In an attempt to gain an understanding of the relationships between the brook and sea-run groups, progeny from these two stocks of trout have been planted in Ellerslie Brook as fish of the year and as yearlings, after being marked differently by fin-clipping. As yet these planted trout have not entirely moved through the population of the system, and the data upon them are therefore incomplete. For the present it can be reported that the progeny from both parentages have run from the stream. Thus apparently the sea-run group can be recruited from a brook stock that has not been to salt water for many generations, but it is yet to be determined how effectively this may be realized.

In the programme at Ellerslie Brook the anglers' catch was one of the more important criteria by which the effects of pond formation upon the trout stock were to be gauged. We have noted that without pond formation the yield to the anglers has varied from 1,086 to 1,942 trout over a four-year period, and the rate of capture from 1·5 to 1·9 per rod-hour. Obviously the establishment of a reasonably constant level for comparative measurements of fish production in nature is difficult, even, as in this case, in a small stream. The lesson is clear that if worthwhile fish management procedures are to be developed they must rest upon data obtained over a sufficiently long period to delimit natural fluctuations.

A COMPARISON OF NYLON AND COTTON GILL NETS USED IN THE LAKE WINNIPEG WINTER FISHERY[1]

by

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The introduction of nylon gill nets to the fishery on Lake Winnipeg during recent seasons has aroused considerable interest and some controversy among fishermen, and others. Various opinions regarding their efficiency have been expressed. Lawler (1950) suggests that in the gill net fishery for lake whitefish on Lake Erie, nylon netting is about three times as efficient as linen.

Some fishermen claim that the nylon gill net takes a greater number of small fish than an equivalent mesh size in a cotton gill net. Others feel there is no essential difference in size of fish taken, but that a nylon gill net will catch more fish than a comparable cotton gill net. Still others believe there is no real difference at all.

During January and February of the 1950-51 winter fishing season on Lake Winnipeg, Fisheries Research Board of Canada personnel of the Central Station had occasion to record data pertinent to this question. The data recorded were from the gill nets lifted by commercial fishermen fishing at various points on the ice throughout a distance of about 120 miles. For convenience, this distance was divided into three adjoining areas of approximately equal size. The fishermen from whose nets the data were taken were selected at random.

Record Weight of Each Fish

Each gill net was lifted singly during the winter fishery. As it was being lifted a record of the weight of each individual fish was taken. The fisherman was asked to report as accurately as possible the length of the gill net as well as the mesh size and net depth. The material from which the netting was made was also recorded.

Only those data from nylon and cotton gill nets reported as three-inch mesh were used in this paper. The bulk of the data was collected from gill nets which were fished under similar conditions. In only a few cases was it possible to record data from adjoining cotton and nylon gill nets.

An examination of Table I shows that in each of the areas the average weight of individual fish is generally greater in the nylon nets. This difference is evident probably because cotton nets tend to shrink with usage.

As shown in Table 1, Area 1, cotton nets caught considerably more fish per 100 yards than the nylon nets. The figure for availability (i.e. catch per unit effort) for the cotton nets is probably misleading as it was computed on only 70 yards of gill net for the whole of the area, as compared with 930 yards of nylon gill net. In Area 2 the

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Table I

The average round weight of species and the average availability of representative samples of fish from nylon and cotton gill nets of three-inch mesh used in the Lake Winnipeg winter commercial fishery during January and February, 1951. The number of individuals is shown in parentheses.

		Area 1		Area 2		Area 3		All areas	
		cotton	nylon	cotton	nylon	cotton	nylon	cotton	nylon
Average weights of species (lbs.)	Sauger	0·64 (33)	0·68 (295)	0·56 (652)	0·60 (127)	0·56 (652)	0·59 (197)	0·56	0·63
	Pikeperch	1·05 (10)	0·96 (183)	0·79 (211)	0·80 (179)	0·68 (547)	0·77 (269)	0·72	0·83
	Burbot	1·17 (41)	1·47 (173)	1·72 (54)	1·32 (27)	1·05 (11)	1·35 (10)	1·16	1·44
Average catch per 100 yards of gill net (lbs.)	Sauger	30·0	21·5	11·0	14·5	5·5	11·5	7·5	15·5
	Pikeperch	15·0	19·0	5·0	27·5	5·5	19·5	5·5	21·0
	Burbot	68·5	27·5	2·0	7·0	0·18	1·0	1·0	12·0
	Other species	18·5	11·0	5·0	12·5	1·5	2·5	2·5	7·5
	All species	132·0	78·5	23·0	62·0	13·0	34·5	17·0	57·0

comparisons are based on 3,316 yards of cotton gill net and 516 yards of nylon. In Area 3, 6,420 yards of cotton gill net and 1,046 yards of nylon were used in determining the availability. In all areas, the availability of all species is roughly three times as great for nylon gill nets as for cotton ones. Total yardage for all areas is 9,806 for cotton, and 2,492 for nylon gill nets.

Regarding working characteristics, the fishermen reported that during very frosty weather nylon gill nets were more difficult to clear than the cotton ones. On the other hand, cotton gill nets became occluded by a heavy phytoplankton pulse much more quickly than did the nylon gill nets. This appeared to be an important factor in the relative size of the catches.

It seems clear that the three-inch mesh nylon gill net is considerably more efficient in the Lake Winnipeg winter fishery than the three-inch mesh cotton. The average size of fish taken in each is similar.

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THE USE OF PECTORAL FIN RAYS FOR DETERMINING AGE OF STURGEON AND OTHER SPECIES OF FISH

by

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Until the last few years, little has been written in the scientific literature of North America on the sturgeon, which were for a time of great economic importance in many parts of Canada and the United States. Ryder (1890), Harkness (1923) and Greeley (1937) are probably the only authors who so far have published papers to which students, investigators and administrators may refer for information. At present, biologists are witnessing activities and research in connection with various species of sturgeon and, as a result, a considerable amount of new information is, or will be, on hand to increase our knowledge of this enigmatic fish and to establish basic principles for its best utilization and conservation.

Investigators of this continent who, to the writer's knowledge, are actively interested in some phases of the biology of the sturgeon may be listed as follows: I. J. Donaldson, Corps of Engineers, Oregon, studying the growth and migration of the Pacific Coast sturgeon; Dr. J. Greenbank, Wisconsin Conservation Department, working on the commercial fisheries for the Mississippi sturgeon; Dr. W. J. K. Harkness, Chief, Fish and Wildlife Service, Ontario, supervising the commercial fisheries for lake sturgeon in Northern Ontario and working on a voluminous manuscript on the early stages and other phases of the life history of lake sturgeon; Dr. V. D. Vladykov and G. Beaulieu, Department of Game and Fisheries, Quebec, studying morphological characteristics, food and migration of the two species of sturgeon inhabiting the lower St. Lawrence River; and the writer, who, until recently, was engaged in the study of commercial fisheries, growth, food, gonad maturation and migration of the lake sturgeon in the Montreal region and the Ottawa river. The collection of records of recaptures of tagged sturgeon is being continued by G. Prévost, Provincial Biological Bureau, Department of Game and Fisheries, Quebec.

The most essential data for guidance in establishing adequate management and proper legislation governing any fishery are size, age, the rate of growth, the rate of development of the gonads and the spawning behaviour of the species of fish concerned. For the lake sturgeon, *Acipenser fulvescens* Raf., data on age and growth were first obtained by examining otoliths as described by Harkness (1923) in his study of this species in Lake Nipigon, Ontario. In order to carry on a similar study, about 300 samples of otoliths of sturgeon were collected on Lake St. Peter (St. Lawrence River) during the summer of 1945. This method was not found satisfactory, and study of the material collected was delayed by experiments in sectioning the otoliths.

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[1] *Investigations on sturgeon under the auspices of the Department of Trade and Commerce, Province of Quebec, were carried out by the author prior to July, 1949, before he joined the Canadian Wildlife Service.*

In the spring of 1947, while the author was preparing the programme and the organization for a general survey of the sturgeon fisheries in the St. Lawrence River and a collection of material and data to study the biology of this species, a visit was paid to the Institute of Biology of the University of Montreal by Dr. Georges Roussow, a distinguished Roumanian biologist, who had recently arrived in this country. In the course of general discussion, Dr. Roussow informed us of his experience with sturgeon and mentioned the technique used by workers of Eastern Europe to determine its age and study its rate of growth. This technique, which he himself (Roussow, 1938) and his chief at the "Institut National Zootechnique" of Roumania, Dr. Th. Negulesco (1934), had used in studying the Sterlet, *A. ruthenus*, was based on cross-sections of marginal rays of the pectoral fins. Specimens of sturgeon were taken from the fish collection room, cross-sections were made and ages were determined to our satisfaction. Roussow (1947) discussed the technique in a brief paper presented at the Société Canadienne de Biologie, Montreal. This information led the writer to undertake an extensive collection of fin rays and search in foreign bibliography for information on various methods used for determination of age of sturgeon. The bibliography on the subject has brought to light some material which might be useful for other workers interested in this subject.

This paper is intended to summarize the bibliographical material collected by the author on methods for determination of age of sturgeon, to discuss the technique for preparing and examining the marginal rays of pectoral fins, and to illustrate by figures cross-sections obtained from pectoral fin rays and pectoral spines of various species of fish.

Methods for Determination of Age of Sturgeon

As far as could be found out from various papers and bibliographies examined, Arnold (1911) is probably the first author who determined the age of sturgeon and studied the growth of representatives of *Acipenseridae*. For this study, the claviculum bones were used by Arnold, and later by Soldatov (1915).

In 1916, Kleer or Clair published a paper on age of sturgeon determined for the first time by the cross-section of marginal rays of the pectoral fins and also by the caudal fulcra.

