when added to water which simplifies treatment considerably.

Two imperial gallons of the formulation were mixed with two gallons of water and applied just beneath the surface of the water by means of a Brown No. 4 open head type pressure sprayer. The formulation was such that a concentration of 5 p.p.m. by weight of 2,4-D was attained in the test area when the addition was complete. Water temperature at the time of treatment was 64° F. and pH was 8·0.

No immediate effect was noted after treatment. There was no sign of distress either among the fish or aquatic invertebrates in the pond. Cladocera and Ostracoda were quite plentiful and easily observed swimming in the shallows. Fish were observed swimming in the cloud formed by the chemical without evidencing any avoiding reaction.

POND No. 2

Above No. 1 and communicating with it by a stream running around the easterly end of the dam, Pond No. 2 has an area of about three acres and a maximum depth of 11 feet. The communicating stream flows from a funnel-like bay in the south-easterly corner of the pond. In this bay the growth of Anacharis was comparable to that in the treated area Pond No. 1. A half-acre area was laid out bounded on two sides by bank and on the third by the clear channel. This was treated with ten gallons of Benechlor 3C applied beneath the surface with the Brown's No. 4 sprayer. Treatment was according to instructions issued by the Benechlor Corporation. An endeavour was made to work from the shore out, in the belief that by this method any fish in the area to be treated would be driven ahead of the treatment into the clear channel. This worked very well and fish were observed darting out of the weed banks ahead of the boat. This compound is lethal to fish and to aquatic invertebrates. Twenty-six fish were counted which apparently had been trapped in the weed beds and could not escape. Many aquatic invertebrates were observed dead by the time the application was completed.

Some difficulty was experienced in treatment owing to the density of the weed beds. It was obvious that complete dispersion was not obtained in the denser weed beds.

Benechlor is a heavy liquid which disperses as a white cloud and quickly sinks to the bottom. This fact, and the heavy weed growth around the outflow minimized the quantity of material which was carried out by the stream, and it is believed that this loss was negligible. The temperature at the time of application was 56° F. and the pH was 7·7.

Re-Action to Applications

The ponds were visited six days after the application on August 31. At this time it was obvious that a more complete kill had been obtained in Pond No. 1 with the use of 2,4-D. This may be due to the fact that the original growth was slightly less and better dispersion of the chemical was obtained. The majority of the weed population was down from the surface and the green colour was gone. At this time there was no sign of new growth.

In Pond No. 2, considerable areas were killed out where growth was relatively light. The well-known scouring effect of Benechlor was observed, the bottom in places being quite bare. In those areas where growth was thickest, however, the chemical was less efficient and although considerable areas had been bleached out, the growth was apparently unaffected below the upper fronds of weed.

The ponds were visited again on October 4, and at that time a new growth was appearing in each pond. The concentration of Anacharis was considerably reduced from the pre-treatment level, but was reappearing with equal frequency in each plot.

It is recognized that such treatments are temporary and must be undertaken regularly to be effective. Since this is the case, the 2,4-D treatment seems to be more desirable than the Benechlor treatment. While both appear equally effective in reducing growth of Chara and Anacharis the advantage is with the 2,4-D in that it is not injurious to fish, and is much easier to apply, since the quantity used is smaller and the material itself is much lighter. We also found the 2,4-D treatment to be less expensive since the ester was purchased at $11.25 per gallon, making a total cost of $22.50 for treatment of one-half acre. The Benechlor was $3.25 a gallon, total cost for the treatment of one-half-acre being $32.50.

The author wishes to acknowledge the indispensible assistance of Dr. C. H. D. Clarke and Dr. H. R. McCrimmon of the Ontario Department of Lands and Forests, and of Mr. J. Cruickshank, technical sales representative of the Naugatuck Chemical Corporation, whose attention to the compounding of the 2,4-D formulation was invaluable.

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The Use of Nylon Netting in the Gill-Net Fishery of the Lake Erie Whitefish

by

G. H. Lawler

Royal Ontario Museum of Zoology

Nylon twine, a more efficient type of fishing gear, appeared in quantity on the market in 1949. From its first usage it seemed apparent that nylon twine would supersede linen and cotton in the gill-net industry, just as the trap-net had surpassed the pound-net in efficiency. During the early part of 1949 the output of nylon twine by the manufacturers was low yet those who were fortunate enough to obtain the meagre quantities, on stringing and then fishing the twine found, that in a body of fish, more fish were taken in the nylon twine than in either linen or cotton twine fishing in the same body. By the middle of July as many fishermen as the twine companies could supply were using the nylon netting. The fishermen and state authorities became alarmed lest nylon nets might threaten the stocks of fish in the Great Lakes. Dr. John Van Oosten at the insistence of members of the fishing industry called a meeting of fishermen, state officials and twine company representatives at Erie, Pennsylvania, on July 28, 1949, to informally discuss the question of nylon. Evidence presented at this meeting tended to show that one nylon net captured more fish than two of either linen or cotton. However, no legislative action could be taken on the evidence presented because the majority of those involved were not convinced of the necessity for such action.

The relative efficiencies of nylon, linen and cotton became a matter of importance in certain research problems, for instance in determining the contribution of different year-classes to the fishery. Advantage was therefore taken of the operations of a commercial fisherman to obtain information on this point. An experienced fisherman, on his own volition, was experimenting with nylon and linen in catching whitefish. It was not feasible for him to fish alternate nets (reason will follow later) of linen and nylon, so alternate boxes of linen and nylon were used (1 box = 6 × 60 yard nets). Records of actual catch per box for a period of 20 consecutive days were obtained from him. Only 11 days' data were used however as the fisherman did not consider it worthwhile to continue to use linen. It is felt, however, this evidence, sparse as it may seem, might give a reasonably reliable index of the efficiency of nylon. The ratio of fish per box of nylon to linen was 3.2 : 1, considerably higher than was expected.

TABLE I

Comparison of catch of whitefish in nylon and linen nets in Lake Erie per box of nets

Can. line	No. of fish per box of 6 nets		Ratio Nylon/Linen
	Nylon	Linen	
13 fathoms	17·3	5·0	3·5
14 fathoms	19·0	6·5	2·9
15 fathoms	21·9	6·4	3·4
16 fathoms	19·3	7·0	2·7
Average	20.05	6·3	3·2

The whitefish fishery in Lake Erie during the past three years has been largely dependent upon one year class, that of 1943. The Canadian catch in 1948 was relatively high with an estimated 3,500,000 pounds taken (actual figures while compiled, are not yet available for publication). It was to be expected that the catch would remain fairly high during the spring of 1949 with a gradual decrease with summer fishing. This was not the case however as the catch did not show an appreciable decrease over 1948 during this latter period.

Table II indicates that the contribution of whitefish of the 1943 year class to the commercial fishery of Lake Erie remained fairly constant during 1948–49. A decrease of two per cent cannot be considered significant. With the intensity of fishing as great as it was during 1948, one would have thought that the percentage of the 1943 year-class fish in the composition of the commercial catch would have been considerably lower in 1949. It may be concluded that the sustained high production during 1949 was directly attributable to the use of nylon twine.

In average years during the spawning season large numbers of whitefish move inshore where they are taken in the shallow water pound-nets. Questionnaire returns and observations during the fall of 1949 indicated a marked absence of spawning fish. The conclusion to be drawn from these results is that the whitefish population had been so reduced through the use of nylon twine that a sufficient spawning stock did not remain. However, the gill-net catch, as reported by the fishermen in daily reports, remained consistently high up to the end of the fishing season. This seems to indicate that although the whitefish population was intensively fished with nylon, a sufficient spawning stock did remain and that the absence of fish in the shallow waters may have been attributable to adverse environmental conditions.

Nylon Possesses Unique Physical Properties

What are the qualities which tend to make nylon twine more efficient and so much in demand? Nylon possesses a unique combination of physical properties, some of which are:

(1) It shows excellent resistance to rot-inducing organisms, mildew, etc. Because of its resistance to rot, nylon twine will not mildew or suffer loss in

strength especially in cases where there is no opportunity to dry the twine after wetting, or where it is put in storage while still damp or wet.

(2) Nylon fibre has low moisture absorption.

(3) Nylon loses about 15 per cent of its strength when wet, yet the initial tensile superiority of nylon over cotton makes it possible to use nylon from a strength viewpoint. Nylon twines have about double the wet strength of equivalent sizes of cotton twines.

(4) Nylon stretches appreciably when loaded and has high elastic recovery when the load is removed. At the meeting held in Erie, Pennsylvania, mentioned previously, the concensus of opinion was that nylon nets seemed to catch larger fish than the cotton and linen nets and fewer small-sized fish than the latter type. In view of the elasticity of nylon twine this seems quite possible.

(5) Nylon twine is exceptionally fine. The American type is reputed to be twice as fine as the Canadian, due to more twists being applied. It is the contention of the fishermen that the fish cannot see the nylon as readily as the linen. However, fishermen claimed that when nylon twine became dirty it was more easily visible and its increased efficiency over linen and cotton was lost.

Nylon twine, possessing the physical properties mentioned above is a definite asset to the fishing industry. If its efficiency is 3 : 1 as compared with linen as suggested by this test, its use would be a boon to fishermen. In order to catch the same quantity of fish, one-third the amount of nylon twine would be required compared with linen or cotton assuming the efficiency of nylon over the other twines to be 3 : 1. This should mean proportionately less effort and cost for the fishermen. The use of nylon twine, provided its use is directed in a proper and regulated fashion, could well be another step in the evolution of commercial fishing.

TABLE II

Percentage age composition of two samples of Lake Erie whitefish taken on the same date in two consecutive years (Actual numbers in brackets)

Date of Capture	Age Group					
	III	IV	V	VI	VII	VIII
12 Aug. 1948.......	2·9 (1)	82·4 (28)	8·8 (3)	5·9 (2)		
12 Aug. 1949.......	5·0 (2)	10·0 (4)	80·0 (32)	2·5 (1)	2·5 (1)	

Some Notes on Brown Trout With Particular Reference to Their Status in New Brunswick and Nova Scotia

by

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While the following article refers principally to Brown trout, *Salmo trutta*, as inhabitants of the waters of New Brunswick and Nova Scotia, the results of introductions of the species into other areas are so diverse and interesting that they merit some comment.

The first introduction of Brown trout to Canadian waters appears to have been made in Lac Brulé, Quebec, in 1890 with the progeny of eggs from Caledonia Hatchery in New York State. In 1913 the species was imported into Ontario. Much earlier than this, in 1884, Newfoundland added *S. trutta* to its indigenous salmonoid fauna. In 1921, Brown trout were first brought into the Maritimes and planted in the Saint John Hatchery ponds and Loch Lomond system, Saint John County, New Brunswick. The stock, of German origin and obtained from the United States, was considered to be from a sub-species of *S. fario* known as Von Behr's trout.

Subsequent plantings of varying numbers were made over the years in Nigger or Shadow Lake, Ping Pong Lake, Ashburne Lake, Blindman's Lake and the Loch Lomond and Little River watersheds, Saint John County, New Brunswick; in Rays Lake, Kings County, New Brunswick; in Cornwallis River, Kings County, Nova Scotia; in Clam Harbour River, Guysborough River and Salmon River, Guysborough County, Nova Scotia and in Round Pond, Halifax County, Nova Scotia.

While in some parts of Canada, Brown trout, when released, have apparently thrived, yet, on reaching maturity, they have failed to reproduce naturally. This is definitely not true of the stocks planted in the Little River, Loch Lomond, and Guysborough River watersheds. In these waters, specimens may be taken ranging in size from fingerlings to the occasional ten-pounder. The presence of fingerlings in years when they cannot be assigned to any planting admits of no other explanation than that natural reproduction is successful.

To the expert angler the plantings of Brown trout have been a success. The inexpert or non-proficient angler finds a great deal of difficulty in taking the fish in the Little River and Loch Lomond watersheds. This is not so in the case of the Guysborough. From this stream some individuals remain in the river while others resort to salt water. Those that remain in the river are yellowish on the belly and have yellow or red spots scattered sparsely among the denser black spots just above and below the median line. Each black spot is usually but not always surrounded by a pale nimbus. The anadromous individuals are bright silver on the sides, white on the belly and have black spots without nimbi. In only a very few cases will close observation reveal pale spots corresponding to the common yellow and red marks of the residual strain.

Neither the residual or anadromous Brown trout in the Guysborough has proved difficult to catch. In the stream itself, they afford good fishing as well as in its salt water estuary where numbers have been taken by trolling and a few on the fly.

Salt water usually does not appear to be a barrier to the spread of salmonoids, yet in the Maritimes Brown trout seemed to have mainly confined themselves to the waters of introduction except in the case of the Guysborough plantings. Here some of the fish have gone to sea and, as sea trout, entered Salmon River, the first stream southward, prior to its planting with Brown trout.

History of Two Strains

Following the original 1921 introduction into the Maritimes of the Von Behr type of *S. trutta*, other strains were introduced and developed locally. The histories of two of these are of interest:

(1) *S. levenensis*—This subspecies, if it may be so considered, originates in Loch Lomond, Scotland. When established in an alien habitat, it frequently shows marked changes from its ancestors both in colour and size. The original strain rarely produced individuals greater than two pounds in weight. In colour, the complete absence of red and yellow spots in the adults was one of the main barriers to their classification as *S. trutta*. On transplantation Sir J. R. G. Maitland described the occurrence of the coloured spots in fish of pure Loch Leven origin reared at the Howietoun Fishery, Scotland. Incubation of *S. levenensis* eggs from the Madison River, United States, at the Saint John, New Brunswick, hatchery resulted in many specimens with coloured spots. Mature individuals from the Madison have been reported to have reached as much as 23 pounds.

(2) "Salar-trutta" Cross—In the eighties of the last century some British fish culturists believed that the "Salar-trutta" (Atlantic salmon—Brown trout) cross reduced to one-eighth "salar" blood produced an improved "Brown trout". At the Saint John hatchery, the eggs of a two-pound Brown trout were fertilized with the milt of a 20-pound Atlantic salmon. The progeny of this cross and those succeeding proved fertile "inter se". In the first cross the ratio of those resembling the male, the female and the definite hybrids was approximately that generally accepted as a genetic probability. The results of the hybridization did not produce fish markedly better than those of any good Brown trout stock.

Comments and Opinions

Since Brown trout in their many forms appear to be of very definite interest to many people, the writer ventures hereunder some comments and opinions which may be just, but only just, possibly right.

The late Dr. A. C. L. G. Gunther split the residual Brown trout into *S. fario*, *S. s. macrostigma*, *S. lemanus* (?), *S. orcadensis*, *S. ferox*, *S. stomachicus*, *S. nigripinnis*, and *S. levenensis*. He also broke down the anadromous type into *S. cambricus*, *S. trutta*, *S. brachypoma*, and *S. gallivensis*. Dr. Tate Regan lumps all of the residual and anadromous as *S. trutta*. That Dr. Regan is apparently right is exemplified by the results of the plantings in the Guysborough for the Von Behr strain was strongly residual since many fish for generations could not migrate from the rearing ponds in which the stocks were held. The change in environment from United States waters to the more northern ones in Nova Scotia may have developed again the migratory instinct which had become latent.

The difficulty experienced by inexpert anglers with *S. trutta* in the Little River and Loch Lomand watersheds may be due to the fact that the strain has developed an inherited wariness. In so far as it can be discovered, the original hatchery stocks were obtained from waters fished by anglers since Caesar's Gallic invasion and the Roman occupation of England. During the centuries incautious fish were captured leaving the more wary and active individuals to reproduce with the result that a strain of more active or cautious fish remained. In waters which have not been fished intensively such as the small locks, tarns and moor streams in the British Isles, Scandanavia, Balkan States and Balearic Islands, it is just as easy for an unskilled angler to catch Brown trout as it is for one to catch speckled trout in the virgin waters of Labrador and Quebec.

In both continental and insular northern Europe, Brown trout and Charr are commonly indigenous in the same bodies of water yet in the Maritime provinces of Canada and in eastern United States, one frequently hears that the introduction of Brown trout caused the depletion or disappearance of the speckled trout (Charr.). This view does not appear to be well reasoned. Fine development of fishing tackle has rendered the angling effort more efficient. This effort applied to speckled trout, not yet established as a wary race, has decimated or destroyed the speckled trout in many waters in which Brown trout have been planted. When the angler finds that speckled trout have become scarce or have disappeared from these waters which still contain plenty of exotics, he is prone to blame the Brown trout instead of himself. It might be mentioned here that there are two lakes owned by clubs close to Saint John which have been fished hard for the last 80 or 90 years. These lakes still contain plenty of speckled trout but they are becoming decidedly cautious and difficult to capture.

A Novel Method of Catching Sea Lampreys

by

H. H. MacKay

Supervisor, Game Fish Section, Ontario Department of Lands and Forests.

Since the sea lamprey constitutes a potential threat to the important commercial fisheries, especially the lake trout and whitefish of the upper Great Lakes, it has been the subject of an intensive study during the past five years by Ontario and state and federal authorities of the United States. The study has been designed to obtain information pertinent to the development of practical methods for controlling the numbers of this undesirable parasite.

The initial experimental lamprey fishery conducted in Ontario in the spring of 1946 was successful. Major spawning runs were located in a few streams flowing into the North Channel, one of the chief centres of abundance being the Thessalon River. These preliminary studies were described by MacKay and MacGillivray,* 1949, pp. 148–159. Reprints of this paper are available from the Ontario Department of Lands and Forests.

One of the chief disadvantages of the portable weir used in Ontario for the capture of lampreys is that it is ineffective during periods of flood water. Observations have indicated that by the time the weir is in place in the stream in the spring of the year many lampreys have already migrated up stream. Changing the structure of the weir by increasing the height of the wings from 3 to 5 feet is impractical since it is difficult to hold it in place against the force of the current during periods of flood. A weir with slanted wings facing downstream will be tried out this year, and although this type may be more effective than the one formerly used it is also impossible to set during periods of flood water.

At the present time the Ontario department is operating a new type of weir in the Saugeen river at Southampton. This weir has been developed along the lines of the one used by Mr. Peters Lipsbergs for catching sea lampreys in streams flowing into the Baltic Sea. Mr. Lipsbergs who was formerly a commercial fisherman in Latvia, is now employed by the Ontario Department of Lands and Forests, for work on the lamprey with which he has had many years' experience.

Construction of the Weir

The construction of the weir is illustrated diagrammatically in Figs. I to V inclusive. Spruce or cedar logs are used as a foundation of the weir. A convenient length of log is 8 or 12 feet. A flat surface is hewn on opposite sides of the log and a 2 X 4 scantling is nailed along the length of the upper

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* *Reprinted from Vol. 76 (1946), Trans. Am. Fish. Soc.*

surface. Tapered holes (4 inches in diameter on the upper side and 3 inches in diameter on the lower side) are bored through the log at intervals of 5 feet. The logs are then rolled into place end to end across the stream and at right angles to the current. Stones are rolled against both sides of the log to keep it in place, larger stones being placed on the upstream side. The logs are anchored to the bottom by means of stakes driven through the holes as indicated in Fig. 1.

Pairs of poles (3 to 4 inches in diameter) are then placed at intervals of 8 feet adjacent to the foundation log as shown in Figs. II and III. These uprights are tied together by horizontal rails. The uprights stand at least 3 feet above the water and a plank catwalk is arranged between them about one foot above the water, in order to facilitate the operation of the traps.

A series of perpendicular wooden walls 28 inches wide and 18 inches apart are nailed to the edge of the 2 × 4 as shown in Fig. IV. These walls serve as dams and the water is forced through the 18 inch openings between them as indicated. Opposite each opening a trap as illustrated in Fig. V is placed. The lampreys in their endeavour to negotiate the current racing through the openings fail to do so and are washed into the trap.

It has been Mr. Lipsbergs experience that sea lampreys in their upstream migration during periods of flood in the spring follow the shores, rather than the main channel. For this reason construction starts at the shoreline and more and more traps are added across the stream as the water recedes, when there is evidence of lampreys in the outer but not the outermost trap. A similar construction of traps is undertaken on the opposite shore, both constructions eventually being tied in at midstream.

The best time to lay the foundation for a weir of this kind is during a period of low water in summer. This year, however, it was constructed with much difficulty in winter in order to avoid a year's delay.

The results of initial operations at this station up to May 15 were highly satisfactory. During this short period 6,160 sea lampreys were caught.

It is probable that some lampreys pass upstream through a weir of this kind and the extent of this migration should be checked by operating a second weir farther upstream. However, a weir of this type has many advantages over those in current use. It may be operated in flood water prior to the upstream migration of the sea lampreys in the spring or fall. It is inexpensive to operate, and does not require experienced men, except for installation and general supervision. During its operation the entire stream does not need to be obstructed in order to obtain a good catch. This arrangement is especially desirable during logging operations on large rivers.

On the whole this method bids fair to providing a useful control method especially with the object of developing a sea lamprey commercial fishery. Experiments are being conducted on the desirability of smoking lampreys and of placing them on the market. Presumably those taken during their upstream migration in the fall are the most useful for this purpose. However, proof of an upstream fall migration in Ontario streams remains to be proven.