In 1932, Derjavin published a paper on the biology of the Sevriuga (*A. stellatus*); his age determinations were made from the cleithrum bones. It may be mentioned here that cleithrums collected from lake sturgeon of the St. Lawrence River very frequently showed the formation of large cavities in the centre of the bone, which would have limited their use for age determination. Such resorption has been noted by Chugunov (1925).

In 1923, Harkness published a paper on age and growth of the lake sturgeon from Lake Nipigon, Ontario. His growth study is based on examination of otoliths, contained in an internal ear sac, the saccula. Harkness is quoted as the first investigator to use the otoliths for the determination of age of sturgeon.

D'Ancona (1924) used for the determination of age of sturgeon the scutes or plates which are present along the back sides and belly of the *Acipenseridae*. This technique could not be used with lake sturgeon except among young individuals because the scutes show degeneration and disappear almost completely as the adult stage is reached.

The same year, 1924, Holzmayer published a paper on the marginal rays of pectoral fins and their use for determining age of sturgeon. Reference to this author will be made later on.

Chugunov (1925), who quotes Kleer's paper, used the pectoral fin rays and the fulcra to determine the age and study the growth of sturgeon collected by the Asov Scientific-Industrial Expedition. In his 1925 paper, this author described briefly the technique for the preparation of cross-sections of pectoral fins.

All subsequent investigations carried on by European biologists regarding growth of various species of sturgeon were based on examination of cross-sections of marginal rays of the pectoral fins: Petrov (1927), Probatov (1929), Negulesco (1934), Menshikov (1936), Roussow (1938), and Classen (1944), who also used dorsal scutes. Most of these authors, particularly Classen, have presented in their papers illustrations of cross-sections of "marginalia", as they are called by Classen.

On this continent, Bajkov (1930), Greeley (1937) and Schneberger and Woodbury (1944) have studied the growth of various species of sturgeon by using the otoliths as did Harkness (1923).

In the author's investigations since 1947, anterior marginal rays of pectoral fins of about 2,000 lake sturgeon were examined; part of this material has been discussed in manuscript reports submitted to provincial authorities. Some of these reports are being revised for publication (Cuerrier, 1949 (a); Cuerrier and Roussow, 1951). A brief paper on the growth of lake sturgeon with an illustration of a cross-section of the "marginalia" was published in 1949 (Cuerrier, 1949 (b)). For illustrations of sections of pectoral fin rays of Pacific Sturgeon, one may refer to the *Oregon State Game Commission Bulletin*, November, 1949, and to *Popular Mechanics*, December 1950.

Lea Dahl's formula has been adapted for sturgeon and utilized to calculate the size of the fish at any given year of its life. Derjavin (1922), Roussow (1938) and particularly Classen (1944) have studied the relation between the annual growth of cleithrum bones or of the marginal rays and the size of the fish at the time of the formation of a year-mark. Classen presents in his paper many tables and illustrations on age and length relationship based on calculated growth and indicates in the illustrations how the measurements are made.

For fish provided with scales, many authors have proved the validity of the use of the scales for determining age. Regarding the marginal rays, little such work has been done. The method, however, is not taken for granted. Holzmayer (1924) made a control age determination of preserved material of Sterlet (*A. ruthenus*) raised by A. A. Ostroumov (1925), who studied the periodicity in the rate of growth of Sterlet reared in captivity during as long as, in one case, 10 years and 4 months. Cross-sections of the marginal rays of the pectoral fin showed a number of annual marks corresponding to the recorded age of the fish. Indirectly, Roussow (1938) and Classen (1944) have been able to confirm the age determinations obtained with fin-ray sections by comparing average lengths obtained by this method with averages obtained from lengths calculated according to age. The calculated lengths corresponded to the measured lengths of fish of known age.

A further attempt is being made to confirm the validity of the method of using pectoral fin rays for determination of age of sturgeon. During 1947 and 1948, several hundreds of lake sturgeon caught by commercial fishermen were tagged and released in

the St. Lawrence River after the anterior portion of the marginal ray of one pectoral had been collected. It is hoped that some of the individuals will be recaptured in order to compare the reading obtained from the portion collected with the reading obtained from the marginal ray of the other pectoral fin at the time of recapture.

The Pectoral Fin Marginal Rays Method

While the collection of otoliths, operculums or other bones from sturgeon requires much time and also spoils the appearance of the fish for market, the pectoral fins can be secured without trouble or deterioration of the specimen.

Details concerning collection, sectioning and preparation of the material for determination of age based on pectoral fin rays are given by Chugunov (1924) and by Negulesco (1934). As these publications are not readily available, the technique applied during our investigations since 1947, without having on hand at that time the two papers mentioned above, will be discussed here.

The pectoral fin of one or, preferably, both sides is cut with a knife at the articulation with the cartilaginous basal piece. Usually, only the first few rays are cut from the fish or retained from the entire fin already collected. Then a small hole is drilled in the sample, a card is filled with the usual data and the fins and the card are tied together with a brass wire. The samples are hung to dry in the sun, because they have to be dried perfectly before further processing.

When dried, the sample is placed between the jaws of a vice, the marginal ray being up. Then sections are obtained by using a single thin blade saw adapted to a small hand jigsaw. For best results, the saw should have about 70 teeth to the inch; such saws are of a type usually used by jewellers. Chugunov and Classen have suggested and used two saws fastened parallel to each other and divided by a thin plate in order to obtain sections of about 0·5 mm. thick. But I personally prefer a single saw; after some practice, sections of 0·5 to 0·3 mm. and even less can be obtained easily. Sections must not be too thin, because then they would be too transparent. For special purposes, the sections can be polished on a fine-grain carborundum plate as designed by Mr. I. J. Donaldson of Oregon; but this operation was found unnecessary for routine examination and even for recording on photographic plates.

The sections are made by cutting perpendicularly near the base of the ray when perfectly dry, at about $\frac{1}{4}$-inch from its articulation. If made too far from this point, interior rings laid down during the first years of the life of the fish are lost.

When sections are to be studied, they are placed on a glass slide in a few drops of pure glycerine. Water, alcohol or Canadian balsam can be used instead of glycerine, but the latter gives much better results. The main point is to obtain the best differential transparency of the zones which exist on the cross-sections. If sections are too thin, the penetration of the glycerine becomes uniform and makes them entirely transparent. With a section of 0·3 to 0·5 mm. the glycerine will infiltrate slowly into some zones and rapidly into other zones. Permanent mounting was not made, because within a few months the differentiation between zones is mostly lost and the sample is almost uniformly transparent. To keep samples for further checking, the sections were washed in hot water, passed from diluted alcohol to absolute alcohol, dried and then stored in their respective vials.

PLATE I

Sections of Marginal Pectoral Fin Rays of Lake Sturgeon

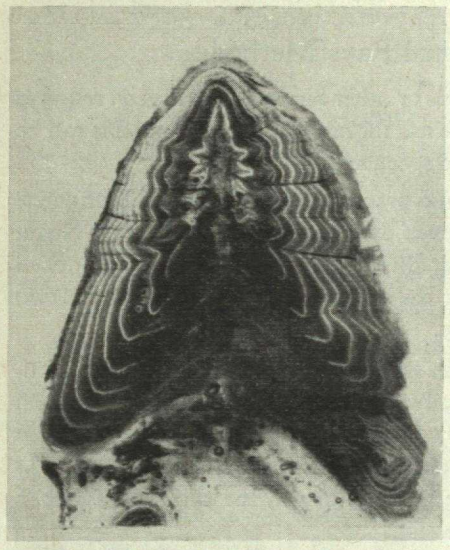

Figure 1. Lake St. Francis, July 9, 1947. Fork length, 28·5 inches; weight, 6 pounds; age, 9 years.

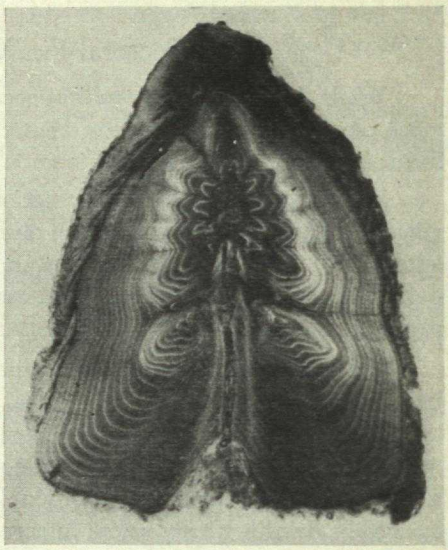

Figure 2. Lake St. Peter, June 18, 1948. Fork length, 31·5 inches; weight, 8 pounds and 11 ounces; age, 17 years.

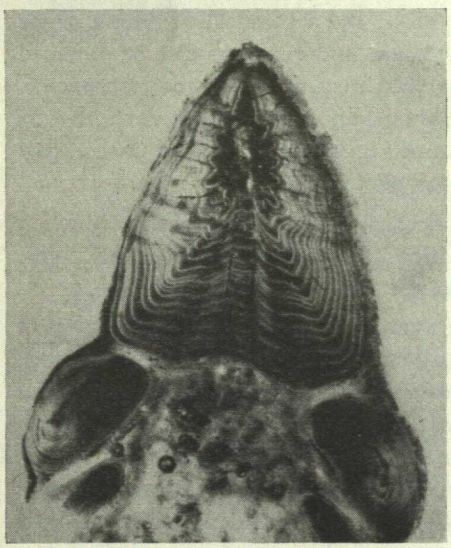

Figure 3. St Francis River (Lake St. Peter region), May 27, 1947. Fork length, 45·5 inches; weight, 25 pounds; age, 22 years.