Figure I

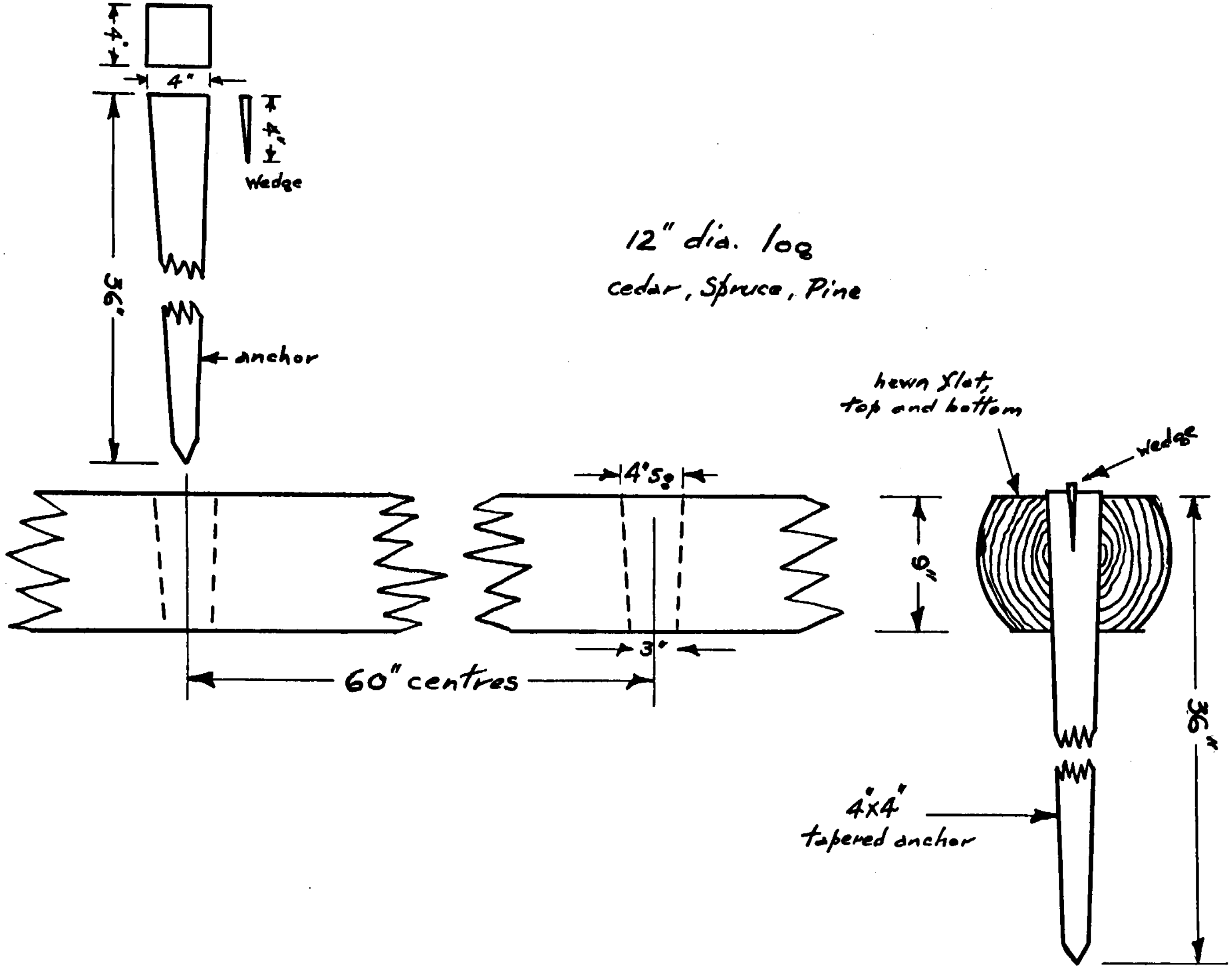

4"
4"
4"
wedge
36"
anchor
12" dia. log
cedar, Spruce, Pine
hewn flat, top and bottom
wedge
4 5/8"
6"
3"
60" centres
36"
4"x4"
tapered anchor

Figure II

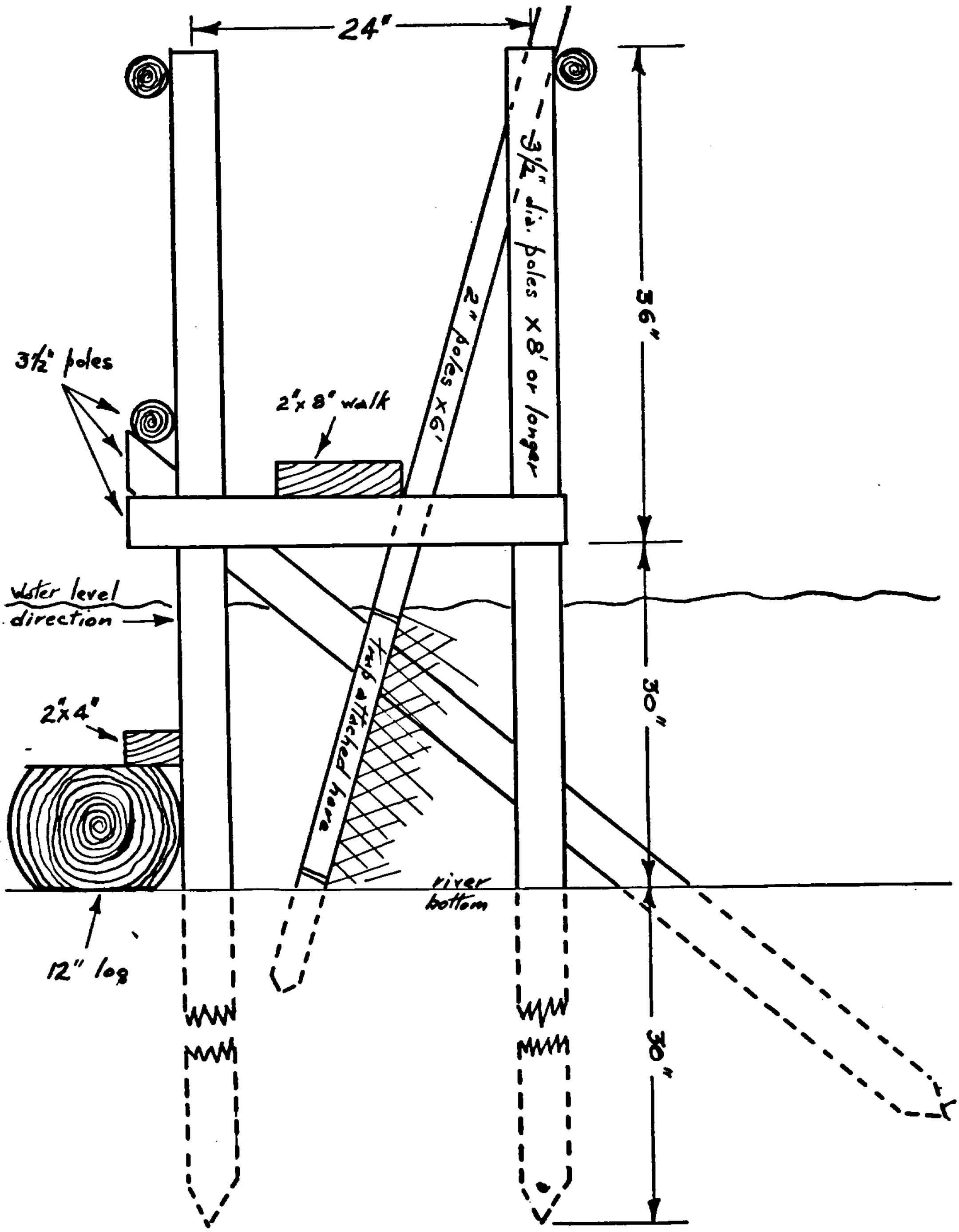

24"
3½" dia. poles x 8' or longer
2" poles x 6'
36"
3½" poles
2"x 8" walk
water level
direction
30"
trap attached here
2"x4"
river bottom
12" log
30"

Figure III. Rear View Perspective.

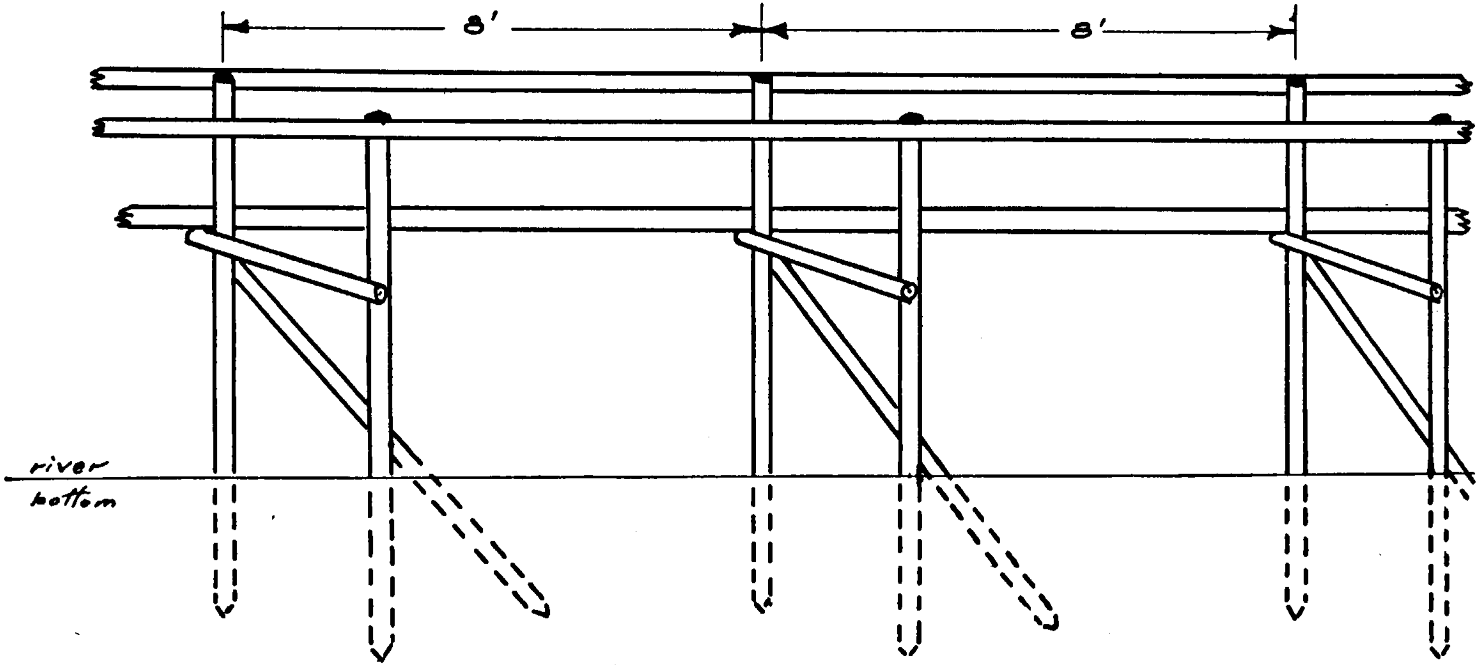


Figure IV

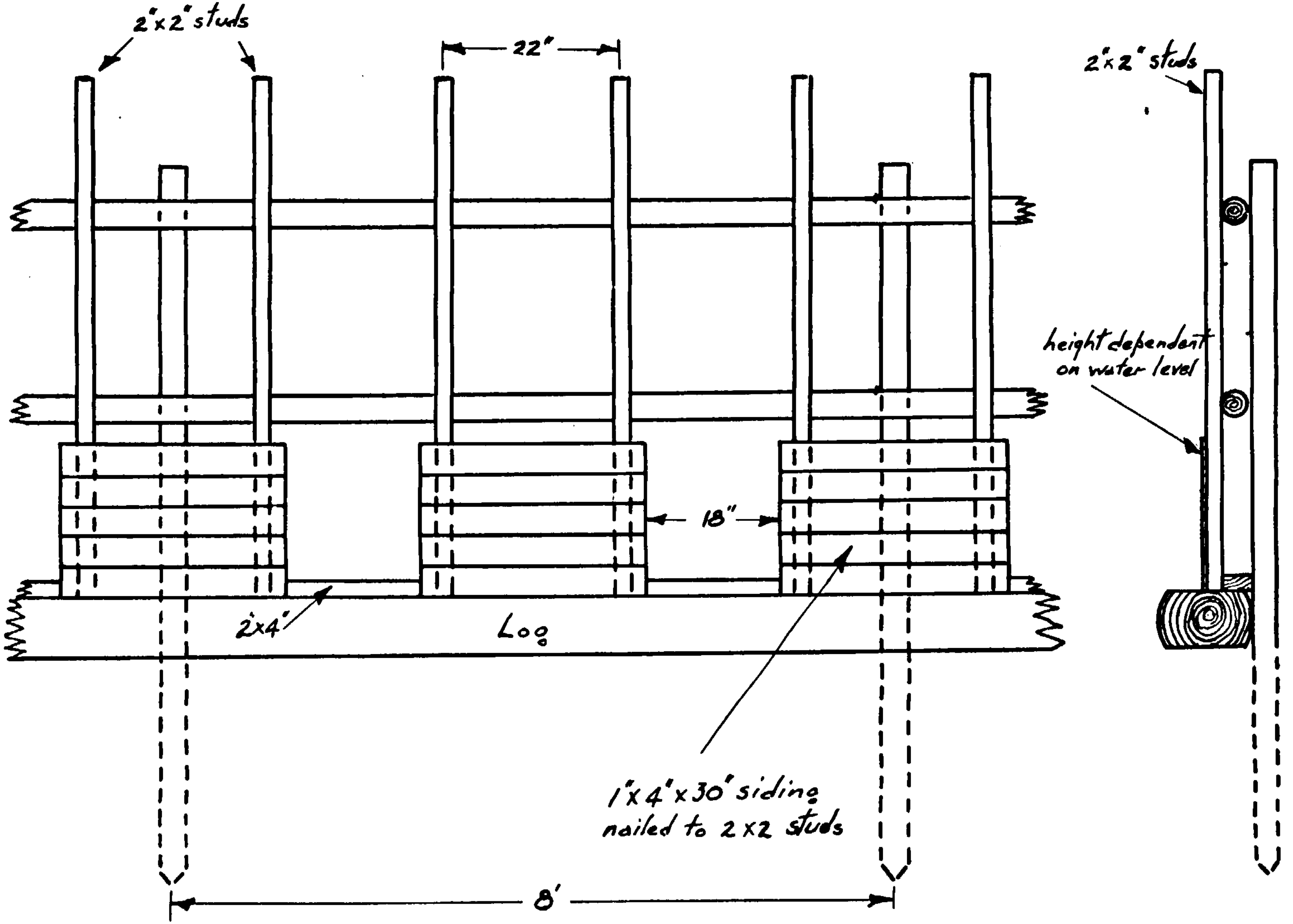
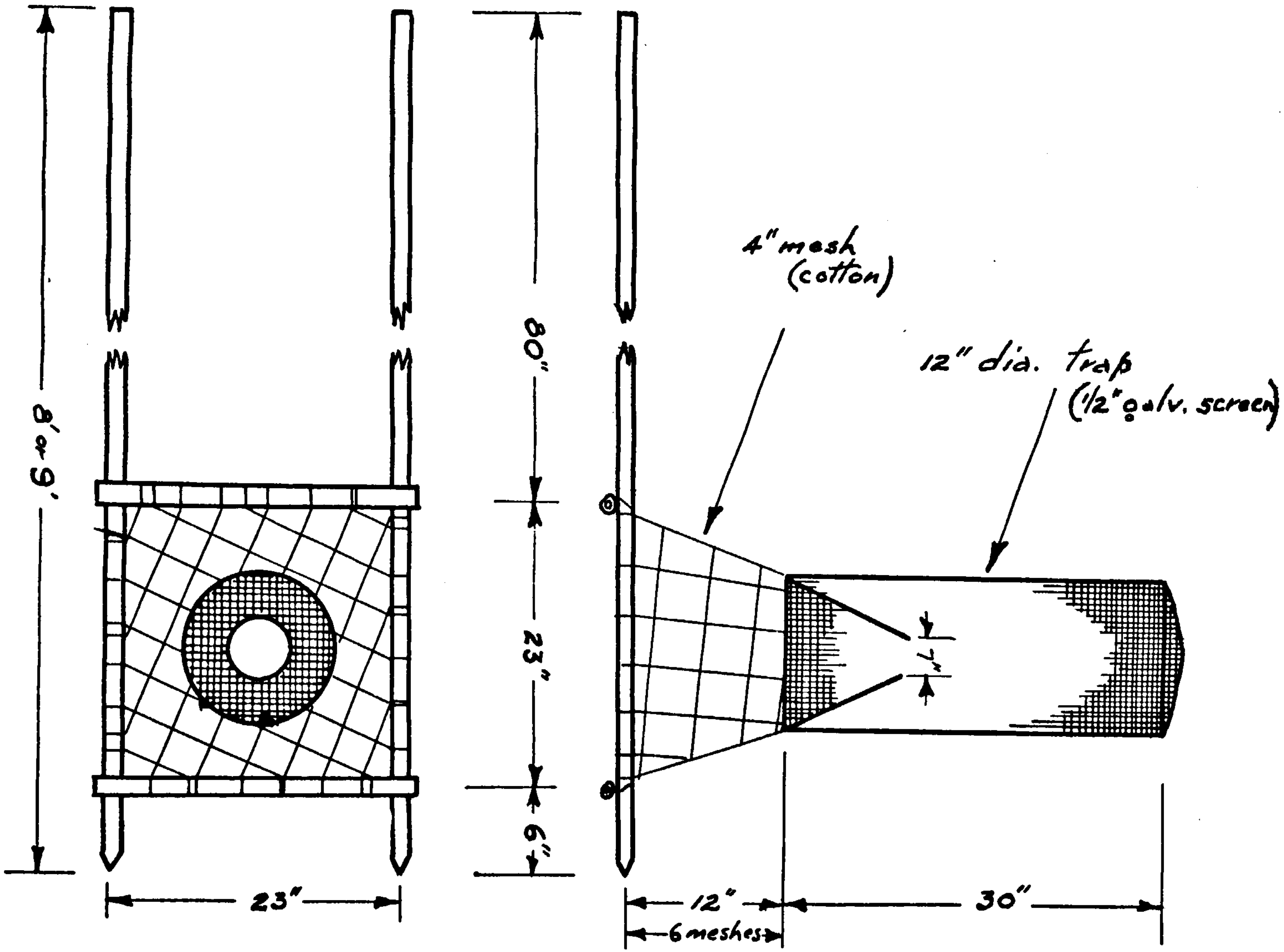

2"x2" studs
22"
2"x2" studs
height dependent on water level
18"
2x4"
Log
1"x4"x30" siding nailed to 2x2 studs
8'

Figure V


8' or 9'
80"
23"
6"
23"
4" mesh (cotton)
12" dia. trap (1/2" galv. screen)
7"
12"
6 meshes
30"

Annual Report for 1948 and Short Papers of the Institute of Freshwater Research, Stockholm

Review by

F. C. Withler

(*Assistant Biologist, Pacific Biological Station, Nanaimo, B.C.*)

Annual Report for the Year 1948 and Short Papers. Institute of Freshwater Research, Report No. 29 of the Fishery Board of Sweden, Stockholm, 1949. 152 pages, 1 plate, 27 text figures.

This is the first annual report of the Institute of Freshwater Research of the Fishery Research Board of Sweden. Formerly the Institute was directly under the Fishery Bureau of the Board of Agriculture; on July, 1 1948, the Swedish Fishery Board was established and the Institute's former director, Dr. Gunnar Alm, was appointed to the administration of freshwater fishery research within the Board. The present report is prefaced by a director's report for 1948 by Dr. Sven Runnström.

The general aim of the Institute is to investigate the possibilities of increasing the fish yield in Swedish lakes and rivers. Because the fish production of lakes depends upon the supply of suitable food, which in turn is determined by the general metabolism of the lakes, the Institute has concentrated its investigations on bottom and plankton fauna and its importance as fish food. Emphasis has been placed on the Chironomids, the most important bottom animal in the Swedish lakes, so that to date over 300 Chironomid species have been identified. The quantitative and qualitative production of insect fauna is being related to bottom biotopes, classified organically and mineralogically.

Having the knowledge of what food is available, the investigators hope, by a study of the food actually taken by different fish, to be able to populate the lakes with species which will utilize the known food fauna most efficiently. Consequently they are now undertaking extensive researches of food habits, and are considering the possible introduction of *Mysis relicta* and other organisms to increase food production for trout. Already there are indications that food supplies may be more efficiently cropped by better combinations of species within lakes, following judicious plantings of char (*Salvelinus alpinus*), trout (*Salmo trutta*) and whitefish (*Coregonus lavaretus*).

The institute is now taking the extensive Swedish fish cultural practices under consideration, and has started a critical investigation to evaluate the financial advantage of this work. The present attitude is that the existing cultural programmes need revision, and that the effort may be more beneficially directed toward particular unsatisfactory conditions, e.g. where spawning has been limited in rivers by hydroelectric dams or in lakes by regulating dams. For comparison of artificial and natural propagation, the investigators are following closely certain naturally spawning populations. Prompted by examples of differences in physiological behaviour, such as growth and time of spawning between fish morphologically similar and occupying the same lakes, the Institute is carrying on extensive examinations of systematic characters of similar groups. Such work has practical application for assessing the value of different forms before their introduction to new lakes.

Concurrently with the more fundamental research on fish yields, the Institute is investigating the effects of hydroelectric and regulating dams with the hope of utilizing the water resources to the fullest extent even though drastic changes in water environments may take place. Some practical research on producing stronger fish nets is also being done.

Twenty Short Papers

Some of the 20 short papers appended to the director's report merit special attention. Dr. Gunnar Alm describes an experiment in which he raised two closely related forms of trout, *Salmo trutta lacustris*, and *Salmo trutta fario* through two and three generations respectively under identical environmental conditions. He is able to show that the growth differences between the groups are determined by the environment, but that colouration of the body and certain fins, and the age at sexual maturity are determined by genetic factors.

In another paper by Jöran Hult and Alf Johnels, the effect of predators on plantings of salmon fry was investigated. After estimating the number of predators present in the release area by marking, the workers calculated an 11 per cent loss of the liberated fish within 24 hours. They further estimated that losses could reach 30 per cent within the same period under less ideal conditions accompanying other plantings.

In a theoretical discussion of the mechanism by which egg number in fish is determined by the effect of natural selection, Dr. Gunnar Svardson postulates that the force opposing the tendency for increased egg number is fundamentally that of the advantage gained by larvae produced from large eggs. By reason of their physical superiority in being able to forage more effectively than their smaller fellows, they grow faster during the vulnerable fry stages; hence their survival is better, allowing the genetic determinants for larger (but fewer) eggs to be maintained in the population and thereby opposing the tendency toward increased egg number. Other selection pressures no doubt are operative, but secondary in importance.

Because the Swedish inland fisheries are so closely cropped, and because fishing rights in some areas are privately owned, the fishermen are vitally interested in the biological problems of the populations affected. This is a distinct advantage to the fishery scientist who, through co-operation from the fisherman, is able to obtain accurate historical records from which he derives fundamental knowledge more quickly. The Swedish investigations characterize the thorough and meticulous work done by European researchers in general.

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Requests for earlier issues of The Canadian Fish Culturist continue to be received. A limited number of copies of issue No. 5, May 1949; issue No. 6, March 1950, and issue No. 7, July 1950, remain on hand and distribution will be made on request until the supply runs out. No copies of earlier issues are now available.

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No. 8

Introduction

Each year recently the Fisheries Research Board of Canada has convened a meeting of research workers from the Canadian universities, provincial governments and its own staff, to discuss in detail the general problems connected with freshwater fisheries research.

In January 1950, the Committee on Freshwater Fisheries Research, reviewed the question of the use and effectiveness of poisons in fisheries research and management with a view to familiarizing the group generally with the advances and accomplishments in the field. The Canadian Fish Culturist takes pleasure in presenting in this issue papers presented on the subjects in the hope of making available a background of information for others interested in the technique.

History and Use of Fish Poisons in the United States[1]

by

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The earliest use of poison to remove an unwanted fish population from a body of water appears to have been made in 1913 by Titcomb (Titcomb, 1914). Copper sulphate had previously been used in a weak concentration as an algicide and was known to be toxic to fish at higher concentrations. Titcomb determined to apply this known toxicity of copper sulphate for fish to fish management and remove from former trout ponds the warm-water fish which had been introduced with poor results. In October, 1913, Silver Lake, Vermont, was treated with 2,700 pounds of copper sulphate dragged in bags over the lake surface, and since this proved insufficient 3,600 pounds more were added in a second treatment. The lake had an area of probably less than 65 acres, and a maximum depth of 25 feet. "Pike, pickerel *(Esox lucius)*, pikeperch, yellow perch and horned pouts" were killed, but a few of the pike survived. Following this experiment a Lake Tarleton club in New Hampshire undertook to exterminate "pickerel" from a trout pond of 40 acres. The material was further tried by Graham in Massachusetts, who drained a small pond until only a stream remained running through. The spring source was then treated over a period of days. Only "bullheads" survived. Titcomb also carried out certain laboratory experiments to determine the concentrations of copper sulphate required under certain water conditions and for different species of fish.

In a later experiment, the Massachusetts State Board of Health found a large population of "white perch" killed by a very small concentration of copper sulphate while very few other fish were harmed (Discussion following Belding, 1927). At the same time Titcomb stated that "bass" had been found to be the most resistant, "carp" quite sensitive and "northern pike" highly resistant (more so than pickerel *reticulatus)* to copper sulphate solutions. Hazzard reported on a Utah stream in which "trout" were killed by copper sulphate (Smith, 1935). Back Lake in New Hampshire was treated with the same material with only incomplete success. (Siegler and Pillsbury, 1946).

Many Substances Toxic to Fish

Many substances are known to-day which are toxic to fish, but their poisoning action on fish has been only incidental to their other uses. For example, phenyl-mercuric lactate, used in pulp processing in some mills is highly toxic to fish at concentrations of 0·2 p.p.m. and higher (Ellis, 1947).

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[1] This review contains information compiled up to December 1, 1949.

A water-soluble fraction of crude oil has been found to possess a toxicity to fish quite apart from the effect of the oil itself (Wiebe, 1935). Various gas waste products are also known to be poisonous (Shelford, 1917). However, the most frequently encountered poisons of this type are insecticides or herbicides, particularly DDT. This substance is very toxic to fish, although the method of application has considerable effect on the toxicity. Emulsions of DDT are more toxic than oil spray, wettable DDT and dusts less toxic. For example wettable DDT at one pound per acre killed no adult fish in contrast to deaths obtained with an equal application as an oil spray (Hoffman and Surber, 1948). As a dust at 1 p.p.m. (approximately one pound per acre also) DDT did not prove toxic to brown trout *Salmo truta* (Everhart and Hassler, 1948). Different species vary in their susceptibility to DDT, fall fish *(Leucosomis corporalis)*, common suckers *(Catostomus commersonii)*, common and golden shiners *(Notropis cornutus)* and *(Notemigonus crysoleucas)* being more susceptible than "brook trout", bluegills *(Lepomis macrochirus)*, largemouth bass *(Huro salmoides)* and yellow perch *(Perca flavescens)* (Surber, 1946).

Among other insecticides, chlordan is not toxic in a field formula of 0·25 pounds per acre, but at one pound per acre proved toxic. Toxaphene proved lethal in concentrations as low as one part in 200,000,000 and as such is more lethal than the fish poison, derris. Tetraethyl pyrophosphate is also toxic.

The herbicide 2, 4-D and its derivatives are not lethal except at high concentrations, although one of the solvents used with 2, 4-D, tributyl phosphate, is poisonous to fish at concentrations of 15 p.p.m. Several chlorinated hydrocarbons are toxic to fish, for example "benoclor", a chlorinated benzene with added emulsifiers.

An excellent summary of the toxicity of various insecticides and herbicides is given by Surber (1948). That any of these substances will be used some day primarily for their piscicidal properties does not seem too probable, since in most cases they would be highly destructive to desirable plants or other animals.

In Iowa, the powder "HTH" with 70 per cent available chlorine was used in one poisoning project. It proved most unsatisfactory, primarily because of cold water and dilution (T. Moen, personal communication).

Cresol has been used as a fish poison to a very limited extent. Its chief uses are in those places where it is desired to collect the fish without permanent injury to them, as in census work, or where a reduction in numbers but not total elimination is required. Embody (1940) pointed out the value of the substance for census purposes. Laboratory experiments were made at Cornell University on the toxicity of cresol in relation to fish size, cresol concentration and solution temperature (Embody, Schuck, Crump, Freese and Ross, 1941). Tennessee (G. Gentry, personal communication) and the Tennessee Valley Authority (R. W. Eschmeyer, personal communication) both report use of this material, the latter finding it not very satisfactory.

It was only with the introduction of rotenone as the poisoning agent in the 1930's, that poison showed possibilities of being a really valuable tool in fish management.

While plants containing rotenone were used by the North American Indians in their fishing, its widespread use in the United States stems from the first importations of rotenone on a commercial basis from Sumatra in 1928. In 1931 a source of rotenone in the United States was found in *Tephrosia virginiana* and Clerk showed that an ether extract of the roots of this plant was essentially as toxic to fish as pure rotenone (Clark, 1933). Since then still other sources have been discovered and in addition "cube" and "timbo" are produced commercially in South America and imported into the United States.

The early commercial use of rotenone was as an insecticide. Its first use in fisheries management was made by the Michigan Institute of Fisheries Research at the suggestion of Hubbs, then its director. On July 17 and 23, 1934, two small ponds on a private estate in Michigan were treated with an aqueous solution of powdered derris of five per cent rotenone content in an effort to remove a heavy carp and goldfish population. While many fish were killed, some survived, probably due at least in part to the relatively weak concentrations of less than 0·1 p.p.m. rotenone in the pond volume. Later work has shown that in most cases a minimum concentration of 0·5 p.p.m. is required for a complete kill.

This beginning was followed in September of the same year by the derris poisoning of a pit lake of 4·3 acres also in Michigan to remove a population of badly stunted perch (*Perca flavescens*) so that the lake could be restocked with "trout" (Eschmeyer, 1937). Again the kill was not complete. Two more pit lakes of the same group, overrun with stunted perch, were treated with complete success, a lake of 3·3 acres in 1935 and a lake of 10·7 acres in 1936 (Eschmeyer, 1938). In 1937 three more Michigan lakes were successfully poisoned (Eschmeyer, 1939; Ball, 1948).

By 1938 the National Park Service (Barrows, 1939), Illinois (Bennett, 1943) and New Hampshire were beginning to use rotenone. In New Hampshire Hoover began work on reclaiming streams (James, 1939). Until this time rotenone had been applied only to small bodies of water but in September, 1938, Hoover used derris on a hitherto untried scale when he successfully treated Back Lake with an area of 358 acres (Siegler and Pillsbury, 1946). A project on a similar scale was carried out in Maine the following year when 300-acre Sabbath Day Lake was treated in November with six tons of "timbo" powder. November was chosen since the lake was at the turnover state and being cooled, which favoured distribution of the poison by vertical currents to deeper water, although at the same time the toxicity of the poison was reduced by a low water temperature of slightly over 40°F. Some 200,000 white perch *Morone americana* were destroyed, as well as 300,000 other fish (State release).

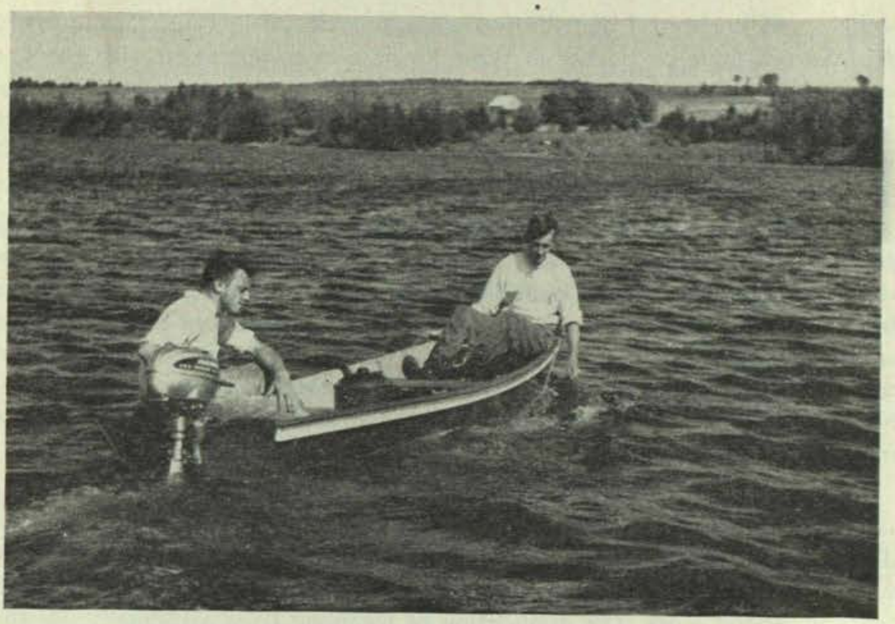
In 1939 Leonard published the results of the first extensive experimental work carried out with rotenone on fish in aquaria for the purpose of obtaining definite data on its action (Leonard, 1939). He studied the rate of loss of toxicity in standing water, the effect of different concentrations, the susceptibility of various fish species and of fish eggs, the loss of toxicity in stock suspensions and the effect of pH and temperature. He concluded that 0·5 p.p.m. by weight of derris root with five per cent rotenone content to water was the lowest concentration that could be counted on to kill all species of fish.

Until 1938 poisons had been used solely for the purpose of wiping out entire fish populations. In that year Wright introduced selective poisoning (Greenbank, 1940). At Fish Lake, Utah, he spread derris in the shoal areas at each end of the lake, where chub *Gila atraria* came in large numbers to spawn. Many chub were killed, while the "brook trout", congregated in the main part of the lake, remained unharmed. In 1939, Greenbank applied the idea in a somewhat different form (Greenbank, 1940). The complete surface area of two small lakes and a pond on a private estate were treated in August. The pond was shallow and in it the kill was probably complete. The two lakes, however, while not large, had depths down to 50 feet and were thermally stratified. The rainbow *Salmo gairdnerii irideus*, brook *Salvelinus fontinalis* brown *Salmo trutta* and lake trout *Cristivomer namaycush* and suckers *Catostomus c. commersonnii* mainly in the deeper waters of the lake below the thermocline, where the derris presumably did not penetrate, were relatively unharmed while the kill of warm-water fish, perch *Perca flavescens*, rock bass *Ambloplites rupestris* and largemouth black bass *Huro salmoides* and others was practically complete. Greenbank concluded that in lakes deep enough for species segregation selective poisoning could be carried on satisfactorily.

Developments in Rotenone Poisoning Most Important

Probably the most important recent developments in poisoning have to do with the forms in which rotenone is available and the methods by which it is applied.

Rotenone was first used in the powdered derris or "cube" form. In early work, a dilute aqueous suspension of the powdered material was poured into the wake of a moving outboard motor boat to obtain surface distribution and charges of dynamite were set off to facilitate distribution to lower levels (Eschmeyer, 1937). Coarse meshed bags filled with a thick suspension of the material towed beside or behind motor boats have been widely used. This is supplemented by various means of spreading the poison in shallow areas, such as distribution with a dipper, or by tossing paper bags filled with the material into shallow water (Siegler and Pillsbury, 1946). Soon after these methods were tried, the application of the solution by spraying with pumps was begun. Leonard (1939) mentions the use in Michigan of fire pumps and in the same year New Hampshire began to experiment with an apple



Towing poison contained in coarse bags through surface waters.

spraying machine. In this latter State, sprays have proved the most satisfactory method of distribution (Siegler and Pillsbury, 1946). Even where methods of pouring solutions or towing sacks are used in the main parts of lakes, application to the shores is almost always made now with a pump and spray of some sort.

Pumps are also used to treat the deeper parts of lakes. The dynamite method has been superseded by them or by various other devices, as for example, the towing of weighted sacks of powder, a simple siphon method where a solution siphons from an elevated tub down a weighted hose (Wales, 1947) or a method depending on suction from an inverted funnel at the end of a weighted hose drawing solution from the source of supply (Krumholz, 1944).

The simple powdered derris remains the cheapest form of rotenone available, but it has the disadvantages of being inconvenient to mix, of being somewhat irritating to the workers using it and of having slower action. To overcome some of these disadvantages various other products have been produced.

A wettable rotenone paste (three per cent rotenone content), which is more convenient to handle and more rapid in action, is produced by S. B. Penick and Company, 50 Church St., New York 7, N.Y. Another product of the same company is more widely used, emulsifiable rotenone five per cent, a concentrated liquid form of rotenone readily mixed with water. It is designed to disperse widely and settle toward the lake bottom, providing vertical and horizontal distribution without artificial mixing. Some experimental work done by Surber in West Virginia in co-operation with the company showed that in one hour the material penetrated to a depth 20 feet, although after 92 hours it still had not reached 30 feet (Company publication). In addition to its improved dispersal qualities it also is more toxic than powdered derris (Surber, 1948).

In 1948 Florida carried out experiments comparing the action of emulsifiable rotenone five per cent and powdered rotenone five per cent. At water temperatures of 59°F to 61°F, and concentrations of 0·5 p.p.m., the action of the emulsified form was somewhat faster. The kill was not complete. One p.p.m. emulsified rotenone two days later removed almost all the remaining fish. At temperatures of approximately 84°F even fresh powdered "cube" rotenone at 0·5 p.p.m. failed to give a complete kill. (J. F. Dequine, personal communication).

The properties of emulsifiable rotenone make it excellent for inaccessible lakes where equipment to be transported must be reduced to a minimum. Also, its faster action adapts it for use in the running water of streams. Most important, however, it made possible the first use of the most recent developments in poison work, the application of rotenone from airplanes. In 1947 New Hampshire tried this method on five lakes of 708 acres total area, using an airplane spray supplemented by certain surface work. The next year four more ponds were reclaimed, these entirely by plane. A 24-acre lake was treated in 25 minutes (Siegler and Pillsbury, 1949). An airplane service company in New Hampshire is prepared to apply rotenone any place within a radius of 500-1,000 miles from that state (Penick Company).

A helicopter, instead of the more conventional aircraft, was used in October, 1948, to spray an Ohio Lake with an area of 250 acres and an average depth of four feet. The kill was believed to be complete and it was found that the downdraft from the craft considerably reduced the solution loss due to drift (Starr, 1948).

As a result of these trials and of Surber's experiments it was concluded that the aircraft application of emulsifiable rotenone is suitable for lakes up to 25 feet depth, but that where deeper water is involved supplementary treatment is required.

Another product, Rotexcel, with improved settling qualities and, therefore, more adaptable to aircraft use was being offered experimentally in 1949 by S. B. Penick and Company.

Fish Tox, of Standard Supply Distributors (P.O. Box 291, Wenatchee, Washington) consists of a special dispersing agent with a compounded paste form of fish toxicant. It can be applied in the same ways as the emulsifiable rotenone and is said to possess certain advantages. It is effective below the effective temperature range of rotenone, so that it can be used even in winter and special wetting qualities assure uniform and rapid distribution even though stratified lakes and in the presence of aquatic vegetation or suspended material. Its toxicity lasts longer than that of rotenone, about two weeks under average temperature conditions, but it dissipates within 30 days. The State of Washington used Fish Tox exclusively in 1947 in its first extensive trials, poisoning 28 lakes with a total area of 2,211 acres. Since then more than a dozen other states have used Fish Tox or intended to use it during the summer of 1949. Comments received during the early summer of 1949 varied from "expect to try" (C. W. Greene, New York, personal communication), "expect to use quite extensively because we believe it very effective" (E. S. Brynjolfson, N. Dakota, personal communication) and "much superior to the powdered derris root for the reason that it is much easier to mix and much more soluble in water" (A. G. Stubblefield, Montana, personal communication) to "have had varying degrees of success with it" (R. C. Holloway, Oregon, personal communication).

Reasons for Fish Poisoning Vary

The reasons for the destruction of fish by the use of poisons vary considerably. One of the commonest uses of poison is to completely remove a trash fish population containing such species as perch, carp, bullheads or any fish which, due to competition or for some other reason, is not wanted in that particular area. A more desirable fish may then be planted, usually some species of trout. Davison of the United States Soil Conservation Service (personal communication) favours its use in cleaning out farm ponds and a job sheet is distributed by that Service for use by those interested in the treatment. It is pointed out in this sheet, however, that permission must be obtained before poison is used, since many state laws prohibit its use for this purpose. In addition the service has a fish culturist to analyze ponds and carry out poisoning work in almost every state. A number of state fisheries officials in communications to the author have pointed out that while poisoning is used in their states they consider it a dangerous practice which must be kept under the strictest supervision.

Walsh Lake, Michigan, was poisoned to remove a population of fish which, although growing well, were undesirable due to a heavy parasite infestation (Ball, 1948). It was necessary in one case to poison a 26-acre lake, of little use itself as a game fish lake, in order to prevent the reinfestation of another lake connected with it (Fisheries Biological Progress Report 1946-1947, Washington State Game Commission).

Poison is also used in cleaning out hatchery ponds which cannot be drained (T. Moen, Iowa; E. S. Brynjolfson, North Dakota; personal communications). One lake in Washington, treated in 1940, has since been used successfully for spawning purposes (C. F. Pautzke, Washington, personal communication).

Ohio has been using poison to clear out undesirable fish before new impoundments are stocked. The stream being dammed is first cleared of fish above the dam so that the new lake created can be stocked with known numbers of fish and pure stocks assured. Just before the valve in New Grant Lake was closed, five miles of stream of an average width of eight feet and an average depth of two feet were treated with Fish Tox by seven men (Pelton, 1948).

Where water is badly roiled by the presence of bottom feeding fish, it may be cleared by the removal of these fish. Although poisoned primarily to census its bullhead *Ameiurus nebulosis marmoratus* (Holbrook) and *Ameiurus natalis natalis* (Le Sueur) population, a small clay-bottomed pond which had been muddy for years, cleared after treatment (Tarzwell, 1941). When rough fish were removed from an Illinois lake, the water cleared and *Potamogeton foliosus* appeared (Bennett, 1943). An Ohio marsh was cleared of "carp" so that aquatic vegetation which failed to survive in disturbed water could be re-established to serve as duck feed (Starr, 1948).

Selective poisoning provides a means of reducing the numbers of trash fish where it is not desirable to destroy completely the fish population, as in Greenbank's work in Michigan (Greenbank, 1941). In 1941 Lake Almanor, California, was treated a number of times during the summer in the swamps and indentations frequented by "carp". Some 10,000 to 12,000 were killed in that one season alone (Wales, 1942).

Where the fish population of a lake is stunted due to over-population, the removal of some of the fish may make improved growth possible for the survivors. A dense population of rock bass *Ambloplites rupestris* (Rafinesque) was poisoned in the south basin of Booth Lake, Michigan, and the lake restocked by the overflow from the untreated north basin. Examinations of fish at intervals during the next five years showed increased growth rate in fish of all sizes (Beckman, 1943). Partial poisoning is used by TVA as a means of checking on fish growth and the success of reproduction. Late each autumn, representative bays of one to three acres on six to twelve reservoirs are sampled with derris, the same type of poison being used from year to year to give comparable results. In lakes too large to seine, local sampling with poison may become an important procedure (Eschmeyer, personal communication).

In 1940 Krumholz used derris for collecting small fish in salt and brackish water (Krumholz, 1948).

The ability to remove or take a census of entire fish populations is often very important in experimental projects. In Castle Lake, California, it was decided to replace the native lake trout *Cristivomer namaycush namaycush* (Walbaum) and minnows *Notemigonus crysoleucus auratus* (Rafinesque) and *Rhinichthys osculus* (Girard) by rainbow trout *Salmo gairdnerii stonei* (Jordan) brook trout *Salvelinus fontinalis* (Mitchell) or brown trout *Salmo trutta* (Linne). In order to determine the most suitable species, a long-range programme was laid out. First, all these species were planted together, and then, as the second stage, one species alone was to be planted. Poison was introduced to permit analysis of the results of stage one and to allow the carrying out of the second phase—the introduction of a single species (Wales, 1947).

Brown and Ball (1943) used derris on 10-acre Third Sister Lake, Michigan, to determine not only the fish present, but also the effect of the absence of fish on the growth of fish food.

Since most lakes which are poisoned have a population unbalanced in some way, for example an excessive number of coarse fish, or a stunted population due to overcrowding of even a desirable species, population studies made on the collected fish seldom deal with normal conditions. The mere presence of carp *Cyprinus carpio* in Howe Lake, Michigan, though not destructive, seemed to sportsmen to justify the poisoning of the lake and thus gave an unusual and valuable opportunity for the study of a balanced population (Eschmeyer, 1939).

When a pond on the Mason Game Farm in Michigan was drained in 1937, the population of fish present was easily determined and it was desired to compare this population with the population of two tributary streams, one slow-moving with many pools, the other more rapid with fewer pools. An area some hundreds of feet long on each stream was poisoned and the fish collected. Forty days later the process was repeated in order to find out how many fish had moved into the area in the intervening time (Eschmeyer and Clark, 1939).

Since poisoning gives a method of checking on the total fish population, it also provides a method of determining whether partial netting of a population including marked fish provides a reliable means of estimating a fish population. Krumholz found a close correlation between the estimated total fish population and the fish recovered after derris poisoning of a lake of 7¾ acres, but added that further studies would be required to prove the accuracy of the fin-clipping method (Krumholz, 1944). One of the chief items of uncertainty in such an experiment is the completeness of recovery of the poisoned fish. Krumholz recovered 86 per cent of the marked fish. However, work in Michigan in 1946 indicates that such a high percentage is not always obtained, that the proportion of the total population recovered may not greatly exceed one-half and that the total fish populations calculated on the basis of recoveries of poisoned fish may not be sufficiently high (Ball, 1948). In a 28-acre lake in Wisconsin only 30 per cent of the marked fish were recovered, although this percentage may be unusually low due to unsatisfactory collecting conditions. It was concluded also that in this experiment fin-clipping as a means of estimating population is not satisfactory (Fischthal, 1947).

Thirty-four States Use Rotenone Poisoning

Data obtained in the spring and summer of 1949 showed that 34 states had used some form of rotenone poisoning. These included Alabama, Arizona, California, Colorado, Florida, Idaho, Illinois, Indiana, Iowa, Kansas, Kentucky, Maine, Maryland, Michigan, Minnesota, Missouri, Montana, New Hampshire, New Mexico, New York, North Carolina, North Dakota, Ohio, Oklahoma, Oregon, South Carolina, Tennessee, Texas, Utah, Vermont, Virginia, Washington, Wisconsin and Wyoming (personal communications and Krumholz, 1948). The Tennessee Valley Authority and the Soil Conservation Service also use it and Surber of the Fish and Wildlife Service has done some work in co-operation with Penick and Company. The University of Minnesota has students working with Fish Tox and other poisons (L. L. Smith, Jr., personal communication) and the University of Wisconsin has used rotenone as a tool in lake study to a limited extent (A. D. Hasler, personal communication). With regard to the remaining 14 states, either information at hand is incomplete or poison is definitely not used.

New Jersey does not use poison, since all the lakes are used for swimming as well as fishing and their shores are usually heavily built up with cottages. Frequently the lakes are used as a water supply as well (R. A. Hayford, personal communication). Mississippi has done no poisoning on its own, but issues permits for such work to the Soil Conservation Service (R. M. Freeman, personal communication). Arkansas has used no poison and hesitates to give out information on a substance potentially so dangerous. Other management procedures for overstocked farm ponds are advised (J. Hogan, personal communication).

The extent to which poison is used varies greatly from state to state. In Texas the public lakes are mainly large, so that rotenone has been used only by private owners under state supervision (M. Toole, personal communication). In North Carolina most of the work has been done in connection with Tennessee Valley Authority and in general the use of poisons is discouraged (W. King, personal communication). Montana has poisoned only two lakes, one 60 acres and one 90 acres in area (A. G. Stubblefield, personal communication). Minnesota has used poison on only a small scale, since many of the lakes are too large to poison economically and the smaller lakes frequently winter-kill, automatically eliminating fish populations. In addition, there are so many good natural waters that the expense of poisoning is seldom justified. However, the state expects to use about five tons of poison annually (R. E. Johnson, personal communication). By the end of 1948 Vermont had poisoned only two lakes, but plans included a continuation of the work for 1949 (G. W. Davis, personal communication).

New York has used rotenone to a limited extent, and while the results obtained were promising, there was no definite record of a complete kill with the possible exception of a 35-acre lake, the largest worked on (C. W. Greene, personal communication). Ohio has carried out a few small projects, including two stretches of stream, and a few were also undertaken by private individuals under state authorization (L. S. Roach, personal communication). The use of poison in Iowa was being confined to bodies of water usually less than 30 acre feet, where complete seining was impossible—hatchery ponds or the pools remaining after lake drainage (T. Moen, personal communication). Since 1941 complete control work has been carried out on six Oregon Lakes and considerable partial control work has been done on some large trout lakes in the Cascades (R. C. Holloway, personal communication). The largest lake treated had an area of 380 acres. A cement-mixing truck was used to mix to a paste the large quantity of rotenone used in this operation (Oregon State Game Comm. Bull., Oct., 1949). New Mexico worked with poisons in 1948, treating over 150 acres of water, including 25 miles of stream. In areas worked on, 100 per cent support for the program was obtained from fishermen and, once an area has been poisoned, the use of non-game fish as bait is prohibited (F. A. Thompson, personal communication). Colorado's poisoning work was begun in 1946 under the guidance of the United States Soil Conservation Service. Only three small ponds were done at that time, but they served to acquaint the State authorities with the method. Since then trash fish have been eliminated from certain lakes, the largest 165 acres, though of shallow depth (State Department Progress Reports). California (Vestal, 1942) and Wyoming (A. F. C. Greene, personal communication) have tried salvaging fish from lakes being poisoned. Contrary to some reports they have found that if the fish are transferred into fresh water soon enough, transplantings can be accomplished with success. In Utah, rotenone has been used in considerable amounts, never for complete eradication, but as a successful means of controlling fish populations (M. J. Madsen, personal communication).

In Missouri poisoning is carried out both by the State Conservation Commission and by private land owners under the supervision of a field service agent of the Commission. The Commission in 1944 and 1945, for example, poisoned 28 representative ponds in order to study their populations (Bauman, 1946). For private pond owners who wish to use the method, a mimeographed leaflet is distributed containing complete data including information on communicating with the conservation department. In all cases the field agent is required to submit a complete report on the operation. Between 1934 and 1943 Michigan had treated 32 lakes, although all were less than 22 acres in area (Ball, 1948a). The maximum depth of these lakes varied from nine feet to 90 feet, with some thermally stratified and others not, and including nearly every type of lake found in the state except the large lake trout-cisco lakes. Since that time, work has continued. In Illinois the chief use of poisons has been to facilitate the census of populations and since 1938 about 40 lakes and ponds have been treated for this purpose. However, in the past few years, several lake management crews have been set up to renovate public and private lakes by poisoning and subsequent restocking (G. W. Bennett, personal communication).

In a news letter the New Hampshire Fish and Game Department lists a total of 50 ponds treated in the period 1938-1948, half of them done in the last two years of the decade. Four of the total had been reclaimed a second time, five to nine years after the first treatment. This state is also one of the pioneers in the use of the airplane for applying poison.