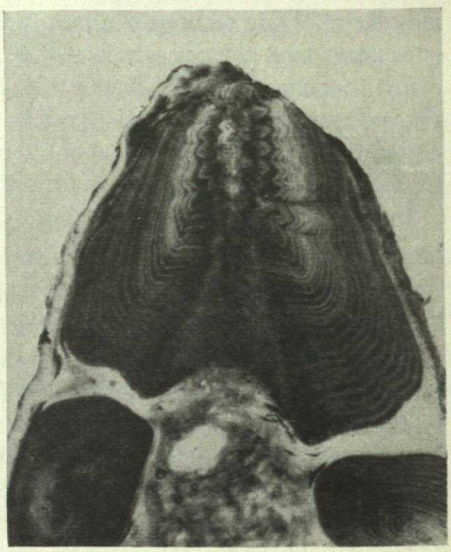

Figure 4. Lake St. Peter, May 16, 1948. Fork length, 42 inches; weight, 23 pounds; age, 26 years.

PLATE II

Sections of Marginal Pectoral Rays of Other Fish

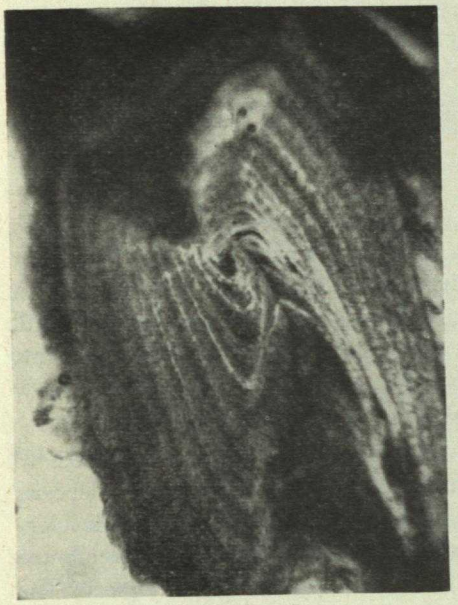

Figure 1. Lake trout pectoral fin ray section—Lake Minnewanka, Banff National Park, July 9, 1950. Fork length, 29 inches; weight, 12 pounds; approximate age, 10 years.

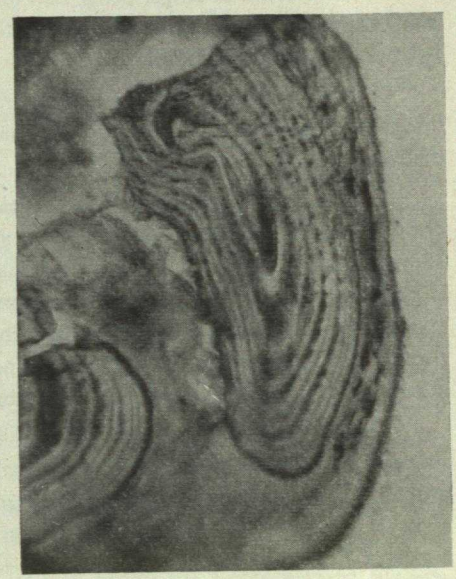

Figure 2. Rocky Mountain Whitefish pectoral fin ray section—Lake Minnewanka, Banff National Park, July 9, 1950. Fork length, 14·5 inches; weight, 12 ounces; approximate age, 9 years.

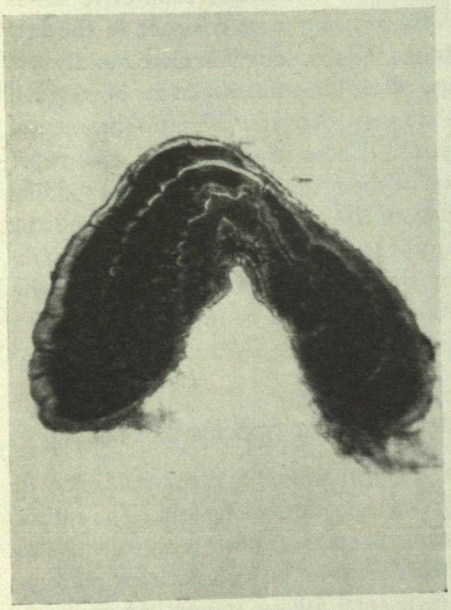

Figure 3. Bullhead pectoral spine section—Sample from part of a skeleton collected at Point Pelee National Park. Approximate age, 4 years.

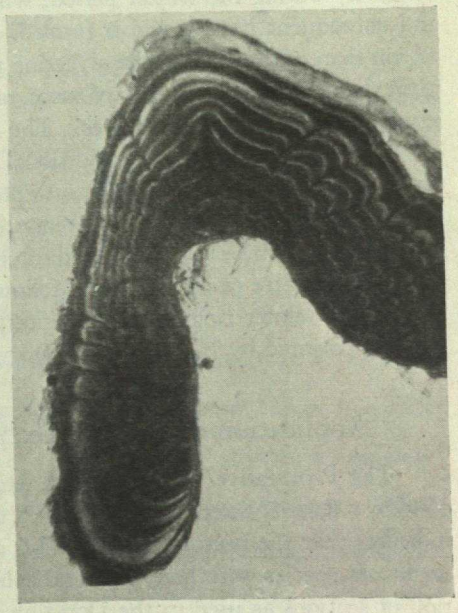

Figure 4. Channel Catfish pectoral spine section —Ottawa River, Lake Deschenes, June 15, 1949. Fork length, 13 inches; weight, 15 ounces; approximate age, 10 years.

Under the binocular microscope with low magnification and with transmitted light, the observer will see some wide opaque zones alternating with narrow clear zones, the former corresponding to summer growth and the latter to winter growth. The summer zones or rings, being rich in what is presumed to be a deposit of calcium-containing material, are not easily penetrated by the glycerine, and appear dark, as the light does not pass through.

The rings observed on the anterior ray of a pectoral fin can be noted on the subsequent pairs of rays, but these rays are much smaller and the rings are not usually so distinct.

The figures, illustrating cross-sections, which are presented in Plate I were obtained by projecting the sample on a glass photographic plate using a projector for 35-mm. films. Prints and transparencies are then made from this negative. If a section is projected directly on a photographic paper, as was done by Classen, the zones will appear as if the sections were examined under a binocular microscope by reflected light; the narrow zones will be printed black and the wide zones white. Photographs reproduced in Plate II were taken through a microscope.

The marginal rays of the pectoral fins of sturgeon are presumably formed by successive deposits of calcareous material on the surface of the ray. The deposits probably vary according to the metabolism of the animal. The formation and development of the bony rays are assumed to be similar in nature to those of the membrane bones of the skull, where the osseous tissue is derived from connective tissue. The wide zones which can be seen on the accompanying photographs are probably the result of an abundant formation of connective tissue during the summer, converted later into bone tissue; the narrow zone would correspond to the period of metabolic inactivity during the winter period, when only a small amount of connective tissue and subsequent bone tissue is formed. The tissue being more compact in the first region than in the second, the glycerine penetrates the second region more rapidly and gives differential transparency of zones, or rings. Plate I illustrates sections of marginal rays of sturgeon of different ages. The rings are very clear and the interpretation of the sections does not require additional comment. Those who have Classen's paper on hand will note a difference in interpretation of the first annual ring corresponding to the first winter. Classen differentiates between the centre of ossification and the zones for the year 0, for year 1, and for subsequent years. According to our interpretation, the centre of ossification is followed by the first winter ring, year 1, then by the second winter ring, etc. Our interpretation appeared to be in accordance with figures presented by Negulesco (1934) and Menshikov (1936).

Application of the Fin Technique for Other Species of Fish

The Progressive Fish Culturist, January, 1950, reprinted a paper published in 1946 by a Russian scientist, E. G. Boyko, on age determination among fish. The author indicates that the pectoral fin method is applicable to species of fish with soft rays as well as to species with bony rays and spines. He describes the technique for preparation of sections as used in the Don-Kuban experimental fishery station, where scales were utilized for age determination. It was found that the annual rings were more distinctly expressed on fin rays than on scales.

Attempts are being made by the Canadian Wildlife Service to utilize pectoral fin rays of trout and other species of fish for determining age. During the summer of 1950, pectoral fins of lake trout, rainbow trout, eastern brook trout, cutthroat trout and other species of fish inhabiting National Park waters were collected. The preliminary tests showed that the present method applied in the case of sturgeon would have to be improved for other fish, due to the small size and fragility of the pectoral fin rays. Samples would have to be embedded and the sections cut with a finer saw blade. However, some sections cut from fins of various species of fish showed relatively clear rings. The readings from these sections gave figures within the range of ages for the sizes of the specimens as found in the literature. So far, the specimens of the collection which have given the best samples of fins had scales rather difficult to read. Samples of fish with pectoral spines, such as bullhead from Point Pelee National Park and channel catfish from the Ottawa River have shown very clear rings on the pectoral spines. In the issue of the Missouri Conservationist for August, 1945, a photograph illustrates the collecting of spines of catfish. A Missouri biologist is at present studying the growth of bullheads by using the vertebrae as indicators. Other biologists investigating freshwater and marine species of fish are planning to use the pectoral fin rays, in the hope of replacing present use of otoliths.

There is no doubt that the fin technique will never replace the scales for age study among species such as bass, yellow perch, yellow pikeperch, sunfish and salmon. For many species without scales or with small or minute scales, the recognition of the use of pectoral fin rays as a satisfactory method of age determination will simplify the study of the large quantity of material that is required to reach acceptable averages and adequate conclusions.