Washington is one of the most active states in fish poisoning work, having begun in 1940. In 1946, 726 surface acres of water were treated and in 1947, 1,932 acres or a total of 57 lakes. Thirty-three of these lake treatments gave complete kills and only six were failures. One 230-acre lake, poisoned in 1947 and restocked, yielded 5,460 half-pound rainbow trout to anglers on the 1949 opening day and more than 56,000 such fish during the season. Before poisoning the average annual catch was 1,000 fish. A considerable amount of work has been done in co-operation with Standard Supply distributors, testing the product Fish Tox. In 1949, 25 lakes ranging in area up to 330 acres and in depth to 131 feet, were treated. The total area involved was over 2,700 acres and 159,000 pounds of rotenone-containing material was used. At each lake a concrete-mixer was used to premix the poison and water to a paste which was distributed by means of burlap bags. Good dispersion was obtained without a wetting agent. In the deepest lake treated, which was supplied with oxygen to the bottom, the poison was successfully distributed through both the epilimnion and hypolimnion (C. F. Pautzke, personal communication).

Where fish poisons have been used they appear to have proved satisfactory, as is evidenced by their increased use in almost every state in which they have been tried. In Washington, the rehabilitated lakes now head the fish production for the state (C. F. Pautzke, personal communication). Care must be taken, however, that any advantages gained are not lost again. For example, six of 12 Michigan lakes which were poisoned and stocked with trout have once again become populated with warm-water fish (Ball, 1948a). While part of this may be due to incomplete poison kill, it is also the result of ineffective barriers to the re-entrance of trash fish and to the illegal use of live bait. For removal to be economical and worthwhile, efforts must be made to safeguard the gains achieved.

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The Use of Poisons to Control Undesirable Fish in Canadian Fresh Waters*

by

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A direct approach to the problems concerned in the development of practical procedures of improving sport fishing in fresh waters is the alteration of the physical, chemical and biological environments in streams and lakes to overcome deficiencies that have arisen with and without man's interference. Such an approach is an attempt to improve upon nature.

The poisoning of fish has been employed as one method of altering the biological environment. Most work of this kind has been directed toward the control of non-game fish in ponds and lakes where the selective removal by angling of game species resulted in a dominance of those that were, at least locally, undesirable. Poisoning has also received consideration in the control of fish which are vectors in the transmission of diseases and parasites of both commercial and game species.

The purpose of this article is to review the progress that has been made in the use of various poisons for the control of unwanted fish in Canadian fresh waters.

A. Rehabilitation of Habitats for Game Species

Two approaches have been made to the problem of improving conditions for survival and growth of game fish in ponds and lakes by poisoning:

(1) with intent to destroy entire fish populations, and

(2) with intent to kill selectively the undesirable species.

1. Poisoning of Entire Fish Populations

Not until recently were poisons placed upon the market specifically as fish poisons. In the first Canadian investigations, copper sulphate was employed, following the lead of Titcomb (1914). However, since copper kills not only fish but other aquatic animals, as well as plants, and also rapidly disappears from solution in ionic (toxic) form when appreciable quantities of carbonates and organic matter are present, it was abandoned in favour of rotenone, as contained in derris and cubé powders. It is more specific in its toxicity to fish. When difficulties were generally experienced in obtaining dispersion of rotenone in derris powder in lethal concentrations throughout moderately deep lakes, manufacturers developed such specific fish poisons as emulsifiable rotenone and Fish Tox, for which better dispersion qualities have been claimed.

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(a) With copper sulphate. Within the period from 1934 to 1938, four head-water lakes in southwestern Nova Scotia were treated with copper sulphate in attempts to destroy populations of coarse fish and thereby to create more suitable habitats for survival and growth of speckled trout *(Salvelinus fontinalis)* (Catt, 1934; Smith, 1935, 1936, 1940, a,b). These soft-water lakes—Jesse, Boar's Back, Tedford and Trefry's with respective areas of 45, 56, 52 and 53 acres and maximum depths of 21·5, 31, 20 and 43 feet—received sufficient copper sulphate to give a concentration of slightly in excess of 3 p.p.m. of $CuSO_4 \cdot 5H_20$, if the salt were evenly distributed. At the time of poisoning, barriers were placed in the outlets to prevent movements of fish, except eel *(Anguilla bostoniensis)* elvers, into and out of the lakes.

Data are available upon the results of the procedure only for Lake Jesse. In both 1931 and 1932 the lake had been stocked with 15,000 trout fingerlings (Rodd, 1932, 1934). When poisoned in 1934, 29 speckled trout (a standing crop of 0·4 lb. per acre) were found in the lake.

This lake was stocked again in 1936 with 45,000 speckled trout fingerlings and in 1937 with 215,000 trout fry (Rodd, 1937, 1938), and, as later revealed, with an unknown number of Atlantic salmon *(Salmo salar)* fry or fingerlings. A creel census maintained on the lake during 1939, when it was first opened to angling after stocking, showed that the anglers captured 64 trout and salmon post-smolts (Smith, 1943) at a rate of 0·6 per rod-hour. The yield to the anglers was 0·9 lb. per acre.

Thus the poisoning of undesirable fish, especially the dominant white perch *(Morone americana)* and yellow perch *(Perca flavescens)* appeared to result in some improvement of Lake Jesse as a habitat for speckled trout (and salmon), but hardly in a worthwhile improvement for the expenditure, effort and introduced stock involved.

The results for Lake Jesse point to the consideration that, although poisoning may eliminate or reduce competition and predation from coarse fish, the extent of the improvement in production of desired game species will primarily be conditioned by the productive capacity of the waters. Creel censuses conducted for a number of years on eight Charlotte County lakes, New Brunswick, with a stocking schedule being concurrently maintained, disclosed an average annual yield of speckled trout (and land-locked salmon in one of them) to the anglers of 0·6 lb. per acre (Smith, 1946). These lakes are comparable to Jesse in fertility, and most of them, like Jesse after poisoning, do not contain dominant populations of perch. These and other studies in Maritime lakes suggest that the mediocre yield of trout and salmon to the anglers from Lake Jesse after poisoning, although less than may have been anticipated, was actually quite commensurate with the trophic character of the waters.

(b) With rotenone in derris and cubé powders. Rotenone, as contained in derris powder, was apparently first used by fishery biologists to destroy unwanted fish in Michigan (Eschmeyer, 1937). Since that time this poison has been employed rather extensively by Canadian investigators in fisheries management. Unlike copper sulphate, rotenone acts as a fairly specific fish poison in fresh waters at concentrations that will kill fish. It has little effect upon aquatic invertebrates, except possibly planktonic crustaceans, at such concentrations (Smith, 1940).

Sufficient poison is usually added to a body of water to give, when evenly distributed, from 0·5 to 1·0 p.p.m. of derris or cubé powder with 5 per cent rotenone. The concentration of rotenone is accordingly from 0·025 to 0·05 p.p.m. Rotenone soon loses its potency in aqueous solution, and, although the time involved varies with aquatic conditions such as temperature and alkalinity, the poison is dissipated within a month in most instances. The poison has been applied most frequently by towing the material in coarse-meshed sacks through the surface waters and/or by spraying the surface with an aqueous suspension. On occasion attempts have been made to secure a better dispersal at depth by sinking and towing the material in sacks at various levels and by siphoning aqueous suspensions to the deeper waters.

Distribution of poison in aqueous suspension by hand pumps. Adaptable for weed beds and shallow areas not easily reached by boats.

In Potter's Lake, New Brunswick, the effectiveness of rotenone in ridding a lake of fish, the possibility of then establishing a speckled trout population by stocking, and the action of the poison in concentrations required to kill fish upon the invertebrate fauna were investigated (Smith, 1941). This head water lake has an area of 111 acres. The maximum depth is 30 feet, but, since there are extensive shoals, the mean depth is only 6·6 feet.

In 1938 Potter's Lake was stocked with approximately 8,000 speckled trout fingerlings. A barrier against the movement of fish was built in the outlet and subsequently maintained during the course of the investigations.

In the summer of 1939, when the waters of the lake were thermally stratified, with surface and bottom (9 metres) temperatures of 27·5 and 11·4°C respectively, the lake was treated with derris powder (5 per cent rotenone) to give a concentration of 0·55 p.p.m. None of the introduced trout was found, but approximately 25,000 small and large eels, white suckers *(Catostomus commersonnii)*, brown bullheads *(Ameiurus nebulosus)* chain pickerel *(Esox niger)* white and yellow perch, smallmouth black bass *(Micropterus dolomieu)* and pumpkin-seeds *(Lepomis gibbosus)* were killed. Sampling before and after the poisoning showed that the only invertebrates seriously affected were the planktonic crustaceans, survivors of which soon repopulated the lake.

In 1940 the lake was again stocked with about 13,000 speckled trout fingerlings, and again none of these was found when the lake received a second similar treatment with derris in 1941. However, approximately 90,000 young suckers, bullheads, pickerel, yellow perch and pumpkinseeds were poisoned. Yellow perch in their first and second year of age numbered about 65,000. Although some may have died during the interval between poisonings, only 26 mature perch were noted in 1941. These data illustrate well how such a species as yellow perch, with a high reproductive potential, may rapidly repopulate a suitable environment when pressure from competition and predation is released. They further illustrate the need, in this one lake at least, of a complete kill in order to accomplish any measure of control.

In 1942 Potter's Lake was stocked a third time, in this instance with 1,000 yearling speckled trout. It was not possible to apply derris to the lake a third time, but in 1943 and 1944 netting revealed a good survival of these trout, where fingerlings had failed. Netting also demonstrated that the second poisoning failed to kill all pickerel and perch.

Round or Cook's Lake (50 acres), New Brunswick, is another case where poisoning did not accomplish a control of coarse fish. Cubé powder (5 per cent rotenone), to give somewhat in excess of 0·5 p.p.m., was applied in September, 1946, (Atkinson, 1948; Catt, personal communication). Whether or not a complete kill resulted in the lake itself from the application of cubé powder, the subsequent repopulation of the lake with coarse fish was possible by migration up the outlet because of a defective barrier.

The events at Round Lake emphasize one of the essentials in a poisoning programme for complete control of coarse fish, namely the maintenance of adequate barriers to prevent re-entry of unwanted species into poisoned areas. Barriers against downstream migration of fish are difficult to maintain even under the most favourable conditions, and this feature has limited all attempts at complete control of undesirable fish in the Maritime provinces to head-water lakes, where permanent affluent streams have been absent, or, if occurring, they have been small and also treated.

That a coarse fish population can be destroyed by poisoning with derris and successful trout angling restored is shown by results obtained at MacFadden's Lake, New Brunswick (Catt and Needler, 1946). Records kept by a club which controls this lake show good speckled trout angling until yellow perch were inadvertently introduced and became abundant. Derris powder (5 per cent rotenone) was distributed in this lake in sufficient amount to give approximately 1·2 p.p.m., when the area was reduced by deepening the outlet to 11·5 acres and the maximum depth to 6 feet in July, 1939. Stocking with speckled trout fingerlings in 1940, 1941 and 1942 re-established excellent angling for this species. No perch have been observed since the poisoning. Two features of the lake may be considered determinative of the success: (1) the shallowness of the water which apparently assured a lethal dosage of the poison throughout, and (2) the good productive capacity of the waters and their suitability for speckled trout in the absence of dominance by coarse fish.

Similarly, an effective kill of eels and lake chub *(Couesius plumbeus)* with derris (5 per cent rotenone) was probably realized in shallow Bill's Lake (10·5 acres, 9·8 feet maximum depth), New Brunswick (Smith, 1948a). The results of poisoning this pond with the low concentration of 0·25 p.p.m. in June, 1938, were assessed by a second application of 1·0 p.p.m. in September of the same year. The weaker concentration killed by count 2,042 eels, 656 minnows and three speckled trout. Only 204 eels and five minnows were found in september. The pond was repopulated with speckled trout from a native stock in the outlet where it had escaped poisoning, and in 1944 records show that at least 132 trout were angled. This yield of 5·3 lbs. per acre was an improvement over the crop obtained when the pond was treated, and better than has been found for neighbouring lakes (Smith, 1946). However, repeated poisoning would have been necessary to control the eels more than temporarily since elvers may migrate into Bill's Lake each year from the sea.

Prévost (1947a) reported that favourable habitats for speckled trout were restored in three Quebec lakes by destroying coarse fish with rotenone in derris powder. Since that time the poisoning of underirable fish as a means of providing better trout angling has been extensively applied in that province, so that by 1949 over 30 lakes have been treated (Prévost, 1947b, and personal communication).

The fish population in Rond Lake (34 acres), Quebec, was poisoned in September, 1945 (Prévost, 1949). During the next three years the lake was stocked with fry, fingerling and two-year-old speckled trout. A creel census conducted on the lake in 1948 showed a good yield of 1,375 trout (7·9 lbs. per acre) to the anglers. Since all anglers were not contacted, it was estimated that as high as 2,000 trout were taken during the entire season.

Unfortunately, the writer has no data at hand for Rond or other treated lakes in Quebec upon the concentration of poison employed, the areas (except Rond) and depths of the lakes, methods and results of assessments of the completeness of kill, and, of an essential character for evaluation of the procedure, the condition of the trout fishery before poisoning and subsequent yields (again except Rond) to the anglers.

Prévost (1949, p. 45) states in respect to application of the poisoning procedure in Quebec: "It is well to recall that any lake can be completely cleaned no matter what its size; restocking will then give almost unbelievably good results". In view of his experiences in Maritime lakes, as well as those of other investigators there and elsewhere, the writer cannot subscribe to this statement as being generally applicable to Canadian fresh waters.

Butler (personal communication) writes that in Manitoba a population of cyprinids, pike *(Esox lucius)* burbot *(Lota lota)*, yellow perch and pumpkinseed was apparently completely destroyed in Telford Pond (5·2 acres, 19 ft. maximum depth) by derris powder (4·4 per cent rotenone) at 0·57 p.p.m. Six weeks after the treatment of the pond in June, 1947, it was stocked with 4,500 fingerling brown trout *(Salmo trutta)*. Test fishing in 1949 revealed survivors from this stocking and gave promise that the procedure had been successful.

In Alberta derris powder of 5 per cent rotenone content was applied at a concentration of approximately 1 p.p.m. to five natural spring-water ponds (0·14 to 15 acres) and their connecting streams to destroy coarse fish and to make these areas suitable for rearing trout brood stock (Miller and Watkins, 1946). All pike were apparently killed. However, a certain number of white suckers survived. The results suggest the difficulty of obtaining a complete kill, even in such small ponds as are here concerned, when appreciable spring drainage is involved (see following M'Gonigle and Smith, 1938).

(c) With rotenone in emulsifiable form and in Fish Tox. Difficulties in obtaining dispersal of rotenone, contained in derris and cubé powders, in concentrations lethal to fish throughout lakes with depths of more than 25 feet, particularly when thermally stratified, and even in more shallow areas which support heavy growths of aquatic vegetation, have led to the recent development of rotenone products containing dispersing agents. The names "wettable rotenone paste 3 per cent" and "emulsifiable rotenone 5 per cent" speak for themselves. Another product, Fish Tox, has a rotenone base, with other synergistic poisons and dispersing agents.

Harkness (personal communication) writes that emulsifiable rotenone has been successfully employed in Ontario to destroy unwanted fish in trout ponds, being effective at 0·5 p.p.m. (0·025 p.p.m. rotenone?) at water temperatures down to 45°F and in the presence of heavy weed masses. No additional details are at hand, however. As yet this rotenone product does not appear to have been used elsewhere in Canada, although it has largely supplanted derris powders in American investigations.

Harkness also recounts that in an artificial lake on the Lynn River at Port Dover, Ontario, when it was at a level to give 30 acres of shallow water, carp *(Cyprinus carpio)*, goldfish *(Carassius auratus)* and other cyprinids, white suckers, bullheads, yellow perch, and pumpkinseeds were largely but incompletely destroyed in early 1949 by an application of 0·5 p.p.m. of Fish Tox, supplemented by 200 lbs. of derris and cubé powders (5 per cent rotenone) when a greater than anticipated flow of water through the area was encountered. The objective was to create a more suitable rearing area for fry of yellow pike-perch *(Stizostedion vitreum)*. In September, 1949, it was determined that the introduced fry had survived and grown well. However, during the course of one summer season the lake was repopulated by "tremendous numbers" of young carp, goldfish, bullheads and pumpkinseeds, which were presumably the progeny of an unknown, although not large number of parent fish that had escaped the poisoning or migrated into the area.

Preliminary tests upon the toxicity of Fish Tox to fish under semi-controlled conditions were made at the Atlantic Biological Station during the summer of 1949 (Anthony, 1949). Fish were held in 60 litres of water in wooden tubs. Banded killifish *(Fundulus diaphanus)* was the principal test species, but white suckers, golden shiners *(Notemigonus crysoleucas)*, lake chub, eels, white perch and pumpkinseeds were also involved. Anthony's results indicated that concentrations less than 2 p.p.m. of Fish Tox would not assure a complete kill. His results are consistent with what was experienced at Cassidy Lake, New Brunswick (Smith, 1949; Alderdice, 1949). This lake, with an area of 233 acres and a maximum depth of 36 feet, was treated with Fish Tox to give 0·5 p.p.m. on September 30 and October 1, 1948, when the waters of the lake were virtually homothermous at 14·5°C. Large numbers of fish were poisoned—alewife *(Pomolobus pseudoharengus)*, white sucker, golden shiner, common shiner *(Notropis cornutus)*, brown bullhead, chain pickerel, banded killifish, eel, white and yellow perch, pumpkinseed. An assessment of the efficacy of 0·5 p.p.m. of Fish Tox to give a complete kill was made by a second application of 1 p.p.m. in July, 1949. Although much reduced in numbers, representatives of the majority of the above species were found to have escaped the initial poisoning. Alderdice (1949) reports that small fish, perhaps killifish, were still present in the lake in late summer, 1949.

Enough Fish Tox to give 1 p.p.m. was distributed in Ritchie Lake (approx. 50 acres) and tributaries, near Rothesay, New Brunswick, in August, 1949 (Alderdice, 1949). Large numbers of undesirable fish, including chain pickerel, eels and yellow perch, were killed. It is yet too soon to evaluate this effort by which it was hoped to create a favourable habitat for speckled trout.

Fish Tox was applied to two lakes in British Columbia in 1948 to control unwanted fish (Larkin, 1949; Clemens, personal communication). Any beneficial effect was largely nullified, however, by migration of fish into the lake during periods of unusually high water.

(d) With DDT. This insecticide (dichloro-diphenyl-trichloroethane) is toxic to fish at low concentrations, but most interest in it as a fish poison has been with respect to the damage to fish populations that might accrue from the treatment of large natural areas for the control of black flies, mosquitoes, spruce bud-worm and other insects, rather than its direct use for eradicating undesirable fish (Surber, 1948; Cope, Gjullin and Storm, 1949; Langford, 1949). However, Langford (personal communication) reports that Found Lake (32 acres, maximum depth over 100 ft.), Algonquin Park, Ontario, was treated in 1947 with 25 pounds of DDT dissolved in acetone and ethyl alcohol in an attempt to destroy a population of smallmouth black bass and to establish speckled trout. No bass have been taken in subsequent years, although it was observed in 1949 that numbers of creek chub *(Semotilus atromaculatus)* were present. Introduced trout have apparently done well, but assessment of results will have to await the opening of the lake to angling in 1950. An unfavourable effect of the poisoning was the destruction of much of the bottom fauna, and for this reason, if for no other, it would appear improbable that DDT would have greater value than rotenone as a fish poison in fisheries management.

2. Selective Poisoning of Undesirable Fish

Stress has been laid upon a complete kill in poisoning undesirable fish as a procedure to improve angling for game species. Obviously this method provides maximum control. Yet, in lakes where coarse and game fish both occur, it may be desirable and possible to poison the coarse fish selectively when they are largely segregated by habitat preferences from the game species. However, selective poisoning probably needs to be a repetitive process since, as instanced by events in Potter's Lake, New Brunswick, and in the lake on Lynn River, Ontario, surviving coarse fish can repopulate lakes rapidly when population pressure is reduced.

An experiment upon the selective poisoning of non-sport fish as a method to better speckled trout angling is currently in progress at Copper Lake, Nova Scotia (Hayes, 1949a). In early August, 1948, derris powder (5·1 per cent rotenone) was applied to the littoral zone of the lake in sufficient quantity to give a concentration of 0·56 p.p.m. in that volume of water contained between the 10-foot contour and the shore. The expectation was that the poison would not reach trout in the deeper and cooler water in lethal concentration while largely destroying the unwanted yellow perch and other fish in the shallows.

An estimated 21,000 fish, predominantly white suckers, golden shiners, banded killifish and yellow perch (19 per cent) was poisoned. A similar application of derris in 1949 resulted in a kill of only about 1,500 fish. "The reduction to less than one-tenth the previous number was brought about by a substantial reduction in all species, but mainly by the almost complete absence of *Notemigonus crysoleucas* and *Perca flavescens*, two of the dominant species in last year's kill" (Hayes, 1949b). Only five trout were found dead in the lake in 1948 and none in 1949. Anglers took 147 trout in the spring of 1949 at the rate of 0·49 per rod-hour.

Hayes (1949a) plans to repeat the poisoning annually for several years in conjunction with a stocking experiment and creel census. Data from creel censuses conducted before the experiment, as well as from an estimate of the trout population in 1947, will serve as a basis for comparison in gauging any betterment in the trout angling that may accrue from the selective poisoning (Hayes, 1948; Smith, 1948b).

B. Control of Fish Diseases and Parasites

1. Total Destruction of Fish in Water Supplies to Fish Hatcheries and Rearing Stations.

Before opening the Cobequid Fish Hatchery, Nova Scotia, an attempt was made to eradicate all fish in its water supply and in this way to remove natural sources of parasitic infections and disease (M'Gonigle and Smith, 1938). In August, 1937, the source of water to the hatchery, involving about 25 miles of stream (with tributaries) and a shallow six-acre lake, was progressively poisoned from the head-waters downward with 200 pounds of derris powder of 5 per cent rotenone content. Roughly 75,000 speckled trout and young Atlantic salmon were killed. The only other species noted was the blacknose dace *(Rhinichthys atratulus)* in small numbers. Although care was exercised to leave no area untreated, especially where springs entered the system, the objective of destroying all fish was not realized, for by 1942 the stream was again supporting a large population of small speckled trout. Inability to maintain lethal dosages of poison in the numerous springs and areas of spring seepage was probably the reason for the incomplete kill.

A successful effort in this direction has been reported by Armstrong (1949). Speckled trout, which were known to be a source of infectious diseases plaguing hatchery stock, and spoonhead muddlers *(Cottus ricei)* were eliminated from the headwaters of the Dorion rearing station, Ontario, by an application of calcium hypochlorite (HTH). Fifteen hundred pounds of the chemical were added in 1948 to the spring-fed pond (6 acres, average depth, 4 ft.) which comprises the headwaters of this establishment. The rate of flow from the pond was estimated at 7,516 gallons per minute, and the volume of the pond at 105,600 cubic feet. No doubt the sinking and weighting of sacks of the hypochlorite in the 20-odd spring-depressions in the area contributed greatly to the success of the venture, as did also the removal of much of the rooted aquatic vegetation prior to the poisoning. Sodium thiosulphate was employed to neutralize the hypochlorite in the waters flowing from the treated area.

However, Harkness (personal communication) failed to destroy all fish in a small trout pond in southern Ontario with calcium hypochlorite, presumably because of poor dispersal of the poison throughout heavily weeded areas. Calcium hypochlorite reacts readily with weak acids, such as carbonic acid in natural waters, to give the fish toxicant, chlorine, which, however, is quickly absorbed by organic materials. Thus, Harkness writes that a large amount of hypochlorite is required to establish and hold a toxic concentration in the presence of weed masses. It may be concluded that hypochlorite, or chlorine in other form, has no advantage over rotenone, except that it can be neutralized immediately by sodium thiosulphate, and accordingly have merit in restricting the destruction of fish to limited areas, such as the pond at Dorion.

2. Selective Poisoning of Pike to Control Tapeworm Infestation in Other Species of Fish.

In lakes of western Canada the pike is definitive host to the tapeworm, *Triaenophorus crassus*, while the encysted plerocercoid stage is found in the flesh of the commercially important whitefish (*Coregonus clupeaformis*) and tullibees (*Leucichthys sp.*) and seriously affects the market value of these fish (Miller, 1943). Recent attempts have been made to poison the pike selectively, and by controlling the numbers of this host of the parasite, to reduce its infestation in the valuable coregonids.

Miller (1949) experimented upon pike control in Square Lake, Alberta. The principal spawning sites of the pike in this lake, with an area of 2·5 square miles and maximum depth of 120 feet, were treated in May of both 1947 and 1948 with about 3,000 pounds of Atox (0·5 per cent rotenone) and in May, 1949, with 500 pounds of Atox and 2,012 pounds of Fish Tox (10 per cent rotenone?). It was estimated that the numbers of pike present in the lake in each of the three years were reduced by 34, 50 and 90 per cent respectively. There was no progressive decline in actual numbers, however, since the population was augmented by migration of pike into the lake between poisonings. Presumably as a result of the selective poisoning, the infestation of tullibees by *Triaenophorus* was reduced by 30 per cent over the three years. Miller nevertheless concludes, "A total reduction of worminess of 30 per cent in a 2·5 square mile lake at a cost of $5,024.50 (for materials and labour) leaves room for but one conclusion. Pike reduction by poisoning is too costly and, apparently too ineffective to be practical."

A like conclusion was reached by Doan (1949) in Manitoba following an effort to reduce by poisoning the pike population of Heming Lake (588 acres). A total of 488 acre-feet of the shallow water in Heming Lake was treated in early July, 1949, with Fish Tox at the rate of 2·34 pounds per acre-foot. This resulted in the destruction of only about 9 per cent of the pike over 15$\frac{1}{5}$ inches in length which were estimated to be present in the lake. The poisoning proved selective, however, in killing very few whitefish but destroying over 2,300 pike and other warm-water species.

C. Summary

1. In shallow lakes, undesirable fish have been totally destroyed by poisoning, and successful populations of game fish then established where previously, in the face of competition and predation from coarse fish, such had not proved feasible. Practical application of the poisoning procedure to shallow waters would appear seriously limited only *(a)* by unsuitability of the physical and trophic characters of the habitat for survival and growth of desired species, *(b)* by inability to prevent entry of unwanted fish into the poisoned waters from tributaries, and *(c)* by considerations of the cost and effort to treat extensive areas.

2. In lakes with depths over about 25 feet, difficulty has been encountered in obtaining a complete kill of fish by poisoning, presumably as a result of an inadequate dispersal of the poison in toxic concentrations to all depths. A partial kill of undesirable fish, even if it is almost complete, is ineffective for continuing control, since repopulation by the undesirable fish may be surprisingly rapid. If and when a complete kill of fish can be realized in the deeper lakes, practical application of the poisoning procedure to them will be subject to the limitations listed above in (1). The demonstrated value of the poisoning procedure in shallow lakes in which a complete kill of fish has been obtained, stimulates further effort to overcome the difficulties of adequately dispersing poison in deeper lakes.

3. Selective poisoning of undesirable fish in a lake without materially affecting game fish, thus reducing population pressure against the latter and presumably improving the habitat for them, has been found possible if the undesirable and game fish are segregated by habitat preferences. Although a marked reduction in the number of undesirable fish has been attained by selective poisoning, repeated treatments, the frequency of which will depend upon the rapidity of repopulation by the unwanted fish, are necessary for lasting effects. A current investigation in a Maritime lake has not yet progressed far enough to demonstrate whether the procedure, as a method to improve angling for speckled trout, is worthwhile.

4. Selective poisoning of pike in lakes of western Canada as a means to control the damaging infestation of the commercially important whitefish and tullibees with plerocercoid cysts of a tapeworm, of which the pike is the definitive host, has not as yet proved sufficiently effective or economical to justify it as a practical procedure.

5. Attempts to obtain a complete kill of fish in spring-fed streams and ponds have failed unless care has been taken to place poison in spring-holes and over seepage areas in sufficient quantity to assure a continuing toxic concentration in the water at those sites.

6. Rotenone has proved to be the most effective fish poison. It kills fish at low concentrations (0·025 p.p.m.) and at such concentrations it is not toxic to most aquatic invertebrates. Until recently, rotenone was only available as contained in derris and cubé powders, but, when difficulties were experienced with these products in successfully treating even moderately deep lakes for a complete kill of fish, rotenone products with dispersing agents—wettable rotenone, emulsifiable rotenone, Fish Tox, etc.—were developed, as specific fish poisons, to improve the penetration of rotenone in toxic concentrations to greater depths of water and throughout beds of aquatic vegetation. Investigators in Ontario have found emulsifiable rotenone very effective, presumably more so than rotenone in derris powder, but elsewhere in Canada this product appears to have been little used. Semi-controlled experiments and treatment of a 233-acre lake in New Brunswick have not shown Fish Tox to have greater merit than derris or cubé powder as a poison for complete elimination of undesirable fish.

7. Copper sulphate, DDT and calcium hypochlorite (HTH) have no advantages over rotenone as fish poisons, except possible the latter, which, since it is rapidly reduced by sodium thiosulphate, may prove useful in treating and confining the toxic effects of the poison to restricted areas.

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A Critique of the Need and Use of Poisons in Fisheries Research and Management

by

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In the preparation of this critique I have reviewed such literature on the use of fish poisons as was readily available, but I have relied mainly on the reviews prepared by Smith (Canadian use) and Solman (use in United States). The conclusions which Smith has set down in the summary of his review provide, alone, an adequate 'critique' on the use of poisons and the greater part of my paper is merely an amplification of these conclusions.

Of the various piscicides none is as generally useful as those containing rotenone; the remarks in the critique will be confined to rotenone poisons.

Solman's review of the use of rotenone poison in the United States suggests one point rather strongly—a general lack of follow-up work or controlled experimentation with rotenone. The literature is conspicuously short of data on either (a) the completeness or otherwise of kills, (b) the proportion of the whole populations actually recovered, supposing a kill was complete, and (c) the rapidity with which repopulation with undesirable species takes place. A large part of rotenone use in fisheries has been by state agencies who were using it in management procedures before really adequate preliminary research was done. Some of the Canadian experiments are subject to the same criticism; Smith's work in the Maritime provinces provides a noteworthy exception. In that minority of experiments where effort has been made to find out what actually happened, the results have not been entirely as hoped. Smith's work on Potter's Lake showed, by a second poisoning, that there had not been a complete kill by the first, and that in the interval between poisoning, the fish left alive had increased to equal and exceed their former abundance, and this in but two short years! Later netting work showed that the second poisoning had not produced a complete kill. Smith also noted repopulation following poisoning in Round Lake and mentioned several other examples of failure of complete kills in his review. The complete kills on record have been in very shallow ponds.

In the United States, Ball reported on 32 lakes in Michigan treated with rotenone (Ball, 1948a). On 19 of these, attempts were made to recover all the fish. Although the largest of these lakes was only 22 acres, Ball presented no evidence of a complete kill on any. Of 12 believed to be complete, six have been subsequently repopulated with undesirable fish, three were apparently successful and for three there are no records. Vestal failed to kill all the goldfish in Crystal Lake, California (Vestal, 1942). On 20 lakes treated in New Hampshire (Siegler and Pillsbury, 1946) no data were given on completeness or otherwise of kill. Ball (1948b) marked fish before poisoning and recovered only 58·9 per cent of one species and 44·7 per cent of another. I recovered much smaller percentages in Alberta as did Doan in Manitoba. The very extensive programme in Washington, reported by Pautzke to Solman, has been widely used by conservation officials of that state for 'sportsman propaganda'. I have seen no published data, although the propaganda has been so effective that Alberta anglers are asking us why we aren't 'progressive' and modern and poisoning our lakes.

I feel it is reasonable to conclude that complete kills are possible only in exceptional cases where lakes are either very small or very shallow or both. And, further, that even where complete kills do occur, repopulation may be very rapid unless the lake is unusually easy to screen, or has no drainage.

With this general conclusion in mind, I would like to re-examine the uses of rotenone. There are two broad categories of use—(1) for research purposes, and (2) for management purposes.

Research

Rotenone may be used in research for studies of population, taxonomy, growth rate or population succession.

For studies of populations rotenone may not be confidently used if it is desired to find the complete population of a body of water by actual count. However, it is an excellent tool for facilitating a simple Petersen estimate. A number of marked fish may be liberated, a lake poisoned, and the returns of marked and unmarked fish used to calculate the population. If the marked fish are carefully chosen, this method eliminates errors commonly introduced into such calculations by selective action of nets.

For taxonomic studies rotenone is a valuable tool, particularly when a collector is in remote territory or alone, and the use of heavy gear is not possible.

For growth rate studies rotenone has a great value since it enables the collection of a complete series of age groups without involving net selection. Normally the young fish are either not taken in nets, or if taken, are selected so that the faster growing members of the year class dominate the sample.

For studies of population succession rotenone should also be useful. It affords the collection of a random sample in such a way that it is readily repeated in successive years so that comparable data of species composition (at least relatively accurate, if not absolutely) may be obtained. In this way changes in the species composition of a population due to angling, natural causes or pollution could be assessed.

In one experiment in Michigan the intention was to kill all fish in a lake and see how the absence of fish affected the population of fish food organisms

(Brown and Ball, 1943). The success of this experiment depends on complete eradication which, as we have seen, is by no means easy to achieve.

Management Purposes

The uses of rotenone in fisheries management may be (1) complete eradication of an undesirable population with subsequent stocking of a desirable species; (2) reduction of predator or competitor species; (3) selective poisoning for some purpose such as parasite control. Let us consider these in order.

Complete eradication of undesirables is only rarely possible, and, when possible, repopulation is difficult to prevent. Furthermore, as Smith has emphasized, trophic conditions in the lake may have led to the situation which the poisoning is supposed to correct, in which case even a complete poisoning is of only temporary value; i.e., the lake may be relatively low in its productive capacity for the desired species. The second and third items involve partial or selective poisoning. The reproductive potential of coarse fish being what it is, such selective or partial poisoning must be repeated at frequent intervals. The costs must be considered. I found that repeated partial poisoning of pike *(Esox lucius)* in a 2·5 square mile lake cost over $5,000 in 3 years. Siegler and Pillsbury (1946) in New Hampshire found their average costs were $1.40 per acre foot; in swampy lakes their costs rose to $4.75 per acre foot. The cost of rotenone-containing preparations has risen since the time their estimates were made. I was particularly impressed with the limitations of selective poisoning in my own work in Square Lake. We obtained incontrovertible evidence that the pike fled the poisoned areas, and took refuge in untreated areas. This led me to suggest that poisoning be combined with netting for pike reduction in connection with ***Triaenophorus*** control. Nets could be set along the shore and the pike driven into them with rotenone.

Conclusions

(1) Poisoning for total eradication of fishes in fisheries management is completely successful only under unusual circumstances in very small or very shallow lakes.

(2) Selective poisoning must be repeated regularly and a study of costs may show it to be uneconomical in many cases.

(3) As a research tool in growth rate, population or taxonomic studies rotenone may be very useful since it provides a method of collection free from errors introduced by gear selectivity.

I would judge Conclusion No. 3 to be the most important use of rotenone at the present time. Greater value of rotenone in management awaits the development of methods of assuring complete kills in a variety of lakes.

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Usefulness of Electrofishing Methods*

by

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The following critique of the usefulness of electrical fishing methods is designed to assist the fishery worker in deciding whether these relatively new techniques are likely to be of value for attacking his particular problems.

Needs for Catching Fish

Studies of fish populations are receiving increasing attention from fisheries biologists. The tools provided by the science of statistics are particularly well adapted to such studies (Mottley, 1942). For the use of these tools the necessary raw materials are measurements, whether of populations, changes in populations, sizes or growth rates. In order to obtain these measurements fish must be taken from the population under study. These fish should be gathered in such a manner that the collection, or sample, bears a definable relationship to the total population. Estimates of total population, or some other parameter, can then be made, together with an evaluation of the accuracy of the estimate. The chief difficulty encountered lies not in getting a sample of fish, but rather in defining the relationship between sample and population. Sometimes, and especially in stream work, the attempt to solve this problem has assumed that the relation between sample and population is similar to the relation between the area from which the sample was drawn and the total area occupied by the population under study. Fish-catching problems are then resolved into catching either all the fish from the chosen sampling area, or a known proportion of these fish. Whatever device is selected for defining the relationship, the need is present for catching considerable numbers of fish.

Since reported uses of electrical fishing deal only with stream work, the remarks which follow are concerned primarily with the study of fish in similar habitats.

Features of Other Fishing Methods

1. *Angling and Trapping.*

Both angling and trapping have been used for taking fish for study purposes. Angling, because of the gear used, is somewhat selective for size, species and individual habits. Similarly, trapping is dependent on habits of fish and is also affected by such factors as species and age. Both methods are too selective to be useful for studies of populations composed of diverse groups of fish.

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* *Contribution to Canadian Committee on Freshwater Fisheries Research, Ottawa, January, 1950.*

2. *Seining.*

Seining consists, in principle, of straining the water through a screen sufficiently fine to separate out the desired fish. Variations of method may involve the screen, or seine, being moved through a large mass of water, or they may involve fish being driven into a restricted mass of water which is repeatedly strained. Since seining involves going right into the fish's habitat there is less dependence on strictly voluntary movements of the fish. Where conditions are suitable seining is of rather general utility for removing a high proportion of the population. Various workers (Trippensee, 1937; Shetter and Hazzard, 1939) have reported taking up to 90 per cent of the fish present in a barred-off area. In our own experience (Elson, 1949) under reasonably favourable circumstances up to 80 per cent of marked fish of some species may be removed with fair regularity. Nevertheless, seining all too frequently involves factors not subject to control. Some selection for species, size and individual habits of fish is involved. Thus, in Atlantic coast streams, few eels (*Anguilla bostoniensis*), ammocoetes (young lampreys (*Petromyzon marinus*)) or young ling (*Lota lota*) are taken by seining, even though they are sometimes plentiful. Individual fish of all kinds may succeed in consistently avoiding the net. The experience and energy of personnel are variable but important factors for success. The type of bottom greatly influences the success of fishing.

3. *Use of Toxic Drugs.*

The use of cresol for temporarily immobilizing fish has been advanced (Embody, 1940; Embody, Schuck, Crump, Freese and Ross, 1941). Such a procedure has the advantage of making many of the fish readily available for capture. Capture, however, depends on having immobilized fish where they can be gathered with a net and fish immobilized while in protective cover may be missed altogether. There have been no reports of the proportion of fish present, which such drugging makes available to capture. The technique of handling the poison requires consideration of such factors as water flow and temperature. While this application of the principle of immobilization seems a decided addition to fish-catching techniques, the introduction of electrical shocking methods at about the same time has offered another method of immobilization which includes additional advantages, and drugging has received little subsequent publicity.

Features of Electrofishing

Recent uses on this continent of electric current as an aid to fishing have been described, with extensive references, by Omand (1950) and Larkin (1950). Although direct current (D. C.) offers features which appear to have advantages over alternating current (A. C.) fishing, both methods have two features in common which, for many problems, offer improvements over other ways of catching fish for biological studies.

1. *Mechanics of Fish Collection.*

Electrofishing resembles seining in that it is dependent on the use of nets for finally gathering the fish from their habitat. Its distinctive features are (1) fish are nearly always driven from cover as a result of the electrical stimulus to movement; (2) once having been driven from cover and placed within effective range of the electrical field fish are immobilized and usually can be picked up. The electrical dislodgement is more effective than mechanical dislodgement or frightening as employed in seining. Success in dislodgement is less dependent on the energy expenditure and experience of personnel, which is frequently a variable factor in seining. The immobilization is an advantage over ordinary seining in which fish may frequently escape from the net before removal from the water. Electrical dislodgement and immobilization together result in more consistent success under varying conditions of bottom formation, depth of water and velocity of water flow, than in ordinary seining. A few fish in cover may, of course, be stunned where they are not readily recoverable, so collection is not necessarily complete. In general, electrofishing gives both larger and more consistent sampling catches than does seining. This, in turn, means quicker and more accurate computation of populations.

2. *Effectiveness of Electrofishing.*

Some quantitative tests of the effectiveness of electric current as an aid to fish-catching have been made. These have involved tests on populations containing known numbers of marked fish. Fishing with A. C. gave recaptures varying from about 40 per cent in a boulder-strewn stream, to 75 per cent in relatively unobstructed areas, several species being involved (Haskell, 1940). For legal-sized trout (*Salvelinus fontinalis* and *Salmo trutta*) Schuck (1942) reported that A. C. fishing gave returns of 80 per cent to 90 per cent. In warm-water streams under various conditions of fish cover, turbidity and water velocity, the electric seine gave recoveries of one-sixth to one-half of the marked fish liberated in blocked-off areas as large as about 15,000 square feet (Funk, 1949). Tests with D. C. on marked fish, mostly under four inches long, have given recoveries of 80 per cent to 90 per cent, with mixed species (Smith and Elson, 1950). In the same places where the D. C. tests were made, seining under favourable conditions gave only 60 per cent as many fish as electrofishing, though estimates of populations from both methods were equally good.

3. *Selection for Size.*

Most investigators using A. C. report that there are size differentiations in electrofishing, large fish being more readily taken. Schuck (personal communication) reports the effectiveness on size groups of brown trout (*Salmo trutta*) as follows:

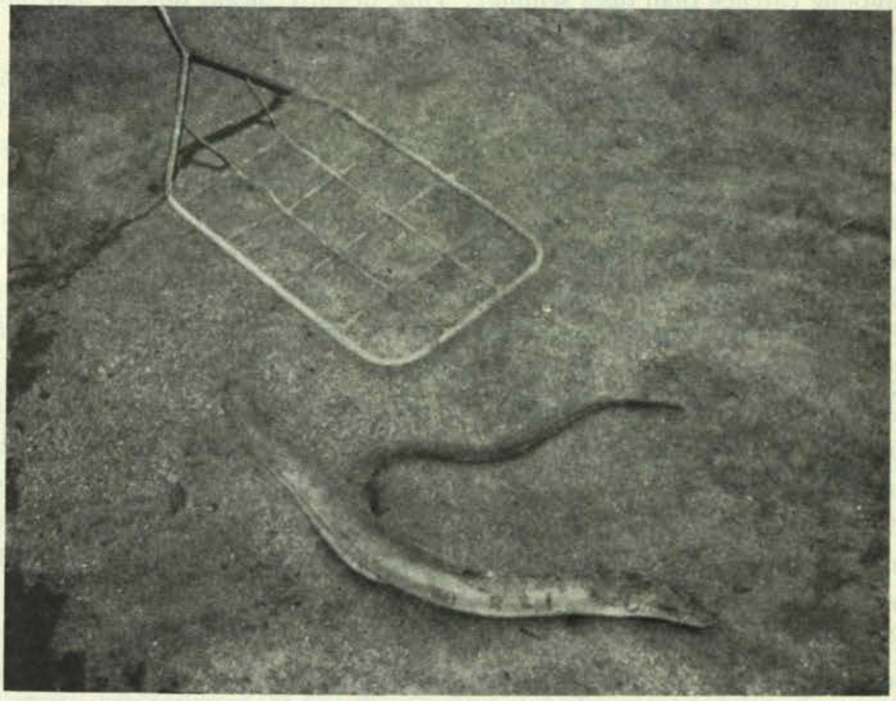
5·2 cms. to 10·5 cms.	— 50%
10·6 cms. to 16·8 cms.	— 81%
16·9 cms. to 21·3 cms.	— 92%
21·4 cms. up	— 95%

Hauck (1949) describes the drastic effects of moderate voltages on large rainbow trout.

Qualitative statements of stronger effect on large fish have been made for D. C. also. A direct-current apparatus developed in Sweden provides for selection among several voltages, thus allowing choice of a voltage best suited to particular sizes of fish (Smith and Elson, 1950).

4. *Selection for Species.*

Some reports suggest that particular species are less susceptible to effects of electric current than others. For example, killifish (*Fundulus diaphanus*) are reported noticeably less affected by D. C. than are eels (Smith and Elson, 1950). In general, however, such differences seem likely to be of less importance in this type of fishing, where involuntary responses to electrical stimuli are involved, than in seining.



Two live eels being held in field of electrode after removal from beneath nearby stones by Wolf electrical machine.

5. *Necessity for Visibility.*

Most reports indicate that shocked fish have been gathered with dip nets, hence it is usually necessary to see the stunned fish if they are to be recovered. During the past summer, when D. C. fishing was used on New Brunswick salmon streams, both eels and other species were taken more successfully in swift water when a block-seine was used immediately below the electrode than when depending on dip nets only. Unseen fish were carried into the seine by the flowing water and, with the electrode sufficiently close, were kept immobilized until the net was lifted. With turbid, flowing water the same system should be effective. Where water velocity is not sufficient to carry fish into a net the importance of good visibility is increased.

6. *Depth of Water.*

To date most investigators, whether using A. C. or D. C., have found depth to be a limiting factor for electrofishing. Three or four feet is usually specified as maximum depth for effective work. Minnesota workers (Smith, Johnson and Hiner, 1949) have recently reported success in pools up to 8 feet deep, but such success has not been reported generally.

Control of Field Shape by Electrode Systems: Grounding of Current

As intimated by Fisher (1950), present systems for fishing with the aid of an electric current have been developed on an empirical basis. Little is known of field characteristics produced by particular equipment. Perhaps less is known of the characteristics required for most effective fishing. Holmes (1948) has pointed out the difficulty of measuring voltage gradients in water. Users of electrofishing have, however, done considerable experimenting which involves field shapes and have found various adaptations to give satisfaction under different circumstances.

The earliest methods described used a single, movable fishing electrode with the stream bed immediately beneath serving as the second electrode, since one pole of the generator was also grounded. In this case the energized field was presumed to be a column between electrode and substratum.

Later, to circumvent conditions where the stream bed had relatively high electrical resistance, two electrodes were employed, one connected to each pole of the generator. These electrodes were used at distances of 10 to 20 feet apart and in depths up to 3 or 4 feet. Variations of this method have involved elongation of the electrodes horizontally or vertically. The fields produced in the one case were adapted to use in shallow water; in the other, deep water. In the Kentucky electric seine (Joeris, 1949; Funk, 1949) a series of electrodes attached to one generator pole were suspended at the surface of the water and a series attached to the other pole were suspended at a depth of 3 or 4 feet below the surface electrodes.

Now, field characteristics involved in these variations have apparently been measured only by their observed effect on fish. The assumption appears to have been made that the current flowed directly through the water between electrodes. Fisher (1950) has remarked on the distorting effect of a low resistance substratum on an electrical field in the water. Holmes (1948) has discussed the same subject in reference to electric fish screens using electrode arrangements similar to those described above. He stated that in most cases the ground, or substratum, acts in practice as one electrode. He added that, in many cases, up to 90 per cent of the electrical energy is thus dissipated in the substratum. As a general rule in fresh waters the substratum of a stream actually has lower electrical resistance than the water. Inasmuch as this is the case, electric currents can only flow without distortion between electrodes which are closer to each other than to the ground beneath. Where electrodes are several times farther apart than the distance from either one to ground, much of the current must flow through the substratum with resultant distortion of the field.

During the past summer opportunity was afforded for observing a 2-electrode A. C. outfit in action. In the high-resistance water (not measured) which characterizes Maritime streams the electrodes had to be used at a distance not exceeding 10 feet apart in order to energize completely the area between. When one electrode was laid on the bottom of the stream and the other used at distances over 20 feet away, the latter still had an effective field, though only about half the size of the field obtained when using two electrodes.

These considerations suggest that 2-electrode systems are, in fact, frequently employing two contiguous fields between electrodes and substratum, rather than a single field between electrodes. Be that as it may, the additional fishing capacity has proved an asset. Field distortion applies equally to A. C. and D. C. However, in those instances reported, use of D. C. has involved either use of the substratum as one electrode or else no particular assumption regarding shape of electric field has been advanced. With the D. C. apparatus tested in Canada, provision is actually made for the use of two positive electrodes, i.e. two fishing fields.

Importance of Voltage Gradient

Fisher (1950) has stressed the importance of voltage gradient in the energized field and the fact that from the physiological viewpoint this is a matter of greater importance than the actual amount of electrical current flowing. Where fields are built between the water surface and the bottom, the voltage gradient, because of the horizontal bulging of the field, must necessarily vary as between that portion of the field directly below the electrode and the horizontal periphery. Therefore the requirements for voltage gradient, at least in systems using the substratum as one electrode, are elastic and call for a relatively large stunning area with as little danger of injury to fish as possible. In the use of A. C., available equipment seems to have helped set the terminal voltage standards generally in use, with about 100 volts being satisfactory for taking fish and over 150 volts having definite danger of injuring trout (Rayner, 1949). In D. C. experiments performed in New Brunswick in 1948, the author found that a gradient of about 3 volts per inch was sufficient to stun all fish over 3 inches in length. A gradient of 1 to 2 volts per inch gave stimulus to movement for smaller fish and frequent stunning of fish over 5 inches long. Here again the nature of the field set up in fishing is such that a uniform gradient does not occur and different responses are elicited in different parts of the field. This may well be both desirable and unavoidable.