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RESULTS OF A BACTERIOLOGICAL EXAMINATION OF A DISEASED SUCKER

by

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A specimen of the common sucker (*Catostomus commersonii commersonii* Lacépede), found close to death, floating on the surface of the Ottawa River near Ste. Anne de Bellevue, was brought in for examination by Dr. L. P. E. Choquette of the Institute of Parasitology, McGill University.

Five superficial skin lesions, consisting of haemorrhagic areas about one centimeter in diameter, were visible on various parts of the body of the fish. The scales were either lost or damaged in the vicinity of the lesions. The underlying muscle tissue was not affected. Gross pathological changes were not present in the internal organs or the gills.

Microscopic examination of material scraped from the lesions revealed a large number of motile, Gram-negative rod-shaped bacteria, 0·6-0·8μ by 1·3μ, mostly arranged in pairs. This finding suggested that the condition was possibly of bacterial origin.

Aerobic cultures on beef-heart extract nutrient agar were made from material from the lesions and underlying muscle and from the heart blood. The cultures from all the lesions yielded a practically pure culture of a bacterium which was identical, morphologically, with the organisms seen in the direct smears from the lesions. A mixed culture of three species of bacteria, with the predominance of one species which was proved to be identical with the organism isolated from the lesions, was obtained from the heart blood. No growth was obtained on plates inoculated with material from the muscle underlying the lesions.

The organism isolated from the lesions and also found in the heart blood, had the following characteristics:

Morphology: Straight rods with parallel sides and rounded ends, 0·6-0·8μ by 1·3μ, occurring mainly in pairs but also singly. Motile, with peritrichous flagella. Gram-negative.

Agar colonies: Circular, smooth, entire, low convex, translucent, glistening, buff-gray.

Agar slant: Moderate, filiform, glistening, buff-gray.

Nutrient broth: Turbid, with delicate pellicle and sediment.

Gelatin stab: Liquefaction.

Litmus Milk: Peptonization. Litmus reduced. Fluid becomes yellowish and translucent.

Nitrites produced from nitrates. Indole is produced. Hydrogen sulphide is not formed. Growth in Koser's citrate medium. Methyl red test negative. Voges Proskauer test positive. Slight production of ammonia from urea.

Financial assistance for the research was given by the National Research Council of Canada.

Catalase is produced. Glucose +, galactose+ , mannose +, lactose + (slow), starch +, glycerol +, mannitol +, inulin + (weak), sorbitol + (weak), salicin −, dulcitol −. (+ =fermentation with production of acid and gas: − =no fermentation.) Good growth at 25°C. and 37°C. but more rapid at the higher temperature.

From its characteristics it is evident that the organism belongs to the Family Enterobacteriaceae Rahn. The slow fermentation of lactose suggests placing it in the genus *Paracolobactrum* Borman, Stuart and Wheeler. Of the species of this genus listed in Bergey's Manual of Determinative Bacteriology (Breed *et al* 1948), the organism isolated in this work most closely resembles *Paracolobactrum aerogenoides* Borman, Stuart and Wheeler, which is described as having the same characteristics as *Aerobacter aerogenes* (Kruse) Biejerinck, and *Aerobacter cloacae* (Jordan) Bergey *et al*, except for consistently delayed fermentation of lactose. The bacterium isolated from the sucker differs from *Paracolobactrum aerogenoides* mainly in being proteolytic, that is, liquifying gelatin rapidly and peptonizing litmus milk. It also reduces the litmus dye, a property not possessed by *Paracolobactrum aerogenoides*. In addition to these differences, other minor discrepancies occur in fermentation reactions and growth appearance on nutrient agar. The organism will be referred to in this paper as *Paracolobactrum* sp.

The other two organisms isolated from the heart blood were motile, Gram-negative rods of smaller diameter than *Paracolobactrum* sp. Identification of these organisms was not attempted as they were shown experimentally to be non-pathogenic for goldfish (*Carassius auratus* (Linnaeus)) and yearling speckled trout (*Salvelinus fontinalis fontinalis* Mitchell). As the sucker was dead for about two hours before being examined, these two organisms were probably intestinal bacteria which invaded the blood stream after the death of the fish.

Paracolobactrum sp. was isolated from the Ottawa River water near Ste. Anne de Bellevue and also from the intestines, but not in predominating numbers, of apparently normal healthy suckers taken from the river.

Experimental

Preliminary pathogenicity tests of the three cultures isolated from the heart blood and one of the *Paracolobactrum* sp. cultures recovered from the lesions were carried out on goldfish and speckled trout, as these fish were readily available at these laboratories.

One tenth of a cc. of an 18-24 hour broth culture at 25-28°C. of each of the cultures was inoculated subcutaneously into each of four goldfish, kept in pairs in well aerated one or two litre beakers of water. As a control, four fish were inoculated with sterile broth. The eight fish inoculated with *Paracolobactrum* sp. died in from 18 hours to five days. Small haemorrhagic lesions, one to three mm. in diameter, involving only the superficial skin layers were visible at the sight of inoculation in six of the fish. The two goldfish which died within 24 hours after inoculation showed no lesions. *Paracolobactrum* sp. was isolated from the lesions, when they occurred, and heart blood. All other goldfish used in this experiment were still living and apparently in healthy condition two months after inoculation, when these fish were replaced in their regular aquaria.

Similar pathogenicity tests and controls were carried out with yearling speckled trout, except that 1/5 cc. of culture was used as the inoculum and two trout were

used with each culture and with the control. The trout inoculated with *Paracolobactrum* sp. died within 24 hours without visible lesions. *Paracolobactrum* sp. was isolated in pure culture from the heart blood. Trout inoculated with cultures other than *Paracolobactrum* sp. or with sterile broth showed no signs of illness one month after inoculation, when the experiment was terminated.

Paracolobactrum sp. was never found in the intestine or slime of goldfish or trout kept at the Institute of Parasitology for many months.

Further tests with *Paracolobactrum* sp. showed that goldfish inoculated subcutaneously with doses of 1/10 cc. of a 24-hour broth culture, incubated at 25-28°C., of this organism always died in from one to six days. No external lesions were visible in those fish which died within 24 hours. The goldfish which died between the second and sixth day subsequent to inoculation of the organism, all showed haemorrhagic skin lesions with loss of scales, at the site of inoculation. The lesions varied in size from two mm. to twelve mm. in diameter, the larger lesions occurring on those fish which survived the longest time. Some of the fish which survived for three to six days showed slightly blood-stained peritoneal fluid. *Paracolobactrum* sp. was always isolated from the heart blood, peritoneal fluid and the lesions when they occurred.

Subcutaneous inoculations of goldfish with 1/100 cc. (1/10 cc. of a 1/10 dilution) of a 24-hour broth culture at 25-28°C., of the test organism always failed to kill the fish. Approximately one-third of these fish developed skin lesions at the site of inoculation, between the third and fifth day after being inoculated. *Paracolobactrum* sp. was isolated from the lesions, which eventually healed.

Trout inoculated subcutaneously with doses of the organism in 1/10 cc. to 1/5 cc. amounts of 24-hour broth cultures all died in from one to three days. There were no visible lesions on the body nor did the internal organs show any obvious macroscopic pathological changes. *Paracolobactrum* sp. was isolated from the heart blood and peritoneal fluid.

Doses of 1/100 cc. or less of a 24-hour broth culture of the organism appeared to have no effect on the trout, when inoculated subcutaneously.

All attempts to infect goldfish or yearling speckled trout by adding the test organism to water containing healthy fish, to water containing fish which had been experimentally injured at the body surface or by pouring a 24-hour broth culture on fish with experimentally produced skin lesions, failed.

The Seitz-filtered broth cultures (bacteria free filtrate) of a one-day or one-week old culture did not prove toxic for goldfish or trout upon subcutaneous inoculation, in doses up to 1/10 cc. for goldfish and 1 cc. for trout.

Discussion

The experimental results indicate that infection with *Paracolobactrum* sp. was probably the cause of the death of the sucker. However, the organism does not appear to be highly pathogenic, as doses of 1/100 cc. of 24-hour broth cultures were not lethal for either goldfish or trout when injected subcutaneously.

Evidence for the low pathogenicity of this organism is found in the fact that although the organism was found to be fairly common in the Ottawa River water and in the intestines of healthy fish from the same river, only one sucker was found to be infected.

It appears that *Paracolobactrum* sp. is capable of living in the intestine of fish without causing disease, and is normally not pathogenic, but may produce infection under certain conditions which weaken the fish or if the fish has been injured previously. This potential pathogenicity for fish is a phenomenon well known with other water organisms (Williamson 1929). Stuart *et al* (1942) have suggested, in discussing gastro-intestinal infections of man, that "the paracolon bacteria lack invasiveness and that some predisposing factor for the host or massive infection is necessary before the invader can become sufficiently established to produce symptoms". This statement appears to be corroborated in this investigation.

There are two possible routes by which *Paracolobactrum* sp. may have gained entrance to the blood stream, namely, the intestine and skin abrasions. The organism, which was shown to be present in the intestine of apparently healthy fish, may have invaded the blood stream via the intestine, if the vitality of the fish had been lowered due to some other cause. The lesions would then have been secondarily produced by organisms escaping from small peripheral blood vessels. However, there was no evidence of an enteritis, which it seems apparent, would have been a precursor to the generalized infection if the blood invasion took place via the intestine.

The other possibility is the invasion of the blood stream through small abrasions in the skin, which eventually developed into the characteristic lesions. The inability of the organism to infect goldfish or trout with experimentally produced skin lesions does not support this hypothesis, but the development of lesions in the goldfish, similar to those found in the sucker, upon subcutaneous inoculation of large doses of *Paracolobactrum* sp. and the nature of the lesions is evidence for this hypothesis. The similarity of the lesions in the goldfish and in the sucker indicate that the skin lesions of the sucker were a direct result of the infection.