Current Requirements

Any need for appreciable amounts of power in fish shocking arises not from requirements for affecting fish but from the electrical demands of the field being energized. Such demands are proportional to the conductivity of the water and the size of the field. Most machines now in use are able to supply 5 to 10 amperes at the voltages designated. To some extent this capacity represents a reserve available in case of overload of the machine. Fuses or circuit breakers might provide a satisfactory margin of safety, with a possible saving in weight and cost of apparatus needed. Recording measurements of the current drawn, terminal voltages employed and distance between electrodes, or between fishing-electrode and bottom, for particular operations should advance the development of electrofishing.

D. C. versus A. C.

While methods of electrofishing developed in America have for the most part involved the use of A. C., investigators in Europe have developed methods using D. C. Within the last year, however, D. C. methods have been described from both the west (Rayner, 1949) and east (Smith and Elson, 1950) coasts of North America. Use of D. C. appears to offer two advantages over use of A. C. in that (1) galvanotaxis (movement towards the positive pole) is elicited from some fish and (2) electronarcosis induced by D. C. seems to involve less danger of injury to fish than the immobilization which accompanies use of A. C.

1. *Galvanotaxis.*

When collecting fish at the positive electrode of a D. C. fishing apparatus some fish are observed to swim towards the electrode. The field characteristics which induce such movement apparently vary for different sizes of fish and with the conductivity of the water. Voltage gradient is doubtless involved. This galvanotaxis results in some fish being brought out of hiding and into narcotizing range so that they can be readily caught. According to Harreveld (1938) galvanotropism (***orientation*** towards the positive pole) involves bringing the body axis of the fish parallel to the lines of force of the electrical field. The same author has pointed out that the characteristic reactions of fish in a direct current field are (1) stimulation to movement by a weak current, (2) galvanotropism and galvanotaxis in a stronger current, and (3) immobilization by electronarcosis in a still stronger current. All the reactions described by Harreveld (1938) have been observed in D. C. electrofishing:

fish on the periphery of the field moving away from as well as towards the electrode, those in a field of intermediate strength frequently showing galvanotaxis and those in the strongest part, near the electrode, being narcotized.

Obviously, no galvanotaxis can occur with the rapid alternation of poles accompanying use of A. C., and only random movement and immobilization result in the various parts of such a field.

2. *Electronarcosis or stunning, and injury to fish.*

The immobilization of fish induced in D. C. fishing is characterized by a relaxed condition of the body musculature. Recovery is instantaneous when the current stops flowing. Occasionally, when fish get too close to or in actual contact with the electrode, immobilization may be prolonged or death may result. In this case burn scars are frequently visible at the area of contact. It has been demonstrated that under collecting conditions the amount of injury is small, even with terminal voltages of 300—400 (Smith and Elson 1950).

The immobilization resulting from use of A. C. at ordinary frequencies, while doubtless also involving electronarcosis (Harreveld, Plesset and Wiersma, 1942) is accompanied by severe tetanic contractions of the skeletal musculature. Some investigators (Rayner, 1949; Hauck, 1949) have found that the resulting lesions may cause serious injury or even death, particularly with larger fish. With terminal voltages over 100 such effects become progressively more serious. This is an obvious disadvantage where it may be desired to make repeated observations on a given population or where there is other reason for wishing to keep the animals in good condition.

Thus it is evident that electrofishing with D. C. can utilize materially higher voltages than with A. C. This in turn means that larger effective fields can be employed and therefore there is less likelihood of frightening fish away before they can be placed within effective range of the apparatus.

In summation, it appears that since D. C. will do all that A. C. will do, and a bit more, it is the preferable method for assessing populations or for taking large numbers of fish uninjured especially from cover. Where, however, mortality to fish is unimportant, or perhaps even desirable, as in screening unwanted species from an area, use of A. C. should possibly receive consideration.

Battery-powered Shockers

Recent attempts to improve portability (initial cost of apparatus is also much lower) have involved using batteries of dry cells as the power source (Morris, 1950). Voltages are increased by using induction coils. While such methods may well be very useful in out-of-the-way places, it should be borne in mind that the output of an induction coil is A. C., not D. C., and hence will result in physiological reactions on the part of the fish characteristic of A. C. rather than D. C.

Portability

A chief disadvantage of electrical fishing is the weight and bulk of the apparatus. When studies of electrical field requirements have been made smaller power units may be found feasible. Even now special light-weight units for fishing have been built on this continent (Rayner, 1949). Other ways of improving portability, such as making generator and power source in separable units or using several small units connected in series, will doubtless be tried. Considering weight and bulk of equipment available at present, the method is unlikely to be used extensively in regions far from vehicular or boat transport. It does, however, offer definite advantages as a fish-catching method for sufficiently accessible areas.

Present Stage of Development

From the foregoing discussion it will be evident that electrofishing is still in the developmental stage, though even now a worthwhile addition to fishing techniques. New systems for producing energized fields are being investigated and as the actual requirements for electrical fields are learned, further advances should follow.

Danger to Personnel

The voltages and current capacities of the power units employed in most electrofishing are sufficient to kill a man. The danger lies, primarily, in getting within the immediate energized field or in shorting the electrical circuit through one's body. At the periphery of the field which affects fish, only mild discomfort is felt if unprotected hands or feet are immersed in the water. Nevertheless, the actual amount of current required to kill a man is very small and the dividing line between the relatively harmless periphery and the real danger zone is uncertain; therefore *common sense precludes any risks of contact with the energized field.* By wearing rubber waders insulation is provided against the field. Additional safety is to be gained by careful manipulation of the apparatus and by employing due respect for its potentialities.

Conclusions

Electrofishing is the best known way for taking fish from shallow, obstructed waters, or where fish cover and secretive species make capture by other methods difficult.

For taking maximum numbers of fish, and for least harm to the fish, D. C. is preferable to A. C. Where it may be desired to kill fish, use of A. C. should possibly receive consideration.

Electrofishing should not be depended upon for invariably taking all fish from an area, but can frequently be employed to catch more uninjured fish with less effort than any other method adaptable to similar purposes.

For some purposes other fishing methods may give as good results as electrofishing and be better adapted to particular situations.

Depth of water generally over 3 to 4 feet, poor visibility in the water, and lack of portability of the apparatus are important limiting considerations for use of this method.

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Electrical Methods of Fish Collection

by

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Quantitative studies of populations of fish have for many years yielded valuable information to be applied against fish management problems. The basis for such studies has usually been the more or less complete removal of all the fish from a body of water for examination. This has been accomplished in various ways, the standard method, particularly in streams and along lake shores where it is desirable to return the fish to the water unharmed, being the use of the seine. However, it has long been recognized that in certain environments, the use of the seine is not practical and electrical apparatus was first used for such purposes.

A German publication of Hager, translated and reviewed by Shetter (1938) first described the investigation of "standing crops of trout" in certain Bavarian streams by use of electrical methods. This worker used a two volt A. C. generator connected to electrodes 20 to 40 feet apart. The current was conducted to two copper plates, 10 inches square fastened to the end of long poles. A two volt shock was found sufficient to stun trout up to 18 inches in length. Fish revived in three to five minutes when removed from the influence of the current.

Haskell and Zilliox Experiments

The first recorded use of the shocker in natural waters in North America was described by Haskell (1940). He found that a much higher voltage was necessary, since the fish tended to avoid the electrical field unless it was strong enough to stun them on first contact.

McMillan (1928) reported that a low voltage was sufficient to stun fish in aquaria, but Haskell's work in natural waters was conducted with a 110-220 volt 60 cycle A. C. generator, of 500 watts output which was effective in streams 20 feet wide. A gasoline engine was linked to the generator, the whole being set on a portable mounting.

One terminal of this generator was connected to a ground pipe driven into the stream bed near the shore, the other to a floating metal screen, 10 feet to 15 feet long and 4 inches to 6 inches wide. Since the resistance of the soil beneath the stream was usually lower than that of water, an electrical field was set up between the sub soil and the wire screen floating on the surface. Under certain soil conditions, a number of ground pipes were found to be necessary. An attempt was made to test the efficiency of this method of sampling, by censusing a blocked off section of stream with the shocker, marking the fish, and releasing for subsequent census. Thirty-one fish were taken on the first census, and a total of twenty-one in three subsequent censuses, three being found dead. Approximately 75 per cent recovery was therefore obtained. Further tests indicated that larger fish are more readily collected by this method than smaller specimens. This may possibly be due to the comparative difficulty of locating the small fish after shocking.

Subsequent experiments by Haskell and Zilliox (1941) revealed that both water and soil fell into high resistance and low resistance categories. Where high resistance soil was encountered with high resistance water, a new technique was devised. A bare wire was substituted for the ground bar and dragged along the stream bottom parallel to, and a few feet behind the floating electrode. This worked well but was appreciably slower than the first technique. It also required extra men to handle the second electrode.

Further tests were conducted by Haskell and Zilliox on the relative efficiency of electrical and seining methods of fish capture. Removal of smallmouth black bass (*Micropterus dolomieu*) from a trout stream by the electrical seine in an area where a seine could not otherwise be used, yielded 120 bass per day, four to 12 inches in length. In another stream, removal of smallmouth bass both by seining and shocking was attempted. The two methods were equally efficient, and the cost of both was nearly equal, the disadvantage lying with the electrical method since it was found to be difficult or impossible to move the heavy equipment over certain areas of shore. Further tests with marked fish in a variety of conditions revealed that for fish of about four inches up, recovery was excellent, but in the fry and fingerling stages, the sampling efficiency varied within wide limits.

Workers in Michigan, applying these techniques found that the floating electrode and dragging wire were difficult to handle in snaggy streams and developed another technique. This consisted of two electrodes each formed of a wooden frame mounted on a handle and wound with wire. These are connected to the poles of the generator and are carried by two men at a distance of 12 to 15 feet apart depending on water conditions. This sets up a horizontal field, in contrast to the vertical field set up by the previous arrangement.

Design of Electrodes

Subsequent work on A. C. shocking methods concerned itself largely with the design of electrodes. Virgil Pratt, of the Department of Conservation, Michigan, has experimented with a number of electrodes, and has found that a long, narrow vertical electrode about 30 inches high by 8 inches wide is useful in deeper waters, but creates a narrow field horizontally. In shallower waters he finds a long, narrow electrode, which creates a wide field is more desirable, since the lines of equal potential between the electrodes are more nearly parallel, and there is less danger of injury to the fish.

The electrical seine proper is an arrangement described by Funk (1949). This is a variation of the previous arrangement by which a two-wire cable is used, one wire being connected through a series of floating electrodes formed by wrapping screening on a short piece of 2 × 4. The other wire is connected through a series of lengths of bare wire cable weighted with lead sinkers. These so-called drag wires alternate with the floating electrodes in the two-wire cable. Also in series with these drag wires is a probe pole at each end of the seine; this is a wooden pole with a copper-sheathed end, the sheathing being wired similarly to the drag wires. This arrangement simply creates a series of electrical fields between the drag lines and the floating electrodes. It was found to be easier to handle, and applicable to deeper waters since the distance between electrodes is fixed and relatively short.

Such an arrangement is used by Funk with fair success, using a 110 volt 60 cycle A. C. generator of 500 watts output. Joeris (1949) has used a similar arrangement with a 120 volt, 2500 watt capacity generator. Funk has used the equipment effectively in water which is waist deep. The principal limitation appears to be the difficulty of recovering stunned fish in deeper waters.

The use of direct current for collecting purposes apparently received little attention until recently. McMillan (1928) reported comparable results from the use of direct and alternating current in aquaria, but Haskell (1940) reports briefly that D. C. was not effective in stream work.

Report on Work Done in Europe

Rayner (1949) reports on work done in Europe. Dr. Kurt Smolian found a 4½ horsepower motor of 1,800 to 3,000 revolutions per minute to be most satisfactory. This drives an A. C.-D. C. generator of nine to 10 amps. and 60 cycles of A. C. with voltages of 80 to 250 depending on the speed of the motor.

Smolian found that whereas A. C. tends to drive fish from crevices and hiding places and creates a momentary paralysis, or, in some cases damage or death, D. C. current causes the fish to be attracted to the positive pole. They become limp and relaxed at the same time.

The German workers also found that by connecting one electrode to the negative pole of the D. C. output and the other to an A. C. outlet, a current was produced which they call undulating current. This has the property of driving the fish without attracting them or harming them.

A sign flasher placed in the line of a D. C. electrode produced what was called interrupted D. C. This was found to be particularly effective in attracting fish to the positive pole.

Workers in Oregon have studied the use of these forms of electricity particularly D. C. They have used a 230 volt, 2,500 watt D. C. generator which was found to be very effective in collection of fish since the property of attracting the fish makes them extremely easy to detect and very few are lost even in murky or fast water.

The negative electrode is formed by tacking a sheet of copper screening to a board and floating this on the surface of the water. The workers in Oregon found this to be most effective when large, and an electrode 16 inches by 36 inches was adopted.

The positive electrode was formed by threading copper wire through the mesh of two dip nets. These were then wired into the main circuit in parallel, so that when one was removed from the water for transferring of fish to tanks, the other remained to maintain the electrical field.

The effective distance between electrodes when this method was used was somewhat less than in the case of A. C., but it is generally felt that the greater percentage of fish taken, and the possibility of its use in turbid or fast waters more then compensates for this. Another factor involved is the lower chance of injury to fish by this method.

Houston (1949) describes the work of a German physicist, Konrad Kreutzer, who has observed that when a D. C. field is set up, and the strength of the current varied in a particular pattern, the fish in the field are directed to the positive pole and are made to swim in that direction by variations in current. He finds that the current strength must be built up suddenly and allowed to taper off, the entire pulse lasting about 0·002 seconds. By varying the time between pulses to coincide with the natural swimming motion of fish of a particular size, the apparatus is selective for one size group. Pulses at the rate of 20 per second select small specimens, while less frequent pulses select larger specimens. Kreutzer claims that this apparatus may be used on a commercial scale by attracting any desired size of fish into a commercial net, or into the path of a towed net. He thinks it may also be useful in the commercial whaling industry.

Physiological Effects

Little work seems to have been done on the physiological effects of these electrical fields on fish in natural environments. Haskell (1940) noted a marked difference between recovery of fish under four inches in length and recovery of larger individuals. He attributed this principally to the difficulty of seeing and netting the smaller specimens. Shetter (1947) noted that large fish are actually more readily stunned by the current, and that fingerlings and fry were affected only when the electrodes were closer together. He suggested that the severity of shock depends on the amount of the fish's body which is in the field, smaller fishes offering less body to the action of the electricity. He stated that fish recover in less than five minutes when removed from the field, and less than one per cent are killed.

Hauck (1949) describes in some detail the observed reactions of the fish to an electrical field. This work was concerned with the salvage of large rainbow trout (*Salmo gairdnerii*) in an irrigation canal in Idaho. 80 to 90 volts of 60 cycle A. C. were used, and an electric field of 10 feet effective radius and five feet depth was set up. It is noteworthy that in previous published works, the fish shocked were less than 12 inches long, whereas the work of Hauck deals with rainbow trout, 503 of which were shocked, averaging 3·7 lbs. Of these, 131 died as a result of shocking and/or subsequent handling. This may very well bear out Shetter's conclusion mentioned above.

Hauck states that when fish first came in contact with the electric field, respiratory action increased markedly and varying degrees of paralysis set in. This varied from paralysis of the side nearest the electrode, causing the fish to swim in circles about the electrode, to complete paralysis which caused the fish to float on their sides momentarily and then sink to the bottom.

Several of the fish showed hemorrhage at the gills or vent, or subcutaneous hemorrhage around the vent, or protrusion of the intestine through the vent. Actual contact with the electrode produced dark vertical bars in the area of contact.

Hauck found that the paralysis lasted in some cases for several days after shocking. This is in contrast to earlier results which indicated that the fish revived in a few minutes. There seemed to be impairment of circulation to the caudal region as evidenced by dead or dying tissues in this area.

Autopsy of 10 of these fish revealed that in most cases caudal or abdominal vertebrae had been fractured, or that a rupture of the spinal ligaments had produced spinal curvature. In some cases the vertebrae fracture resulted in the severing of the dorsal aorta and vein, causing breakdown of the circulation posterior to the point of fracture. In some cases, dorsal arteries in the neighborhood of the fracture were ruptured. In one specimen, the fluid in the semi-circular canals was bloody and several showed dilated vessels or blood clots in the region of the brain. Hauck suggests that this may be due to collision with rocks, etc. after shocking.

Rayner (1949) mentions that A. C. shock, "stiffens the fish and may separate the ribs from the vertebrae giving the fish the appearance of having been asphyxiated."

Less work has been done on the physiological effect of D. C. upon the organism. Rayner (1949) describes the effect as "narcotic-like". The fish are attracted to the positive pole, at the same time becoming relaxed and limp. Interrupted D. C. seems to have this attractive property without the narcosis shown by an uninterrupted D. C.

D. C. Current Seems To Be Preferred

Workers who have had experience with both types of current seem to prefer D. C., since the attractive property reduces loss due to inability to see the fish in roiled or fast water, and loss due to sudden revival of the fish on leaving the electric field. Needham in California has both a 110 volt, 1,500 watt machine and a 230 volt, 2,500 watt machine which he is using during 1949. Joeris in Kentucky states that he has almost abandoned his A. C. machine and seine in favour of a D. C. generator. He has been using a 115 volt, 11 amp. generator, but is obtaining a 220 to 240 volt generator for using in wider, deeper waters. Workers in Oregon have also found D. C. to be the more effective agent (Rayner, 1949).

The shocker has been used effectively in studying a number of problems. The first studies described by Haskell (1940) and Haskell and Zilliox (1941) were designed more to test the efficiency of the apparatus than anything else. Subsequent studies have shown that any work involving the removal or collection of fish from streams or shallow lakes may be undertaken with the shocker. Almost all of the wild trout (*Salvelinus fontinalis*) used in the organoleptic tests of Baeder, Tack and Hazzard (1948) were taken by shocker. T. V. A. workers are studying populations in representative streams sections, planning a later check on growth rates, in order to locate productive bodies of water in Tennessee. Workers in Wisconsin are studying stream populations by means of the shocker and find that a more accurate picture is obtained than by other means.

In Minnesota the shocker has been used principally to assess populations in trout streams. It has also been used with great success in taxanomic and distributional studies. These people are also experimenting with smaller, more portable equipment using a 6 volt battery and a model A spark coil. In Missouri a plan has been laid out whereby stations are set up along streams, and samples taken at various times of the year. It is hoped that a fairly complete population picture will result, together with an indication of seasonal fluctuations and developing trends over a period of years. Idaho workers have found the equipment useful in salvaging "trout" from canals after the water is turned off in the fall. In Michigan, the equipment has been used to salvage fish from hatchery waste ditches, and to remove predators from hatchery ponds. A programme is outlined of conducting population studies in conjunction with creel census to determine the standing crop of fish which produces angling of known quality. In New York state it has been extensively used in connection with the hatchery and transfer operations. It is used in connection with the hatchery programme in New Mexico, to determine the population densities before planting of fish.

Some work is now in progress on the construction of smaller units which are more portable and require fewer men to operate. This would mean a considerable advance, for at present the difficulty of transporting the heavy generating equipment in rough, forested or marshy country imposes a severe limitation confining the use of this method to fairly accessible bodies of water. In addition the number of men required to operate the equipment makes this method about as expensive as seining. The method is also confined to fairly shallow bodies of water, less than five feet deep.

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Canadian Uses of Electrical Fish Shocking Devices

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British Columbia Game Commission

Recent development of extensive freshwater fish cultural programs in Canada has stimulated investigation of many techniques and methods of fish culture which are concurrently of interest to workers in the United States and Europe. The uses of rotenone and electrical shocking devices are good examples of this attention to technical problems.

Three separate investigations of the possibilities of using electrical apparatus for collection and enumeration of fish have been reported within the past six years from Canadian sources. The first of these was the work of the Biological Bureau of the Game and Fisheries Department, Province of Quebec (Prévost, 1946). Since 1943 this group has been interested in the use of electrical methods to collect fish for transplantation to other waters. Recently the work has included preliminary investigation of the use of their apparatus for census of fish populations. Dr. T. W. M. Cameron, of Macdonald College, Quebec, was the second Canadian user of electrical shocking devices. Some preliminary tests were conducted with a shocker made after the design given by Shetter (1947). The third and most recent series of trials has been conducted by the Atlantic Biological Station on a European type of shocker. These experiments have constituted the most extensive Canadian investigations. For the most part, the use of shockers in these investigations has been limited to the experimental stage and as yet the method has not been used as a tool in biological investigations. Several refinements of techniques have been suggested by the trials and some progress has been made in outlining limitations of devices as sampling tools. The equipment used and the results of the various trials are briefly summarized in the following paragraphs.

Quebec Biological Bureau

Details of the methods and the apparatus used in Quebec and a summary of results are given in the third report of the Biological Bureau for the year ending March 1945. In the majority of experiments 60 cycle A. C. was produced by a generator of two kilowatt capacity. A transformer and variac allowed variation of voltage and amperage. The electrodes used were two 20 to 25 gauge copper wires. These were placed lengthwise in the stream near the surface so that an electric field was created between them which included a large part of the stream cross section. By this method successful treatment could be given to 3,300 cubic feet of water representing a width of 15 feet, a depth of three feet and a length of 75 feet. A seine at the downstream end of the treated portion of the stream was used to prevent loss of stunned fish, and dip nets were used to remove the fish. A charged metallic "broom" can be used to take fish from protected situations in the stream. It was stated that orientation of the fish to the electrical field was important in the stunning effect; fish which were disposed parallel to the lines of force received a stronger shock. As has been observed elsewhere (Shetter 1947) smaller fish were less easily shocked which was explained by the supposition that fewer lines of force were interrupted by the smaller surface exposed. Generally the alternating current if applied for only a short time paralyses the fish with no harmful effects. Mortality may reach five per cent from electrocution of fish which get too close to the wires. Recently an 8·5 kilowatt generator mounted in an "army truck" has been employed in a similar fashion to that described above and with one shock fish have been stunned in a volume of water 200 ft. × 20 ft. × 2 ft. (8,000 cu. ft.).

Attempts at censusing numbers of fish in lakes with the shocker have given poor results.

Macdonald College

The apparatus employed by Cameron was similar to that described by Shetter (1947), namely, a one horsepower gasoline motor driving a 500 watt A. C. generator (230 volts; 1·5 to 2·5 amperes). Electrodes of various shapes may be used and the field routine is a systematic patrol of an area with two portable electrodes held up to 15 feet apart. The downstream end of the census area is "fenced" by a seine. In its use in Canada this apparatus was employed using 110 volts. This gave relatively little success and the trials were discontinued.

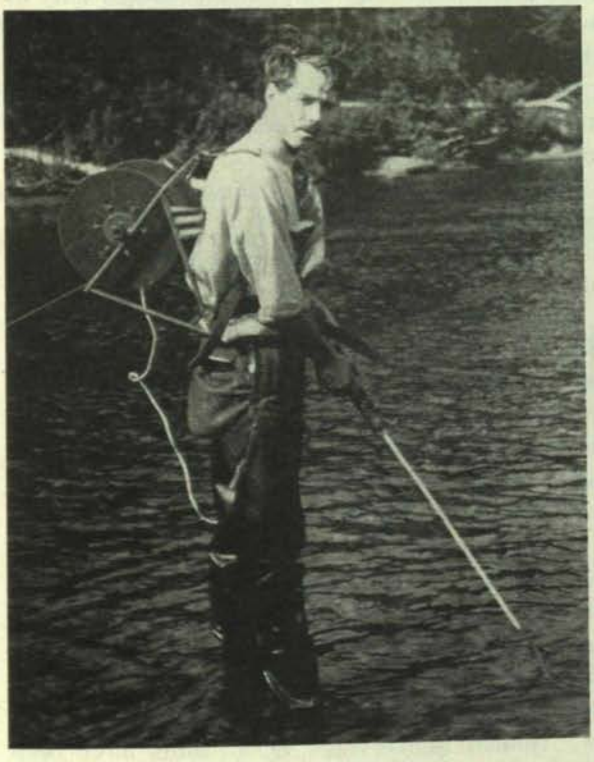
Atlantic Biological Station

Dr. P. F. Elson has recently conducted extensive field trials with a new shocking device imported from Sweden. This apparatus employs a D. C. generator driven by a three horsepower gasoline engine and can produce currents of 10 amperes at 500 volts. A control box connected to banks of resistors permits variation in voltage. The machine without accessories weighs 207 lbs. and mounted on a carrying cradle measures 33 inches × 21 inches × 24 inches.