Experimental evidence indicates extremely low invasive power of *Paracolobactrum* sp. and it does not seem likely that the organism penetrated intact skin of the sucker.

Summary

A diseased sucker, showing superficial haemorrhagic skin lesions, with loss of scales at the sites of the lesions, was retrieved from the Ottawa River near Ste. Anne de Bellevue.

An organism resembling *Paracolobactrum aerogenoides* Borman, Stuart and Wheeler was isolated in practically pure culture from the lesions and as the predominating organism of a mixed culture from the heart blood. The organism is referred to as *Paracolobactrum* sp.

Paracolobactrum sp. experimentally proved to be pathogenic for goldfish and speckled trout upon subcutaneous inoculation. Doses of 1/10 cc. were always fatal for both the trout and goldfish. Doses of 1/100 cc. did not kill goldfish or trout but approximately one third of the goldfish inoculated showed haemorrhagic skin lesions with loss of scales.

Cultures of *Paracolobactrum* sp. added to water in which were kept healthy fish or fish with artificially produced skin lesions did not produce infection. Pouring the culture on fish with experimentally made skin lesions also failed to infect the fish.

The organism does not produce an evident exotoxin.

The possible routes of entry of the organism into the blood stream of the sucker and the pathogenicity of *Paracolobactrum* sp. are discussed.

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A Brief History of the Development of Limnological and Freshwater Fisheries Research in Canada

by

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A considerable number of men have been responsible for the initiation of freshwater studies in Canada but the names of only a few may be mentioned here. The first of these probably was Professor Ramsay Wright, head of the Department of Biology, University of Toronto, who in 1892 in a report of the Ontario Game and Fish Commission urged the desirability of a systematic survey of the provincial waters. The second was Professor Edward E. Prince, who as newly appointed Commissioner of Fisheries of Canada advocated in 1893 in his first formal report to the Minister of Marine and Fisheries, the great need for fishery investigations and the necessity for a laboratory. A further report was made in 1894. Professor A. P. Knight of Queen's University brought the matter before the Royal Society of Canada in 1895, and the support of the British Association for the Advancement of Science was obtained in 1897. Professor Ramsay Wright was also very active in these affairs.

As a result of the various presentations, financial provision was made by the Canadian Government in 1898 and the Atlantic Biological Station was established under a Board of Management. A short time later the Biological Board of Canada came into existence replacing the Board of Management.

Biological Station at Go-Home Bay

In 1901, the Madawaska Club, formed by members of the Faculty of the University of Toronto, received a money grant from the Canadian Government and established a biological station at Go-Home Bay on Georgian Bay not far from Midland, Ont. The prime movers were Professor R. R. Bensley, Professor C. H. C. Wright and Professor W. J. Loudon. Without doubt, Professor Ramsay Wright was active in the initiation of the project.

In 1903, the Madawaska Club relinquished responsibility for the operation of the station to the then Department of Marine and Fisheries so that it might be associated with the Atlantic Biological Station. It thus came presently under the Biological Board of Canada. Professor B. A. Bensley was in charge from 1902 to 1910, Professor E. M. Walker in 1911 and 1912 and Professor J. W. Mavor in 1913. The station continued in operation until 1913 when it was abandoned for various reasons.

Following the closure of the Go-Home Bay Station, Dr. B. A. Bensley began to seek ways and means for establishing some permanent organization for the biological investigation of Ontario waters. Finally, in 1920, he was able to bring about the

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formation of the Ontario Fisheries Research Laboratory within the Department of Biology of the University of Toronto. Dr. W. A. Clemens was given direction of the laboratory and in that year Dr. J. R. Dymond was appointed assistant-director of the Royal Ontario Museum of Zoology and ichthyologist of the laboratory. The first location for field work was Lake Nipigon.

These two organizations, the Biological Board of Canada (now the Fisheries Research Board of Canada) and the Ontario Fisheries Research Laboratory have had a very great influence in the development of limnological and freshwater fisheries research in Canada. The former has undertaken and supported investigations in every province. It is pertinent to point out that the support of the idea of fisheries research came from the biologists of the universities and it was these biologists who gave of their time, thought and energies to the advancement of the work. This close association of the universities with the work of the Board has been continued to the present day with very great advantage both to the Board as a government organization and to the universities.

Many Trainees Join University Staffs

The latter (the Ontario Fisheries Research Laboratory) has trained young men who have gone out to positions in nearly every province. Very many of its trainees have joined the staff of the Fisheries Research Board of Canada at Nanaimo, B.C., Winnipeg, Man., and St. Andrews, N.B., and a considerable number the staffs of various universities, including those in British Columbia, Alberta, Saskatchewan, Western Ontario and New Brunswick.

But not all the training of freshwater biologists or limnological and freshwater fisheries research has been centred at or stemmed from the University of Toronto. More or less intensive programmes developed in many other universities either perhaps influenced to some degree by the activities of the Fisheries Research Board of Canada or the Ontario Fisheries Research Laboratory, or possibly quite independently. Programmes, for example, have been developed at the University of Manitoba, under Dr. O'Donoghue and Professor Wardle; the University of Western Ontario, under Dr. Detweiler; McMaster University, under Dr. Warren; Queen's University, under Dr. Knight and Dr. Curran; McGill University, under Dr. Willey; Dalhousie University, under Dr. Hayes; and the University of New Brunswick under Dr. Cox and Dr. Argue.

A more recent development has been the establishment of provincial organizations for the investigation and management of the freshwater fisheries. All the provinces except New Brunswick, Prince Edward Island and Newfoundland now have, or are in the process of forming, such organizations. In addition the Canadian Wildlife Service has instituted an organization for the study of fishery problems in the National Parks.

It is 60 years since Professor Ramsay Wright advocated a study of Ontario's waters. From a situation of practically no laboratories and no investigators there has been a development to a condition of about 20 laboratories and at least 100 investigators. In the early days, acquisition of knowledge concerning limnology and freshwater fisheries was slow; today it is proceeding at a very rapid rate.

Two types of organizations are involved in the field of fishery conservation. On the one hand there are the universities which are concerned primarily with fundamental research. On the other hand there are the government organizations concerned to a large degree with application.

To the universities largely falls the duty of providing much of the fundamental information and its synthesis. This obligation they should be able to accept because of their organization, their body of graduate students and their extensive library facilities. The universities should consider carefully their research programmes and plan sound programmes in fundamental researches because the governmental organizations need the results for sound application. It is most gratifying that the National Research Council and the Research Council of Ontario are supporting fundamental researches at the universities.

To the governmental organizations falls the duty of application and they should plan their application projects carefully and make provision for determining accurately the results of procedures put into effect.

The two fields of endeavour cannot and should not be completely divorced. Most organizations do have outlooks or programmes which combine the basic and the applied, but the development of the governmental organizations has more or less precipitated the desire for application. However, the great value of fisheries research lies in providing an understanding of nature's processes so that intelligent adjustments may be made to them. In these adjustments, the number of effective management practices may be relatively few. A careful consideration of the role of research in fisheries management is therefore both timely and appropriate.

BACK ISSUES WANTED

Such has been the demand for "The Canadian Fish Culturist" that the only back numbers now available are issues No. 11 and No. 12. Many requests continue to be received for earlier issues. Should any of those in receipt of "The Canadian Fish Culturist" have no use for their back copies we would appreciate the return of them to the Director, Information and Educational Service, Department of Fisheries, Ottawa, Canada.

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Administration and Research

by

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The title of the symposium of which this paper is a part was chosen in order that the role of research in fisheries management could be assessed and through critical review insure utilization of its full potential in future contributions to the development of sound management practices. It was suggested that each paper consider the subject under the following three sub-headings and stress one of these:

1. What has research done?
2. What are the present trends and future of research in management?
3. What does the administrator think of research?

The content of this paper is primarily to answer the provocative query presented by the last sub-heading.

In any discussion such as this, terms should be defined at the outset or, at least, the interpretation being placed on them should be indicated.

According to the Shorter Oxford Dictionary "research" is given two meanings: (*a*) "to look for facts" and (*b*) "to look for a solution to a problem". The former can be considered to define fundamental or "pure" research and the latter, applied research. Just as it is impossible to completely segregate these definitions because looking for facts might be a part of looking for a solution to a problem, so fundamental research can and, in fact, must form a part of applied research.

According to the same source, administration is (*a*) management, (*b*) management of public affairs, (*c*) management and disposal of an estate and (*d*) service. These selected meanings clearly indicate that administration is synonymous with management and thus an administrator may be considered a manager. Although the dictionary does not specifically refer to resources in its definition of administration, we might assume that management of a resource is similar to that of an estate—something willed to us—and therefore administration of a resource becomes the management and disposal of that resource. Since all will agree that the intent is not to dispose of the resource per se, the reference to disposal may imply the responsibility for distribution and disposal of the product, in this case fish, which must be assumed by the administration.

The term "service" as applied to administration indicates another duty. The administrative body associated with a scientific organization should be prepared to give aid to the scientists in any way to enable them to pursue their research relatively unhampered.

Relationship Between Administration and Research

From the definitions submitted, it is apparent that research is a part of the administration of any resource. It is true that research may constitute a large proportion particularly if it is considered to embody the findings of specialists other than biologists such as chemists, engineers, economists, lawyers, sociologists and

others. The art of reconciling all the opposites of any problem—political, social, economic and other phases—must not be discounted and in this, the administrator must be adept to be successful.

The Time Factor

Undoubtedly one of the most obvious differences between administrators and research workers lies in the consideration given to the time factor. The administrator generally works under pressure and must act now. Scentists, on the other hand, like to be free to set their own pace, feeling that if their efforts are rushed, the quality of their contribution will suffer. Fault cannot be found with these different attitudes. Administrators recognize the soundness of the scientist's desire to have time and freedom to carry out a thorough investigation. On the other hand, the scientist should recognize that administration must go forward, and to effect this advance time must be "of the essence". The solution, which would satisfy the desires of both groups, would seem to be adherence to a middle "time-path".

Attitude to "Directed Research"

Another difference between administrators and scientists seems to be the attitude toward "directed research". The administrator is confronted with problems, generally on short notice, which require additional scientific information for solution. At such times the administrator desires to direct the activities of the research organization toward such top priority problems but often the scientists appear hesitant to accept the commission although during periods of national emergency scientists of all types do take up the challenge to seek solutions to problems of vital importance, often with time a limiting factor, and pursue directed research with the same zeal which is displayed when fundamental research is being followed with a free rein. When natural resources are at stake the emergency is still national but in a restricted sense, since failure to produce data which would ensure sound management practice, could mean the loss of a valuable resource rather than the loss of a country.

Desire for "Informed Guesses"

Still another difference, perhaps also related to the time factor, lies in the desire of the administrator to have available for use, interim conclusions or "informed guesses" at a comparatively early stage in any investigation while the scientist rightly wishes to be absolutely sure of his findings before drawing any conclusion. There is little doubt, however, that there are many occasions when the scientist, having accumulated groups of data which suggest an hypothesis, could make an "informed guess" which should be passed on to his administration for background information. This should be accepted with full realization of its limitations. It may not be necessary for the administrator to use this immediately but if, as often happens, it is necessary to take a stand, a better decision will result through availability of this information. At least the administrator would take the step with more confidence than would be possible if the scientist did not provide him with such an "informed guess".

If properly handled, it is unlikely that the scientist's professional reputation could be damaged as a result of following the procedure outlined above. The "informed guess" would be submitted as a progress report only and not for circulation or publication. Publication would follow the completion of his research at which time the work would receive the criticism of other workers in the field. Only at this time

would the scientist's professional reputation be under consideration. It is interesting to surmise what might happen should the "informed guess" prove to be wrong and yet have been used as the basis for a decision made by administration. The responsible administrator will have used this information fully realizing its possible limitations and will be prepared to rise or fall with the decision he has made. The scientist should not be held directly responsible. The fact that the guess and the decision proved to be wrong would no doubt initiate further action and an impetus would be given to related research. The subsequent concentration of effort would likely lead to an early discovery of additional facts which would solve the problem. Thus the original guess, although wrong, would be directly responsible for the resultant progress and the original investigator's reputation would not be damaged but enhanced.

It should not be implied that administrators advocate the establishment of management practices based on "informed guesses" alone. If final conclusions are available, they should certainly be used. On the other hand in some cases management procedures seem essential now rather than later when it may be too late to save the resource. The administrator during his active period must become expert in the art of the possible and lives with his contribution. Like the actor, his worth dies with him. On the other hand, in many cases the scientist, like the poet, may leave a monument to posterity—a reputation, a valuable treatise or a scientific law. Too often he is unrecognized during his active period and is unable to live with his contribution.

Sound Recommendations for Administrator

Although the common objectives of fisheries research such as ascertaining fundamental biological data, determining life histories and effects of environmental factors on certain species and the development of management techniques are recognized by scientists, other objectives of extreme importance are sometimes forgotten. One of these is to provide sound recommendations, based on the findings of research, for the use of the administrator. Generally, a scientific report is submitted consisting of methods, data and conclusions. The conclusions in many cases are not recommendations and the administrator is left with the task of interpreting the data and conclusions to fit his problem. This is not an efficient procedure since the scientist is familiar with his subject and is most competent to interpret the data fully and provide recommendations for desired action. His data or conclusions could be distorted by forcing someone less capable to perform this duty. Fortunately, the recent swing toward applied research in fisheries has done a great deal to alleviate this problem. Now administrators are usually supplied with a series of recommendations which may be readily considered, modified if required and translated into practice within a comparatively short time.

Under the present system the scientist is dependent on the administrator, in one way or another to insure a supply of funds for the continuation of his research. Natural resources are a public responsibility and money required to employ and outfit the scientist must come from public funds. The administrative body should be specially trained to provide this service and acts as liaison between the research worker and the source of funds. To carry out this task it seems essential that the administrator must be supplied by the scientist with concise recommendations for improvement of the status of the resource based on the findings of his research. Early

application of results, or a suggested practical application by the scientist makes it much easier to obtain funds. Experience has shown that support is readily forthcoming if the contributing body, in this instance the public, can be shown that there is a possibility of dividend payment on the investment either for self, community or country.

Value of Demonstrating Management Practices

The value of demonstrating management practices even on a small scale, cannot be overestimated. In most cases regulations concomitant with management of a resource in some way affect the industry. Industry has a large investment dependent on the resource and thus it is difficult for it to take a long-range view of the value of conservation unless the necessity for this can be demonstrated. Once the demonstration is made through application of scientific results and the value of the practice becomes demonstrable or evident, most industries will back the measures to the fullest extent. One proven application will do much more to convince the public and the industry of the value of research and management practices, than two or more worthy treatises which do not go beyond the publication of data and theory stages and which can only be properly assessed or interpreted by specialists in the particular science.

Although there have been instances when administrators and scientists were prone to discount each other's work and value in the management of our fisheries resource, it is now commonly recognized that both are essential and their work interdependent, since generally a single solution to a mutual problem is required.

What Has Research Done?

Certainly a most significant contribution to fisheries management has been made by scientists through the wealth of knowledge pertaining to the habits, requirements, distribution, movements and availability of many species, which has resulted from research programmes carried out across the country.

There are many examples of this important contribution and to list these would be a tremendous task. However, the Great Slave Lake investigation and experiment is worthy of special mention in the field of freshwater fishery research. In this instance preliminary limnological investigations were carried out followed by population studies and finally through the co-operative researches of several scientists, estimates of excess crop were made and sound recommendations were submitted to the administrative body, which led to the development of one of our most important freshwater fisheries. A great deal of valuable information relative to the management of a fishery resource has been obtained from this research and if the practice initiated withstands the trials of time, a pattern may well be formed for the successful management of many inland lakes of commercial importance.

Present Trends and the Future of Research in Management

The term management has become linked with the administration of natural resources only recently but an historical review of the development of any resource shows that controls of one kind or another have been applied from early times. Generally these were intended to insure preservation, but often they were not too soundly

based. Today the pressing need for management in our fisheries is recognized since experience has shown that without proper management the resource may decline. There are several well-known instances of specific species where the decline has proceeded to at least economic extinction.

The modern concept of conservation as applied to renewable resources, includes within the definition of the term such expressions as "wise use" or "sustained yield" which indicate that a crop is produced and that the excess crop should be harvested. Management may be described as any practice which is based on the control of any factor which might affect the resource, with a view to maintaining or increasing the yield. The present trend is toward environmental control and improvement. This has shown most encouraging results, perhaps better than were obtained from methods previously followed.

The future trends which may be followed in the management of any resource cannot be forecast exactly but it is obvious, from the contributions that have been made and from an appreciation of the many scientific data which are wanting, that research will continue to be of paramount importance in forming a solid framework on which improved management practices may be based. Such investigations must be carried out by scientists specially trained in modern research methods. However, if advances are to be made quickly, it would appear that there must be more thought given to the application of results, for management implies action and thus is dependent on application.

What Does the Administrator Think of Research?

The administration of any natural resource cannot be efficiently performed unless those responsible have available the most recent scientific data pertaining to the resource. In every instance, the administrator recognizes his limitations in connection with the procurement of such data and acknowledges his dependence upon specially trained scientists and the findings of research. Experience has shown that administrative policies based on the findings of sound research withstand the pressure of criticism much more readily than those formulated without such a basis. For these reasons the administrator should openly commend the scientist for his worthy contributions and conversely should criticise a research or contribution which in some way falls short of the possible goal. The goal should, however, not be that set by the administrator but the one which could have been attained had the scientist submitted definite recommendations even if these fell into the category of an "informed guess".

The administrator fully appreciates the contribution of research but perhaps views it in different perspective from the scientist engaged in its prosecution. To the administrator it is part of a whole which must be fitted into a sequence which should consist of three stages:

1. The fundamental research stage in which the scientist gathers facts and assembles them to form hypotheses.
2. The "pilot plant" stage where the hypotheses are tested in the field under the supervision of the scientist.
3. The applied stage where action is taken to implement the findings on a general scale with a view to the maintenance of improvement of the resource.

Too often reference is made to the expression "administration versus research", which implies conflict. There is no struggle. One cannot exist without the other. Let us properly associate these in the future and refer to "administration *and* research" in order to stress the fact that each is essential to the development of sound management of the resource.

A forward step, which should dispel any possible idea of incompatability between the administrator and the scientist, has been taken recently with scientists accepting administrative positions. It seems that administration has presented a challenge to these individuals and incited them to accept additional responsibilities in the hope that they might have an opportunity to apply scientific knowledge and contribute more directly to the formation of necessary legislation and regulation, which lead to sound management practices.