The operation of the device is described by Elson as follows: "In operation the negative pole of the generator is connected by a long cable to a piece of wire mesh (about 2 ft. × 5 ft.) which is placed anywhere on the stream bottom. The positive pole is connected to 100 yds. of insulated cable mounted on a reel (25 lbs.) which is carried on the operator's back. As the operator moves off, the cable unwinds and lies on the stream bottom. At one end of this reel is a revolving, sliding contact which connects the long cable to a shorter cable leading to the handle of the positive electrode (anode). The anode is essentially a loop of 3/8-inch metal tubing with a heavily insulated handle. Three types of anode were supplied with the machine. One is used with an accessory handle incorporating a switch which, unless closed by gripping the handle properly, breaks the current by interrupting the generator field circuit through resistors and a condenser to prevent arcing. Another anode consists of an aluminum loop with a 6½ ft. handle (dismountable in three sections) which is used without the handle switch. A third anode is a copper ring about 15 inches in diameter which is suspended from an insulated cable by two cross-pieces; the proximal end of the cable attaches to the handle with built-in switch. The first two electrodes are used in regular stream work where the operator can reach to desired places; the ring-and-cable is used in deep pools, off bridges etc. where it can be flung to the desired place and then drawn in; it has been used principally for detecting presence of fish and casual collecting rather than for population studies. The voltage control box has two switch-banks for selecting voltage; one, with five alternative voltages, is used normally when only one anode is employed: a bank with two alternative voltages can be employed if it is desired to use two anodes (two operators) simultaneously, but under these circumstances no electrode switch is employable.

"Collection of fish is made by immersing the anode and gathering narcotized fish with dip nets and/or seines. The effective electrical field is between anode and stream bottom, with depth not over about two or three feet, and bulges laterally two to six feet, depending on conductivity of the water and directly as the size of the fish. With the anode deeply immersed there is no effective field above. Some species of fish are more affected than others and best results have been obtained with moderate and low temperatures rather than high temperatures. Fish in suitable parts of the field (presumably involving lines of force parallel to the body axis and proper current strength) are attracted towards the anode."

In the field tests the electrical method has been effective in taking fish from difficult cover in streams and it readily takes "unseinable" species such as eels (*Anguilla bostoniensis*) and ammocoetes (*Petromyzon marinus*). In one trial on the Pollet River, N.B., electrical col-



Electrofishing on Pollett River, N.B., showing method of carrying cable.

lections on six sections (433 yards) were made immediately after seining. The catches by the two methods are summarized in Table I. The effectiveness of the electrical apparatus in taking the "unseinable" eels is marked.

TABLE I

Fish collection from six sections (total 433 yards) of the Pollett River, N. B. 1949. Seining followed immediately by electrical collection.

Method	Salmon Parr	Catostomus	Rhinichthys	Couesius	Eels	Total
Seine...............	569	499	1,352	3,362	37	5,819
Electrical...........	90	42	38	113	1,641	1,924
Total...........	659	541	1,390	3,475	1,678	7,743

Similarly, in late autumn and winter, salmon (*Salmo salar*) parr and fry are difficult to seine because they commonly seek cover under rocks and they are relatively inactive. Electric fishing has proven to be of value in these conditions in field trials in the past autumn.

Population estimates based on a collection, marking and a second collection for each of the two methods, seining and electrically fishing, show no appreciable differences. This is an encouraging result and perhaps justifies confidence in estimates by seining that otherwise could be considered only as estimates of the seinable fraction of the population.

Mortality from the shocking is not great although some specific differences are suggested, salmon being more sensitive than trout (*Salvelinus fontinalis*). Immediate lethal effect is most common with high temperatures. Delayed mortality is not considered to be significant.

A comparison between the station's Wolfe D. C. outfit and an A. C. outfit of the Maine Salmon Investigations was based on the Digdeguash River, near St. Andrews, N. B., in August. The results of this comparison are of interest as they afford data on the two major types of shocking apparatus which may be constructed. The D. C. took small fish better than the A. C. and was better at bringing fish out of hiding to the electrode. Considerable mortalities resulted from the A. C. at 220 volts and none from the D. C. at 500 volts. The A. C. method required two movable electrodes and hence extra personnel, but had the practical advantage of a lighter power unit for equivalent output. The added advantage of a lesser hazard to personnel in the use of D. C. would indicate its suitability over A. C. in almost all respects.

The disadvantage of weight of the D. C. outfit is not a general criticism and some trials were conducted at St. Andrews with a portable 89-pound D. C. generator of U. S. manufacture rated at 110 volts and 5·2 amps. but capable of delivering 200 volts. This apparatus has been used for collecting eels at night with success and for late fall work it has proven more effective than seines in taking salmon parr. Similar light-weight D. C. units have been recently manufactured.

It has been concluded that D. C. has many useful fish cultural applications and that in most respects it is preferable to A. C. In relatively shallow and obstructed streams the electrical method has distinct advantages over the conventional methods of seining. Moreover, electrical collection takes large numbers of "unseinable" species of fish such as eels, and other species of fish in unseinable locations.

To date the Canadian uses of electric fish shocking devices have been confined to the experimental stage largely concerned with the biological calibration of the machines and few, if any, projects have been undertaken which utilized the method as a standard sampling device. Its future use in Canadian fish cultural research and practice would seem to depend on the design of units which would combine efficiency with light weight and a minimum personnel hazard. In many parts of Canada, streams, on which the greatest fishing intensity takes place, would combine a need for census usually with ready accessibility. However, in the major areas where stream census is most required, Northern Quebec, Ontario, the Maritimes and British Columbia, the problem of transporting the apparatus is an important practical consideration which will undoubtedly limit the extent to which electric shocking will be used. In British Columbia at least it is considered a notable feat just to propel one's own body weight over the hills and the addition of even 50 pounds excess would be sufficient deterrent.

The use of electrical shocking devices in the field has posed many problems of interest to the physiologist and in this field we may hope to find increased research which will have not only intrinsic value but which will contribute to our use of these devices in the field.

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Physiological Considerations Involved in Electrical Methods of Fishing

by

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The first studies of the reactions of aquatic organisms to the passage of an electric current through the water surrounding them appear to have been made nearly 60 years ago (Hermann, 1885). The total number of papers which have resulted is not large however, probably not over fifty, and fish have not figured in many of these. The nature of the various investigations may be ascertained fairly well by reference to the monograph by Loeb (1918) and to the papers by Harreveld (1938), Abe (1934), and Fisher and Elson (1950). From the work on fish already published and the general information which has accumulated over a period of years about the response of whole organisms, as well as of isolated tissues to electrical stimuli, one can formulate a fairly satisfactory general picture of the physiological phenomena which are involved.

Let us consider first in connection with the passage of an electric current through water, the parameters of the current which are capable of variation. Direction is one of these. The current may flow steadily from one of the electrodes by which we make a connection with the water, to the other, in which case we have a direct current (D. C.); or on the other hand the current may flow first from one and then from the second electrode, in which case we have an alternating current (A. C.). The duration of the current flow is also obviously capable of change for it is clear that one could employ a current lasting only a fraction of a second or that the current could be permitted to flow indefinitely. It is possibly useful in this connection to distinguish between a pulse and a constant current although it is obvious that long pulses merge into constant currents. One could of course employ a succession of pulses of D. C. or A. C. The intensity of the current, whether it be A. C. or D. C., can likewise be applied suddenly, or it can be built up gradually.

Consideration of all the possible variables in the application of an electrical stimulus is necessary not only for the sake of including all the logical possibilities but also because it is easy to demonstrate in any given instance that the reaction of the fish is related to each one of these. Before indicating the effect which variation of these several properties of the current may have, it is necessary to consider what it is that the fish does in response to the current.

Three Primary Responses to Current

There appear to be three primary responses of importance:

1. Locomotion, which may result in a distinct net movement of the organism towards a specific region.
2. Increased or decreased activity with no net change in position.
3. Orientation, body movements which bring some axis of the body into a constant relation with the direction of current flow but which do not cause a net change in the position of the organism. Paralysis, or stunning, or electrical narcosis, whatever it is to be called, which makes the organism incapable of response to subsequent stimuli is a special case of (2). It may cause loss of ability to maintain equilibrium, and in extremes, results in the death of the organism, apparently because of paralysis of the respiratory apparatus.

We may now pass to a consideration of the response of fishes to the properties of the applied electric current. It is convenient to dispose of paralysis first. This reaction is the inevitable result if the magnitude of the current be great enough, whether the current be in the form of a pulse or a constant flow, and whether it be alternating or direct. One gets the impression from watching fish which are stunned by direct current that the treatment is pretty severe. Recently there has been a revival of interest in electrical narcosis in mammals (Harreveld, Tyler and Wiersma, 1943). It seems possible from this that a re-investigation of the analogous phenomena in fish might be profitable.

Locomotion is the most obvious response of a fish to a pulse of direct current. From experiments in which practically only two directions were possible we and others have observed that the movement is usually forward with respect to the position of the animal immediately prior to the pulse.

The effectiveness of the pulse, as indicated by the amount of movement or distance travelled, depends within limits upon the strength of the pulse, upon the rate at which the current intensity is raised to its maximum value and upon the duration of the pulse. In general, to produce a given response the shorter the duration of the pulse, the greater must its strength be. Similarly, for a given response, the more slowly the current intensity is increased the higher must it be raised. It is a curious fact that a pulse of direct current is much more effective, the ratio is approximately 3 X, when the head of the animal is pointing towards the cathode, the negative electrode, than when it is pointed towards the anode. This observation is easily verified although the interpretation of it is still somewhat unsatisfactory (Kokubo, 1934). It also is well established that to obtain a given response the current intensity required is less when the long axis of the organism is parallel to the line joining the electrodes than when that axis is perpendicular to the line joining the electrodes. It is possibly worthy of note that in the few studies where alternating current has been employed there is little or no reference to locomotion as such. We too have done practically nothing with this kind of current. Elson, who made some experiments at Toronto some years ago with the alternating current from an induction coil, found that by comparison with D. C. pulses it is difficult or impossible to reproduce with this current any response involving locomotion.

To sum up the existing information about the locomotory response of fish to the passage of an electric current through water it would appear that while there are certainly locomotory responses to an electrical current, it is not clear that the direction of locomotion bears any relationship to the direction of the electrical current.

Most of the investigators who have been concerned with the response of fish to a current of electricity in the water have reported on the orientation of the animals with respect to the current and with the physiological mechanism which brings it about. In Hermann's early report (1885) there is a description of the way very young fish lined themselves up to be parallel with the direction of current flow, the head pointing towards the positive pole. These observations have been repeated by several authors quoted by Harreveld (1938). It is not at all clear, however, that fish of all species.and all ages behave in this way and, since Gourley and Sullivan in this laboratory were unable to show it on adult trout (*Salvelinus fontinalis*), we have decided to re-investigate the whole phenomenon. In any case, it is not clear that aggregation of the organisms at the anode follows necessarily from such an orientation.

In several instances some study has been made of the movements of the fish which result in this orientation. As early as 1905, Breuer fixed a fish in a clamp so that it could be held in any desired position with reference to an electric field. The recent more refined experiments of Harreveld (1938) indicate clearly what happens. When the long axis of the animal is parallel with the direction of current flow there is no response. If however this axis makes an angle with the direction of current flow there is a flexion of the body produced which effect is to bring the body axis parallel with the current flow. In this connection it is of interest to consider the result of establishing a current flow in a vertical rather than horizontal direction. This results in the passage of electricity through the fish along a dorso-ventral axis rather than an antero-posterior one. In this case the body bends just as it does when the current is in a horizontal plane but now the bend occurs in a vertical rather than horizontal plane. As in the case of the horizontal current therefore the response causes turning towards the anode and subsequent locomotion would carry the fish to it. When alternating current is employed the fish orients with the long axis at right angles to the direction of current flow. Locomotion presumably removes him from the field.

Before leaving the question of the response to current it is important to recognize that these effects of the current are apparently not direct effects on the muscles which do the moving but instead are mediated by the central nervous system. This situation is indicated firstly by the fact that all of the movements involved are well integrated ones and in all probability therefore integrated within the central nervous system. Secondly, destruction of the spinal cord prevents these responses. We may conclude then that the electric current stimulates sense organs and that it is this stimulation, co-ordinated in the nervous system which leads to the reactions observed.

"Engineering" Aspects of Fish Shocking

Let us now pass to what may be referred to as "engineering" aspects of fish shocking. How is an electric current to be produced in a body of water and what are the physical factors involved in this process? The question of whether alternating or direct current is to be used is not involved here since it is as easy to produce one as the other, the electrodes used may be identical, and so on. Similarly, whether or not the current is to flow continuously or as pulses is quite independent of whether D. C. or A. C. is to be used. Those things with which we now need to be concerned apply therefore equally well in the two cases.

It is necessary to commence with a clear understanding of what property of the electricity in the water it is that is of significance in determining the stimulating effect of the current. It may be helpful to recall the characteristics of an electrical system by reference to the familiar water analogy. Suppose one has a tank of water with a pipe at the bottom through which water in the tank may flow. The force or pressure causing the flow of water is measured by the height of the water level in the tank, the higher the level the greater the outflow. Flow and pressure are in fact directly proportional, other things being equal. Pressure (or potential difference) in an electrical system is measured in volts. Flow of water would be in gallons per second but in the electrical system current is measured in amperes. Now while flow in the hydraulic system is proportional to pressure, its absolute value depends upon the resistance which the water experiences running through the pipe. Similarly in an electrical system the actual number of amperes of current which will flow at a given voltage is determined by what is actually called the "resistance" of the system or circuit. We define resistance by the expression $\frac{E}{I} = R$, the resistance R measured in ohms is the number of volts required to push one ampere through the circuit. This electrical resistance is a property of materials which varies enormously from one substance to another.

Suppose there are two electrodes, each one foot square, placed in water so that they face one another. If they are now connected to a source of potential difference (an electrical generator) a current will flow the magnitude of which is determined by the resistance of the water between them. Generally speaking if the distance between them is doubled, the resistance is doubled. Usually the resistance of the water between the electrodes is uniform, that is, there are no portions of the water with a high resistance while other parts have a low resistance. Under these circumstances the drop in potential, voltage, between the electrodes is uniform so that one can speak of the voltage drop per inch or foot.

It turns out experimentally that whether the current flowing in the water around a given fish constitutes a strong stimulus or not, depends directly upon the voltage drop per inch in that water. If now the size of the fish is changed, it is found that in general to stimulate short fish requires a larger voltage drop per inch than is necessary for long fish. (Holzer, 1932; Scheminzky and Scheminzky 1931). Probably therefore it is the voltage drop from head to tail of the fish which determines the relative strength of the stimulus produced by the electric current.

When two relatively small electrodes are immersed in a relatively large body of water the path taken by the current has certain regular but complicating features. Some of the current passes in a straight line from one electrode to the other. Some passes from one to the other in a gentle arc and some more may pass from one to the other in quite a long arc. The long arcs represent longer paths than the straight lines and hence the voltage drop per inch in them is less. A fish exposed to the current in these paths experiences much less stimulation than when directly between the electrodes. It may therefore happen that a strength between the electrodes which would cause orientation would have no effect on fish outside the column between the electrodes.

The characteristics of the bottom of the body of water in which fish shocking is to be practised may have a pronounced effect. Suppose two electrodes are put into a body of water facing one another but fairly close to the bottom. If the electrical resistance of the bottom is similar to that of the water then electrically it does not change the field from that which would exist in water alone. Similarly if the resistance of the bottom is very high it may have little effect on the field. If however its resistance is low then very severe distortion of the field will occur. In the extreme case where the resistance of the bottom is, say, zero, the distortion is so great when the electrodes are near the bottom that the drop per inch near the electrodes is very high while the drop halfway between may approach zero. It would be particularly difficult in this case to establish any sort of uniform field in which a known voltage drop was established.

Comments

Finally a few comments appear to be in order concerning the equipment used to produce the shocking currents. One reads in some of the accounts of the people who have used electric fish shockers, that the generator they used produced 110 volts at five amperes, or that it was a 3,000 watt outfit, and so on. The impression is created that these data are pertinent to the experiments. Actually they are pertinent in only a very vague sense and in almost all instances the really critical information necessary to duplicate the observations i.e. the voltage drop per foot, is missing. Imagine an actual instance in which it is desired to establish a potential drop of 10 volts per foot across a stream. For simplicity let us imagine that the bottom is not a disturbing factor. The electrodes are to be 25 feet apart. If we are to have a drop of 10 volts per foot along a 25-foot column then we must clearly have $10 \times 25 = 250$ volts to apply to the electrodes. Suppose that the resistance of the water between the electrodes is 500 ohms. Then from the formula quoted earlier which relates voltage, current, and resistance, which formula can be written $E = RI$, we can set $250 = 500\ I$, so that $I = 0{\cdot}5$ amperes. Our source of potential then must be able to maintain a pressure of 250 volts even when 0·5 amperes is being withdrawn. Now the source may be capable of maintaining a pressure of 250 volts at even 10 amperes but this fact is clearly not pertinent.

The pressure of water in our hydraulic model multiplied by the quantity of water running out of the tank is a measure of the work which can be obtained from moving water. Similarly the voltage multiplied by the current, i.e. the volts by the amperes, is a measure of the power which is being expended in the electrical circuit. In the example just considered 0·5 amps. of current are flowing under a pressure of 250 volts. The power is then $0{\cdot}5 \times 250$ or 125 watts. The source of the electricity must be capable of producing an output of 125 watts in order that the drop of 10 volts per foot can be maintained. The source may be capable of producing much more power but this is not of any real significance.

If instead of being 25 feet apart the electrodes are only 12½ feet apart, other things being equal, the resistance will be only half as great, 250 ohms; the voltage applied to the electrodes needs to be only half as great, i.e. 125 volts, but the current will be exactly the same as before, i.e. 0·5 amperes. The power required now is only $125 \times 0{\cdot}5$ or 62½ watts. Thus in this instance we have an example in which the power consumed differs from the first case while the condition essential to provide equivalent stimulating effect is the same. The change in the power consumed occurred here because the electrodes were brought closer together.

There are two other conditions which affect the power consumed without any effect on the voltage drop per foot. The resistance of the water is the first of these. Apparently the resistance of natural waters varies appreciably. For a given separation of a given pair of electrodes the power consumed will be greater the lower the resistance. Brackish water will require a much greater expenditure of power than will fresh water. And although the voltage drop per foot may be identical the number of amperes which will flow in the brackish water will be greater than the number flowing in the fresh water. The second factor which can affect the current which flows, and hence the power expended, independently of the voltage drop, is the size of the electrodes. The greater the cross section of the column of water between the electrodes, the lower will be the resistance of the column, the higher the current will be for the application of a given voltage and hence the greater the power expended. In general therefore the lower the resistance of the water in which work is to be done, the further apart the electrodes are and the larger the electrodes are the greater will be the power expended. One has to be somewhat concerned with the power required because, in general, the higher the power required, the larger and heavier the source will be, whether batteries or motor generators or rectifiers are employed.

The question may occur—what happens if the power requirement of a given set-up of electrodes in a body of water is greater than the source is capable of providing, and the source is none-the-less connected to the electrodes? Without going into the technical reasons it can be said immediately that the voltage across the source terminals will, upon completion of the connection, instantly drop to a value below that which the source nominally produces. In fact, therefore, it is impossible under these circumstances to establish the desired potential difference between the electrodes. To correct the difficulty the size of the electrodes would have to be reduced or they would have to be brought closer together.

Summary

Several points need to be emphasized in summary:

1. There are certainly some physiological bases for the procedure of "fish shocking" which various investigators are attempting to apply. Many of the applicable fundamental data which apply to shocking are not yet available however.

2. Large differences in the results can be expected to occur as a consequence of differences in the lengths of fish.

3. In general the effectiveness of the electric current is directly related to the voltage drop per unit length in the water or, more particularly, to the voltage drop from the head to the tail of each individual fish. In general, therefore, the voltage applied to the electrodes will have to be greater to affect small fish than to affect large ones.

4. In going over the existing reports on shocking there appears to be a failure to recognize that it is the voltage drop per unit length which is significant and this information is therefore missing from every report I have examined. It cannot be urged too strongly that if progress is to be made this quantity must be measured and recorded along with the observations on the effects on the fish.

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A Direct-Current Electrical Fishing Apparatus*

by

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The assessment of a fish population in a body of water involves the capture of at least part of the population. In various approaches to the problem traps, weirs, fences, nets, poisons and angling have been used. Each of these methods has its limitations and sphere of usefulness. In recent years some attention has been given to electrical methods of capturing fish. Direct-current, interrupted-direct-current, undulating-direct-current, and alternating-current machines have all been designed and used. The present report is primarily concerned with the use of a direct-current machine in freshwater streams and small rivers to capture fish alive so that they may be counted, measured or marked, and returned to the water.

A demonstration of one such direct-current generator was given to some of the members of the Fisheries Research Board of Canada near Halifax in June, 1949, by Ph. Wolf of the Swedish Salmon and Trout Association. This apparatus, built in Sweden, was subsequently acquired by the Fisheries Research Board and used by members of the Board's staff on salmon and trout waters in New Brunswick and Prince Edward Island. A smaller generator made in the United States of America was also used for some of the work.

Apparatus and Method of Operation

The Wolf power plant is a portable direct-current generator with a direct drive from a small, air-cooled gasoline engine bolted to the generator housing (Fig. 1). The generator is a re-built, shunt-wound unit. Any one of five voltages can be produced by introducing various resistances into the generator field circuit. These resistances and the associated switching device are located in a control box mounted on top of the generator and are shown diagrammatically in Figure 2. The maximum potential supplied is about 610 volts; the minimum unloaded voltage is about 400. Voltages down to 220 may be obtained by closing the throttle of the engine. The maximum current that may be drawn varies from about 1·0 amp. at 550 volts to 5·0 amp. at 250 volts. This variation in power output is due to the generator winding and the power and speed characteristics of the gasoline engine. The power plant, attached through rubber mounts to a tubular steel carrying cradle, weighs 207 pounds. It is 33 inches long by 21 inches wide by 24 inches high.

The smaller American unit is a compound-wound generator rated at 110 volts D. C. and 600 watts at 1,750 R.P.M. For fishing, the speed of

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* *A report presented to the Fisheries Research Board of Canada at its Annual Meeting, January, 1950, with slight modifications.*

operation is increased so that the generator delivers about 160 volts. The weight of this unit is 89 pounds and its bulk is about half that of the Wolf machine.

The terminal apparatus supplied with the Wolf machine has been used with both units. To operate the apparatus the negative pole of the generator is grounded by connecting it through a long insulated wire to a 2-foot × 5-foot piece of non-rusting wire mesh laid anywhere on the stream bottom. The positive generator pole is connected to 100 yards of two-conductor cable mounted on a reel which is carried on the operator's back (Fig. 3). As the operator moves off the cable unwinds and lies on the stream bed. Snagging, snarling and chafing of the cable are thus avoided. At one end of the reel is a revolving, sliding contact which connects the long cable on the reel to a shorter two-conductor cable fastened to the proximal end of the electrode handle.