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The Role of Research in the Management of Freshwater Fisheries in British Columbia

by

P. A. Larkin
British Columbia Game Commission

There are at least three organizations in British Columbia that are interested in applying research findings to freshwater fisheries management:

1. The Department of Fisheries of Canada; with the Pacific Biological Station of the Fisheries Research Board of Canada as its research division and the Fish Cultural Development Branch of the Department's Conservation and Development Service for application of research findings to management of salmon in fresh water stages.
2. The International Pacific Salmon Fisheries Commission. Research and application of research to management of sockeye salmon of the Fraser River system.
3. The British Columbia Game Department. Research and application of research to management of sport fisheries chiefly in non-tidal waters.

These organizations are not comparable insofar as the division of interest into research and management is concerned.

The Pacific Biological Station and the Fish Cultural Development Branch are presumably complementary in the research and management phases of salmon culture. At the present time, the Fish Cultural Development Branch (and the International Salmon Commission and the British Columbia Game Department) is largely occupied with fisheries problems attending the many and varied recent industrial and power developments in British Columbia. Research findings on the effects on fisheries of industrial and power developments have been borrowed from nearby states such as Washington, Oregon and California, but there is a notable lack of information on the environmental physiology of salmon. This lack is reflected in the recent planning of extensive investigation of upstream and downstream migration by the United States Fish and Wildlife Service in conjunction with various state agencies.

Except for obvious protection measures such as screening of irrigation diversions and elimination of obstacles in streams, lake and stream improvement work has not been developed by the Fish Cultural Development Branch, possibly because of the lack of published information on the success or failure of the many techniques that have been suggested or attempted.

Significance of High Mortalities

Research at the Pacific Biological Station has provided valuable insight into many aspects of the life history of salmon, particularly indicating the significance of high mortalities in fresh water stages, but there have been few attempts to evaluate province-wide problems and to turn the research findings into the production of more salmon. For instance, work at Cultus Lake has suggested that netting of squawfish may result in higher escapement of smolts, but this study has not been evaluated or attempted at the province-wide management level.

Recently, the Pacific Biological Station and the Fish Culture Development Branch have devised extensive plans for collecting information on representative salmon streams and as the synthesis of this material indicates the common and important problems, the research and improvement programmes will no doubt be given new impetus. In this regard particular optimism might be placed in the avenues of management suggested by the intensive studies on factors affecting survival in the egg and fry stages. Application of such studies on a scale sufficient to affect commercial production is contemplated in the near future.

Intensive studies at Lakelse are notable for the plan for evaluation of trout and salmon interrelations—a study which is greatly needed as a preliminary step in the establishment of management programmes satisfactory to both commercial and sport fishing interests.

The International Sockeye Salmon Commission has directed the greater part of its management programme on the basis of investigation and survey findings pertinent to the recurrence of dominant year classes and the times of migration of the runs of salmon to the various tributaries of the Fraser. Thus the commercial fishery for sockeye is regulated as far as possible to allow adequate escapement of each run. Similarly, the time of migration in relation to water temperature and the subsequent success of spawning and hatching has been emphasized in assessing effects of industrial and power development. In addition, attempts are being made to rehabilitate runs (for example in the Quesnel system) but to a large extent these efforts are not based on previous experience of the factors concerned with perpetuation of runs.

Surveying Sports Fisheries Problems

The British Columbia Game Department has set up a Fisheries Research Group which is largely concerned at the present time with surveying sports fisheries problems with the object of indicating lines of research which would lead to productive management practices. To a large extent the survey work is directed to examination of the relationship between lake productivity and quality and quantity of sport fish produced, although other surveys on life histories of the fish, surveys of parasites and studies of environmental physiology, are being sponsored or assisted. Several lines of research which may eventually indicate sound practices of improvement have been prompted by the surveys to date. The following are typical:

1. Most oligotrophic British Columbia lakes are conspicuously deficient of profundal crustacea such as *Mysis relicta*, *Neomysis mercedis* and *Pontoporeia affinis*. Research studies on temperature, salinity and oxygen tolerance have given encouragement to the experimental transfers of these organisms to British Columbia lakes.
2. Pursuant to the work done by Mottley on Paul lake the relation between lake productivity, population size and rate of growth has been surveyed in a large number of British Columbia lakes. Accordingly, a number of experimental stocking programmes have been started, and preliminary results have suggested that stocking may be highly effective in many lakes in which there are inadequate spawning areas.

A research programme of directly applicable nature has recently been conducted by the Institute of Oceanography at the University of British Columbia. The

Consolidated Mining and Smelting Company planned power development on Trout Lake and mining mill operations on Kootenay Lake and in each instance a study of the current distribution in Kootenay Lake was required. The Institute developed a picture of water movements by the study of temperature distributions and these findings will be reflected in recommendations to the company.

Some of the greatest research needs in British Columbia fisheries management at present are best classified in the fields of environmental and internal physiology. The great progress of these studies in the past few years at the University of British Columbia, chiefly under Dr. W. S. Hoar, has been most fortunate and has given promise of the development of many new and ingenious management possibilities. The researches of Dr. E. C. Black and Mrs. Black in these fields are also notable.

In the overall picture of the role of research in freshwater fisheries management in British Columbia one might observe that a considerable quantity of research material is at hand and many organizations are beginning to venture more broadly into the field of management. The first result has been the realization of new and different research needs. As yet there are relatively few instances in which research has been applied to the amelioration of existing conditions and in which economically justified benefit has been demonstrated.

The Role of Research in Fisheries Management in the Prairie Provinces

by

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The title of this paper should read "in Alberta" rather than "in the Prairie Provinces". I can write with first-hand knowledge only of Alberta and pressure of other duties has prevented me from taking time to study the situation in Saskatchewan and Manitoba. However, the problems of management are very similar in the three provinces and what is true in Alberta should hold very well for the other two provinces.

Preliminary Surveys

The first task in fisheries management is a routine one. It consists of collecting standard limnological data on the lakes and streams of the area; and also sampling the fish populations of the waters in order to obtain a rough idea of species present, their distribution, rates of growth, feeding and spawning habits. Next comes the administrative task of deciding what is the most desirable use of each lake and stream or group of lakes and streams; i.e., what species to stock, if any, the resolution of conflicting interests of sportsmen and commercial fishermen; setting poundage limits and net sizes in commercial areas, and seasons, size and catch limits in angling areas. These are complex and often difficult problems which require both the experienced administrator and the biologist to solve. In most cases the solution must be a compromise between economic or political interests and biological interests (a fact which the enthusiastic biologist should learn early in his career).

In the development of a management procedure based on preliminary biological surveys, many problems arise which cannot be settled because not enough facts are at hand. In this way research problems are born and the biologist proceeds from general surveys to intensive work on specific problems. These problems fall generally into two groups, management procedures in commercial fisheries and management procedures in sport fisheries. The remainder of this paper will deal with some of each of these kinds of problems. But first, it should be said, that, in the Prairie Provinces, scientific fisheries management is in its infancy; for the most part, the work is still in the preliminary survey stages and the research problems, though pressing, are only beginning to be tackled. This lack of progress is not due entirely to the short time that has elapsed since work began; a large part of it is due to the enormous areas involved and the small number of biologists available; in the Prairie Provinces Dr. D. S. Rawson and I are the only two biologists who have been working on fisheries problems for any great time. Recently we have been reinforced by the Central Fisheries Research Station of the Fisheries Research Board of Canada in Winnipeg (1945), but little of its time is spent on provincial administrative problems.

Management Procedures in Commercial Fisheries

The lakes of the prairies produce whitefish as their most valuable crop, with ciscoes, pikeperch, perch and pike as secondary crops. North, in the forested areas,

and on the Precambrian shield, the whitefish are joined by lake trout as the principal crop. The role of research in these fisheries is the solution of the following problems: proper size of mesh of gill nets, total annual poundage that may be safely removed, length and date of closed seasons, best methods of handling the catch, the use of the hatchery, effects of one-sided exploitation of lakes (i.e., do suckers increase when their competitors, the whitefish, are removed by fishing?), and other problems many of which boil down to the perennial problem, the determination of that elusive quantity, the optimum yield. On the prairies, and in certain other areas, a major problem exists in the parasite, *Triaenophorus crassus*, which has a profound effect on the marketability of whitefish and ciscoes. As a review of this whole situation is currently being prepared, and as it is a lengthy subject, no further mention of it is made in this paper. Some of the problems mentioned above are now discussed.

What is the optimum yield? It is up to the research worker in fisheries to give some advice to the administrator on how many fish should be removed each year from each lake, and what sizes or age groups should be included in the catch. Nowhere has research proceeded far enough to answer this problem for any one fishery (with the possible exception of the Pacific halibut fishery). The answer will be different for each species of fish, possibly in each lake or type of lake. It is determined by growth rates, natural mortality rates and rates of recruitment of young fish. If these rates were constant for any fishery the optimum catch might readily be determined as Dr. W. E. Ricker has recently pointed out. Unfortunately, these are not constants but seem to be, at least partly, a function of fishing pressure. In Alberta, Pigeon Lake was used in an experiment to obtain facts useful for determining the optimum catch (or maximum sustained yield). A brief review of the Pigeon Lake work may not be out of place here. This lake, of about 25 square miles, contains whitefish, suckers, pikeperch, pike and perch. Since 1918 the whitefish have been fished commercially; the average annual yield up to 1940 was 179,000 pounds, and the range 150,000–200,000 pounds. In 1941 the 150,000 pound limit on the catch was removed and more or less unrestricted fishing was allowed. The catch rose spectacularly to over three times the previous annual average and remained there for six years; the seventh year intensive fishing failed to get large returns, i.e., the fishery had collapsed. The catches are shown in Table 1.

Table I.

Whitefish Produced in Pigeon Lake, 1941-1950

Year	Catch (lbs.)	Year	Catch (lbs.)
1941	582,900	1946	350,000
1942	354,600	1947	160,000
1943	340,000	1948	closed
1944	485,000	1949	closed
1945	411,000	1950	66,000

In 1948 and 1949 the lake was closed; in 1950 fishing was again permitted on a small scale.