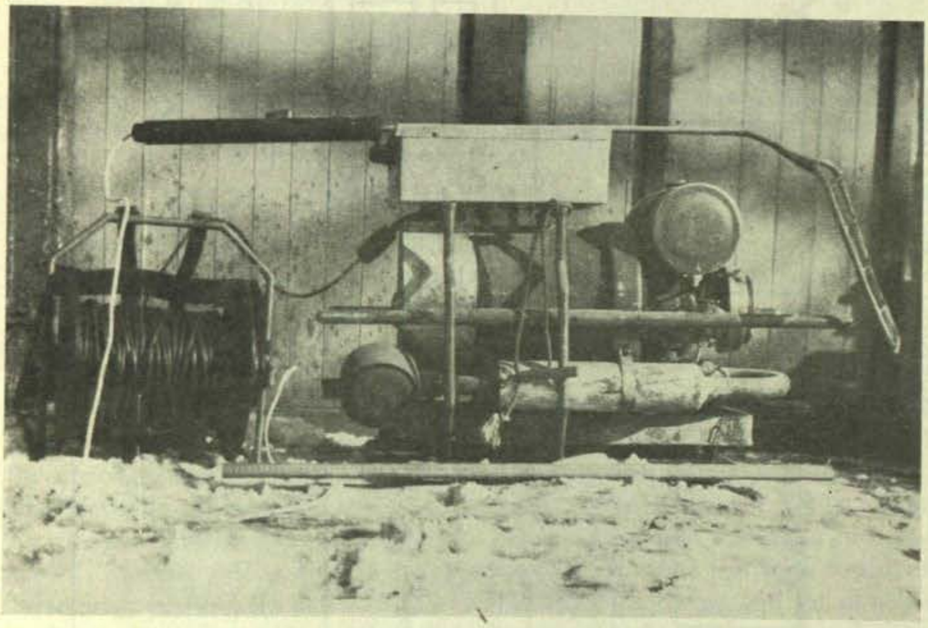

Figure 1

The Wolf D. C. power unit with voltage control box mounted on top. Note (1) fishing (positive) electrode of copper tubing which incorporates an open switch in the large handle-tube, and (2) cable reel to be carried on operator's back.

Three types of positive electrode were supplied with the Wolf apparatus. These are essentially loops of 3/8-inch metal attached to heavily insulated shafts of the same material. One type is an oblong grid (11 by 8 inches) with a 2-foot insulated shank (Fig. 1). This shank can be locked into the end of a tubular insulated handle which contains an open spring switch. The cable, leading from the reel, plugs into the upper end of this handle.

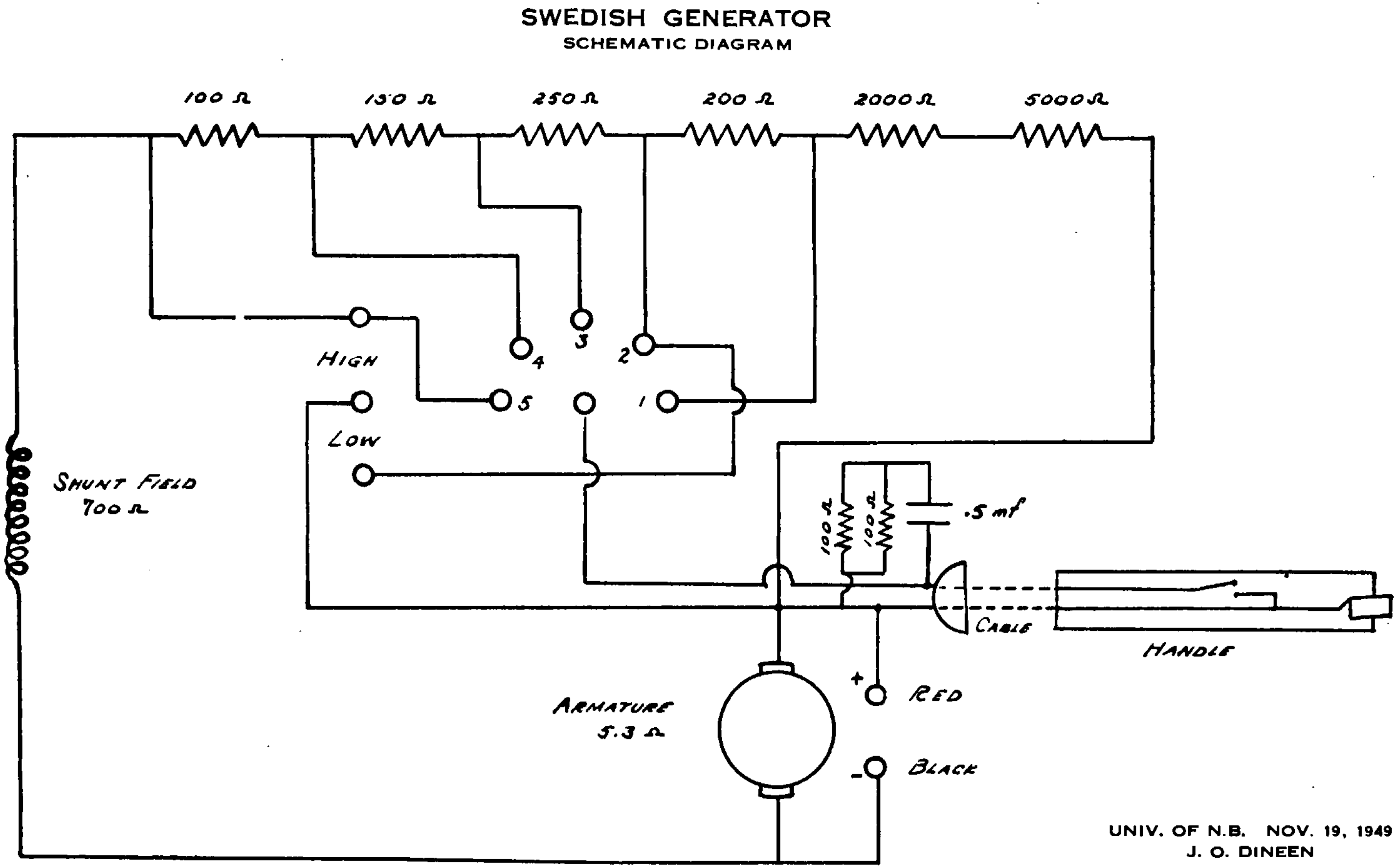

Figure 2

Schematic diagram of the Wolf machine showing (1) voltage control arrangements and (2) manner in which switch breaks field circuit of generator.

Unless the switch is closed by properly gripping the insulated handle the field coil circuit of the generator remains open and no current flows. Another electrode (Fig. 4) consists of a simple aluminum loop (12 by 8 inches) with a $6\frac{1}{2}$-foot insulated shaft (dismountable in three sections). This electrode is used with no handle switch. A third type of electrode is a ring of copper tubing attached by cross braces to an insulated cable which has on its proximal end a fixture for attachment to the switch handle.

Collection of fish is made by immersing the positive electrode in the water and gathering narcotized fish with dip nets and/or seines (Figs. 3 and 4). For ordinary work either one of the first two types of electrode is used. The long-handled aluminum loop is more convenient for reaching under obstructions. The ring-and-cable electrode has been used for casual collection in deep holes, off bridges, etc. It is flung out to the desired spot and drawn slowly in, some fish being immediately narcotized and others following it to within reach of the operator.

The effective field for fishing is between positive electrode and stream bottom with depths up to 2 or 3 feet, and bulges laterally 2 to 6 feet depending on the conductivity of the water. With the electrode deeply immersed the effective field does not extend above the plane of the electrode.

Population Assessments

Demonstration of the fishing effectiveness of the Wolf apparatus during the summer of 1949 was confined to rather small-scale comparisons of this method with seining on brooks and streams.

Recapture of Marked Fish (Benery Brook, near Halifax)

About 25 yards of Benery Brook was blocked off by barrier nets. At the site of this demonstration the width was from 10 to 12 yards and all of the water could be waded in hip boots except a small part of a deeper hole. The section was relatively free of obstructing rocks, snags, etc. The water current was sufficiently slow for there to be no difficulty in wading or in using any of the nets. After the barrier nets were set up some fish were captured by seining, marked by fin-clipping and released. In the second set of seine hauls a record was kept of the marked and unmarked fish captured. An estimate of the population is thus:

$$\frac{\text{Total fish marked} \times \text{Total capture}}{\text{Marked fish in the capture}}$$

In this demonstration no attempt was made with either method (seine or electrical apparatus) to capture all the fish. Unmarked fish from the second set of seine hauls were also marked, and the procedure repeated using the electrical apparatus to capture the fish.

From the results (Table I) it would appear that as a tool for fishing and estimating populations by marking and recapture, without attempting to catch all the fish, the seine and the electrical apparatus give substantially the same result and are in agreement with each other. It is to be noted that the electrical apparatus did, however, recapture a greater percentage of the marked fish (83% as compared with 51%), and a greater total number of fish (131 as compared with 81).

TABLE I

Relative fish* capture by seining and electrical fishing (Benery Brook)

Method	Marked Fish		Unmarked Fish taken	Total taken	Population estimate
	available	taken			
Seine	78	40	41	81	157
Electrical	114	94	37	131	159

* Includes suckers, killifish, shiners and salmon parr.

Total Capture from an Area

(*a*) Grant Brook, near Halifax

Grant Brook is somewhat smaller than Benery Brook, being about 5 to 8 yards wide and no hole in the area selected was more than 2½ feet deep. An undercut submerged root in one bank provided shelter for fish. About 20 yards of this stream was blocked off by barrier nets and an attempt was made to capture as many fish as could be obtained from the area, first with the seine and then with the electrical apparatus. All the fish captured by the seine were marked and released except that the eels were not marked. Each method was continued until the operators were capturing no more fish.

By means of the electrical apparatus 48 marked fish were recaptured (89%) and a total of 93 fish taken compared with 59 by the seine, as shown in Table II.

TABLE II

Total fish captured by seining and electrical fishing (Grant Brook, N. S.)

—	Lamprey larvae	Catostomus	Couesius	Notropis	Semotilus	Trout		Salmon parr	Eels	Total
						large	fry			
Seine	0	6	20	6	8	2	3	9	5	59
Elec. App.										
Marked	0	6	18	6	7	2	2	7	—	48
Not marked	4	3	3	10	1	4	1	0	19	45
Total	4	9	21	16	8	6	3	7	19	93

(*b*) Ellerslie Brook, P. E. I.

On September 11 a pool about 60 yards long and averaging 4 yards wide, with a maximum depth of 2½ feet, was blocked off by nets. The pool was swept four times with a two-man seine, then fish were collected with the electrical apparatus. All of the fish, except the salmon that were killed, were released into the pool and the barrier nets left in place. On September 12 three trips were again made over the pool with the apparatus.

TABLE III

Fish captured (Ellerslie Brook, P. E. I.)

Method	Fishing time	Trout under 10 cm.	Trout over 10 cm.	Salmon	
Seining.......	30 min.	9	49	4	Fish held out
Elec. App.					
1st day					
1st trip	30 "	43	43	72	(6 killed) Fish held out
2nd "	24 "	9	9	33	" " "
3rd "	25 "	2	0	4	All fish of day replaced
		63	101	113	(6 killed)
2nd day					
1st trip	55 "	141		79	Fish held out
2nd "	25 "	45		20	(1 killed) " " "
3rd "	23 "	11		4	
		197		103	

The second sampling recaptured almost the same total number of salmon that had been released the previous day, but disclosed 33 more trout.

Total Capture in an Area with Physical Barriers to Seining. (Ellerslie Brook, P. E. I.).

On September 12 the Wolf apparatus was used in a shallow section of Ellerslie Brook (approximately 30 yards in length). In this section were emergent stones and a heavy growth of filamentous algae, presenting a situation where capture by seining was almost impossible, and very time-consuming at best. The following fish were captured:

TABLE IV

—	Trout	Salmon	
1st trip.......	25	123 (8 killed)	Fish held out
2nd trip......	7	37	Fish held out
3rd trip.......	2	18	Fish held out
	34	178	

Capture of Residue from Seining

On the Pollett River, N. B., assessments of fish populations have been made by thorough seining of barred-off areas. This year, after capture of as many fish by seine as feasible and before their release, the area was fished electrically (Table V). As indicated by the relatively small numbers remaining to be captured electrically, the effectiveness of the seine and the electrical apparatus are of the same order of magnitude for most fish except eels.

TABLE V

Fish collection from 6 sections (total 433 yards) of the Pollett River, N. B. 1949
Seining followed immediately by electrical fishing.

Method	Salmon parr	Catos- tomus	Rhini- chthys	Couesius	Eels	Total
Seining.............	569	499	1,352	3,362	37	5,819
Electrical...........	90	42	38	113	1,641	1,924
Total...........	659	541	1.390	3,475	1.678	7.743

Capture of Eels

The effectiveness of the technique for taking eels was shown in a small brook about 5 ft. wide and 1½ ft. deep near Halifax. Except for a channel a few inches wide the brook was choked by a dense growth of aquatic weeds. The only fish visible were many alewives and a few eels. In one half hour spent covering a couple of hundred yards of the stream, about half a bushel of eels was collected. The eels taken ranged from 3 inches to over 2 feet in length and all sizes were sufficiently immobilized to be readily gathered in a small dip net. Many of those hiding in the weeds were so stimulated as to move into the narcotizing field where they could be seen and gathered. Some small eels and ammocoetes were observed to emerge from mud and gravel within a few feet of the electrode where none could be seen previously.

On the Pollett River, N. B., assessment of fish populations during the past three years has been made by thorough seining of barred-off areas. This year, before liberation of the seined fish, the areas were immediately fished electrically (Table V). Over 40 times as many eels were taken by electrical fishing as by seining. For other species in these places seining seemed to be nearly as effective as electrical collection. In studies involving the interrelations of species, the incomplete collection of data by seining could lead to grave misconceptions if, as in the Pollett, one half by weight of the standing fish crop is composed of such "unseinable" species as eels.

Use of the electrical apparatus on other streams of the Petitcodiac region showed eel populations of a similar order to those found in the Pollett, whereas earlier seining had not revealed that eels were so abundant.

While the Wolf machine was used in the cases referred to above, the small American unit was also effective for taking eels. Since an ordinary incandescent bulb could readily be attached in the external circuit near the positive electrode to provide illumination, this outfit was particularly convenient for collecting foraging eels at night.

Differential Effect on Species

In electrical fishing, populations of some fish species are taken differently from others. For a given voltage output, small fish are less affected than large; hence many minnows are less readily taken than salmon parr, suckers, and trout of moderate size. The habits of the species affect its catchability. Those species which tend to confine their avoiding reactions to relatively small areas are most readily taken, even though they may go into hiding; salmon parr and eels are examples. Species which tend to run some distance are more difficult to take; minnows and frequently suckers are in this category. Trout, depending on the habitat, may fall within either group. Fish in schools are more difficult to collect thoroughly since those fish on the periphery of the electrical field may be dispersed as current is applied and nearby unaffected fish may disperse with them. For most species, differences in catchability observed would appear to be largely associated with the habits of the species rather than any inherent differences in sensitivity to the electrical field. Eels, however, appear to be more sensitive than most other species. With the small generator operating at 160 volts eels were narcotized at normal distances, but *Fundulus* within a few inches of the electrode were not affected.

Temperature Factor

Temperature of the water has a noticeable effect on the success of electrical fishing. Above 25°C. salmon parr did not respond from as far away as with lower temperatures, and lethal effect was much more pronounced. Suckers did not respond well at temperatures above 20°C., but lethal effect was not obvious. Below this temperature they appeared to react similarly to other species.

In late autumn, when many stream fish are relatively inactive in cold water, they are difficult to take by seining since they are frequently in unseinable places. They are still, however, sufficiently active to respond to the stimulus of the electrical apparatus and are thus brought out of hiding and into narcotizing range. Both the large and small machines have been used with better success than seining for taking young salmon, trout, minnows, suckers and eels under these circumstances.

In general, water temperature affects electrical fishing in a manner to be expected from a consideration of the effects of temperature on the behaviour of fish.

Injury to Fish

In field collection and trials occasional fish have been killed by the D. C. apparatus. This has usually been the result of fish coming in contact with, or close to, the positive electrode. A test for any delayed lethal effect was made by holding fish "treated" by the apparatus in cement hatchery troughs for a month. Salmon and trout were taken from hatchery stock in outdoor holding ponds by a seine. Treated and untreated specimens of both species were held in separate troughs. Of the yearlings (3"-5" and larger) the control fish (untreated) were marked by removal of the left pelvic fin and the experimental fish by removal of the right pelvic fin, and the two groups were held after treatment in a common compartment. Treatment of the experimental fish involved liberation in a cement trough and collection with the Wolf machine in the same manner as in field collections.

The delayed mortality (Table VI) is apparently not significant and fish that recover immediately from the effect of the electrical apparatus may be assumed to be uninjured. Salmon appear to be more sensitive than trout and this is in agreement with qualitative impressions from field work. It is suggested that at least some, if not most, of the immediate mortality can be prevented by careful use of the apparatus and prevention of contact between fish and the positive electrode.

TABLE VI

Mortality of shocked fish

	Fish	Immediate Mortality	Delayed Mortality
Shocked Fish	100 fingerling salmon	7	0
	100 fingerling trout	2	1 at 3 days
	100 3-5-inch salmon parr	4	0
	50 5-10-inch trout	0	0
Controls Not Shocked	100 fingerling salmon	0	0
	100 fingerling trout	0	0
	100 3-5-inch salmon parr	0	1 at 1 day
	50 5-10-inch trout	0	1 at 4 days

Comparison with A. C.

A comparison between the Wolf D. C. apparatus and an A. C. apparatus from the U. S. Fish and Wildlife Service was made on the Digdeguash River, near St. Andrews, N. B., in August, 1949. The time available to some of the personnel was insufficient to allow any direct quantitative comparison of the two types of apparatus to be made, and the results are to be taken only as qualitative demonstrations of fishing in the same water. A stretch of the river about 20 yards long and 8 yards wide was barred off by barrier nets. In about three quarters of an hour 144 minnows, salmon fry and parr were captured by the Wolf D. C. apparatus. These fish were returned to the stream and in one half hour 104 fish were captured using the A. C. apparatus.

Figure 3

Electrofishing with the Wolf outfit. Note dip net for gathering nearby fish and seine for taking fish stunned in swift water.

The D. C. apparatus took smaller fish than the A. C. and was better at bringing fish out of hiding places. Considerable mortality (about 20 fish) was caused by the A. C. apparatus but none by the D. C. was observed even though the voltages were about 220 A. C. and 500 D. C. The A. C. method, as used, required the use of two movable electrodes but had an advantage in a smaller, lighter and hence more portable power plant.

Critique of Method and Apparatus

Mechanical features.

A limitation of this method for studying fish populations is set by the portability of the apparatus. The Wolf apparatus, with a weight of over 200 pounds for a single unit, cannot be used conveniently far from places accessible by vehicle or boat. Its range of usefulness could, as suggested by Mr. Wolf, be increased by providing a dolly for land travel and a small scow for water transport, but in unsettled and rough terrain such devices would not encourage use over materially wider areas. The small machine, having less than half the weight of the Wolf machine, has been found more readily transportable in such places, even without special carrying devices, since it is a more reasonable load for one man. Having lower voltage it is not, however, as versatile in operation as the larger machine. More portable units would increase the usefulness. This might be accomplished by having light-weight units built and by having generator and gasoline engine separable for carrying.

The method requires more costly equipment than seining and there is greater need for experienced personnel. On the other hand, under most circumstances an electrical crew of two or three men can accomplish as much as a seining crew of three or four, and will take more fish in rough water and unfavourable seining places.

Electrical Features.

The Wolf apparatus consists of a shunt-wound generator with various resistances that may be put in the field circuit to give various voltages. The variable output voltage is a desirable feature as it allows the selection of the voltage best suited to the conductivity of the water and the fish being captured. It is shown above, for instance, that eels may be captured at a much lower voltage than *Fundulus*. In future designs and use of similar apparatus the requirements of voltage and amperage for collecting fish of various species under a variety of conditions should be considered carefully.

Principles of Electrical Fishing.

It is common knowledge that living material may be stimulated, narcotized, killed or otherwise affected by electric current, potential or discharge. The basic physiology underlying the behavior of an animal under electrical influence is not understood and the present knowledge seems to be the empirical accumulation of observations.

Harreveld (1938) and Harreveld et al (1942) point out that the chief reactions of fish to direct current in water are stimulation to movement by a weak current, orientation and movement towards the positive pole for a stronger current, and immobilization by electronarcosis in a still stronger current. These effects have all been observed qualitatively during the present studies.

Rayner (1949) quotes a German reference (Smolian 1944) as indicating that the empirical requirements for a D. C. electrical fishing apparatus are as follows: 4½ horsepower engine to drive a generator which will deliver up to 10 amperes at 80 to 250 volts. The Wolf apparatus gives somewhat higher voltage but lower amperage. It is also noted by Rayner that A. C. potentials above 150 volts are usually lethal to trout. This is in general agreement with the qualitative comparison in this report between the A. C. and D. C. apparatus. In A. C. there does not appear to be electronarcosis but rather the fish is tetanized and fractures or dislocations of skeletal elements may occur. Rayner states that interrupted direct current is more effective in attracting fish to the positive electrode. Our present observation might qualitatively and tentatively indicate that interrupting the direct current allows the narcotized and partially narcotized fish to recover almost instantly and that a return of the current is a new stimulus to movement toward the positive electrode. More and better-controlled observations on this point might be useful. There is, of course, no attraction of fish to the electrodes in the case of A. C.

Scope and Effectiveness.

The Wolf D. C. apparatus has only been used, to date, in brooks, rivers and streams of such size that they could be blocked off by barrier nets and having water current and depth such that the operator carrying the positive electrode in his hand could reach all parts of the stream by wading. Within these limits the apparatus has proved very useful. It is not suggested that it could not be used on larger, more rapid or deeper waters with suitable changes in handling technique but such applications are outside the present experience. The electrical fishing is more effective than seining for the capture of most fish and is by far the most effective method of capturing eels within our experience or knowledge. The method is particularly useful for collecting fish from small, snag-choked streams where the handling of a seine is difficult, or in very shallow, boulder-strewn and algæ-filled streams. In these cases the fish are stimulated to activity or drawn from their hiding place by the positive electrode. It was noticed at Ellerslie Brook that many of the aquatic insect larvae were apparently killed by the electrical fishing operations. This observation

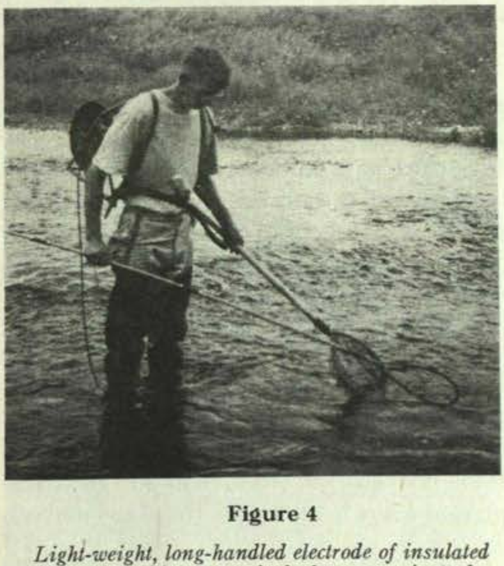

Figure 4

Light-weight, long-handled electrode of insulated aluminum tubing; particularly convenient for reaching into snags, under banks, etc.

would seem to deserve further attention. In swift water, although the fish are immobilized by the apparatus, there is greater difficulty in capturing them before they are carried out of reach of the operator and the apparatus.

Danger to Personnel.

The electrical fishing apparatus develops sufficient power to be dangerous to the operators. The positive electrode is maintained at a relatively constant potential difference from the bottom of the stream but the current drawn is a property of the water in which the apparatus is operated. Should a man touch the bare positive electrode while in electrical contact with the bottom, or while otherwise grounded, the current flowing through the body would be much greater than that flowing through the water, due to the higher conductivity of the human body, and death might result. Any such apparatus should be used only by those who understand the danger involved. In the Wolf apparatus one handle of the positive electrode has a switch which cuts the field circuit of the generator when not held down by the operator. This would appear to be a sound principle, as the generator is not producing a potential unless the field circuit is completed by holding down the switch. The design might be improved by waterproofing the switch mechanism and the plug from the cable, thus eliminating danger when this part of the apparatus gets wet. Similarly, all contacts, plugs and binding posts should be of such a design that danger both to those operating the machine and to bystanders is at a minimum.

Summary

Fishing by use of direct electrical current is a valuable addition to present techniques for studying populations of fish in streams. In waters under three feet deep most fish may be taken from an area, uninjured, regardless of obstructions or other fish-cover.

It is a very effective method for collecting eels of all sizes.

For equal effectiveness it requires a smaller crew than seining.

Use of D. C. is preferable to A. C., especially where it is desirable to collect the maximum number of fish without injury.

For some species, and in some waters, seining may give equally satisfactory results for studying populations. Under these circumstances seining might be preferable since it is less costly and the equipment is lighter to carry.

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