All fishing was done with 5½-inch, stretched mesh, gill nets. A total of 1,594 fish were removed throughout the experiment as samples. From these the age composition and growth rate of the catch were determined. In 1942 the catch was of

five- and six-year-olds. In October, 1947, when the fishery collapsed, 74·5 per cent of the fish were two-year-olds. These two-year-olds were mature spawning fish; in 1942 the fish did not mature until their fourth or fifth year.

The fish increased considerably in growth rate. In 1942 a three-year-old was 13·7 inches (fork length) and about 1·5 pounds in weight; in 1947 a three-year-old was 16·5 inches long and weighed 2·2 pounds. Since 1947 the growth rate has decreased again to almost the 1942 level; this is due to a very large population of unexploited young fish.

This experiment, still in progress, has yielded some information of value to management. Thus, the critical point in the fishery appears to be when the $5\frac{1}{2}$-inch nets take over 35 per cent four-year-old and younger fish. It is also clear that a lake may be overfished with large-mesh nets; this is because as the older fish are taken, the more recent year classes increase in growth rate until the nets take them at a younger age; this process continues until the limit of growth rate increase is reached, at which point only one- and two-year-old fish remain in the lake. Finally this experiment demonstrates that recruitment rate and growth cannot be regarded as even approximate constants for purposes of calculating the optimum catch.

(It is interesting to note that Lake Wabamum, similar in size to Pigeon Lake, also collapsed after six years of overfishing; in 1942, the year after its collapse, 69 per cent of the fish were four-year-olds or younger.)

Another study which has a bearing on the problem of the optimum catch has been the Lesser Slave Lake cisco experiment. In an effort to control *Triaenophorus* infection the tullibee of Lesser Slave Lake have been exploited almost without restriction since 1940-41. Catches rose to over one and one-half million pounds in the first year of the experiment; they continued between 1·5 and two million to 1946–47 when the catch increased to 3·5 million and has remained at that level. The tullibees have responded by greatly increased growth rates and by spawning at younger and younger ages (until now they mature in the second summer). In spite of this response the population has become younger and younger; in 1941 the catch was largely five, six- and seven-year old fish; now it is of 80–90 per cent two-year-olds and has been since 1947. In spite of this critical situation the fishery continues productive although it appears that a spawning failure would cause a collapse in one year. In 1941 a study of this fishery based on catch curves and growth rates would have led to the conclusion that exploitation was at a maximum; however, the fishery has proven it could stand three times as much pressure over a long period.

It is apparent from the foregoing two experiments that an important role for research in fisheries management is the elucidation of population dynamics in commercial fisheries.

Mesh Sizes

The problem of gill net sizes is bound up with the optimum catch; there is some evidence that mesh size is not as important as formerly believed; i.e., if a given mesh size takes fish before they reach spawning age, the population will adjust to the situation and begin spawning at younger ages. However, mesh size is important in that it determines the size of fish taken for the market. The best mesh size must be a compromise between the best size of fish for the market and the biological factors in

the lake. Research is required on the effect of different mesh sizes; such research is really part of the large problem of population dynamics. Optimum mesh sizes may be calculated on the assumption of constant rates of growth and mortality (Ricker's method); Dr. W. A. Kennedy has done this for Lake Manitoba. However, such calculations are open to question because of the probable variable nature of the assumed constants. Actual experiment is needed.

Research is also needed on the effect of thread size and the use of different materials such as linen, cotton, and nylon. It appears from present knowledge that as finer thread is used greater catches result and these increased catches are due to smaller and younger fish being taken.

Role of the Hatchery

The commercial hatchery for whitefish and pikeperch is still in wide use. Research in Alberta on the whitefish hatchery over a period of more than ten years and including seven lakes has shown conclusively that, in lakes where whitefish spawn, the hatchery is without measurable effect. Of the seven lakes studied some were planted in even-numbered years and others in odd-numbered years. Variations in year class strengths proved to be the same in all lakes, irrespective of stocking history; the variations appear to be related to climatic factors. As a result of this work the Alberta whitefish hatchery was closed.

Trouble Shooting

A large part of a fishery biologist's time is occupied with what is best described as "trouble shooting". It is my understanding that Saskatchewan has appreciated that a research man cannot continually desert a project to engage in trouble shooting, and have included personnel in their administration specifically for such work. The trouble-shooter is a biologist that the administration leans on when a ticklish political situation develops; such situations are conflict of interests between commercial fishermen and fur farmers or between either the latter or former and anglers, or perhaps all three interests may be involved. Often a disinterested appraisal of the facts from the biological viewpoint reveals that no real conflict exists. While such work is hardly research it is valuable and necessary. Occasionally a true case of conflicting interests may turn up. Then it is the biologist's task to advise which interest is to be excluded. This may involve research in the true sense. One interesting example is Cold Lake on the Saskatchewan-Alberta border. At one time a mecca for lake trout sport fishermen it degenerated to a mediocre commercial fishery for whitefish with the occasional trout turning up. An investigation of the growth rates of the whitefish and trout convinced the administrations of both provinces that the lake would be more valuable if the sport fishery for lake trout could be restored. The lake was closed to commercial fishing in the belief that the lake trout would come back. There is some evidence that this belief will be justified.

Management Procedures in Sport Fisheries

The problems of sport fish management are too numerous and complex to cover in detail in this paper. In order to narrow the field to the point where it may be dealt with adequately, I have restricted my discussion to trout streams. Alberta,

in particular, has many thousands of miles of excellent trout water on the eastern slopes of the Rocky Mountains. This water is of incalculable value to the prairie farmer for irrigation; power interests are also involved. The sport fishing value of the water is, unfortunately, of secondary importance, perhaps not real, but certainly fancied. Here the role of the fishery biologists is to try and salvage as much fishing as possible in waters used for power and irrigation. Often, if advised in time, the management of large water projects will provide for fishing interests as far as they are able. Dates of raising or lowering impoundment levels may be altered to suit spawning and/or migrating habits of fish; fish ladders may be installed if needed. Dr. Rawson, in a study of the Bow River impoundments, found no evidence that the alterations in the river had seriously reduced fishing; in fact, the additional acreages of water could well lead to increased fishing as it obviously has in the Tennessee Valley.

In the management of unaltered trout streams there is room for a great deal of research. The standard management procedure such as hatchery stocking, legal minimum size limits, closure of feeder streams and closed seasons are based largely on tradition; there is little or no evidence of their value. Many research projects could arise from a study of the efficacy of these standard procedures. Some of them I wish to discuss a little more fully.

The Use of the Hatchery

Since the hatchery is the most expensive tool in modern sport fish management, it is clearly the duty of the fishery biologist to see that it is operated efficiently; this involves testing the efficacy of the procedures commonly used. Little such testing has been done in Canada. In the United States a large body of evidence now exists showing that trout stocked in streams which support spawning wild trout do not survive. Even large trout, over seven inches, seldom come through the first winter. Here is a problem for the biologist; why do these trout die? In Alberta a biological station has been set up as a joint project of the University and the Government. The station is located on the east slope in typical trout stream country. Trout of varying hatchery backgrounds have been planted in a test stream in three-quarter-mile enclosures. Each trout so planted has been weighed and given a numbered Petersen tag just before planting. The trout have been recaptured and reweighed as often as possible and, of course, all mortality has been recorded. It has been found that, of legal-sized trout, about one-third died in the first two weeks following planting due to exhaustion in the new environment. The survivors steadily lose weight; this weight loss seems to result from unsuccessful competition with wild trout in the stream. After 40 days the hatchery fish stop losing and, by 100 days, have almost regained planted weights. However, they are thin compared to wild trout and in no condition to winter. Smaller trout suffer more severely; about half die of exhaustion in the first two weeks; the survivors die of starvation by freeze-up. The question arises, is this death from exhaustion or slow starvation a property of hatchery fish or would any fish (e.g. "wild" trout) transplanted to a new environment suffer in a similar fashion? The station answered this question during the summer of 1951 by transplanting tagged, wild trout to an experimental stream enclosure. Such trout did not die of exhaustion; they did lose a small amount of weight, negligible in comparison to the amount lost by hatchery fish. Thus it is the hatchery which produces weak trout. It is up to the fishery biologist to develop hatchery procedures which will produce strong trout.

Legal Size

The enforcement of a minimum size for "keeper" trout is a time-honoured management procedure. It is designed, presumably, to allow fish to spawn at least once before capture. The biologist can clearly perceive that this is a fallacious policy. It is his duty to gather proof of the fallacy and convince the administrators (and the public). For example, in one Alberta trout stream trout seldom reach eight inches; they mature and spawn at lengths of five inches and weights of 1·5 ounces. No trout could be legally taken. In another stream, part of the same drainage, trout reach 10 inches and a pound in weight in their second summer; in certain lakes the trout reach 2·5 pounds in their second summer; such trout are immature. The eight-inch minimum allows their capture, but they have not spawned. The law is obviously absurd. To be biologically sound each tributary would require a separate legal minimum.

But is it sound to protect immature fish? In Alberta streams it has been found that annual mortality is at least 60 per cent. Thus, of 100 trout as fry, 40 survive to yearlings, 16 survive to two-year-olds, six survive to three-year-olds, not quite three- to four-year-olds. If four-year-olds are mature, and therefore legal, it means the angler has a chance at less than three per cent of the population; further, it means the angler is forced to select from the brood stock for his creel. He is being forced to deplete the most essential part of the population. It would be more logical to make the angler select from the more abundant younger fish.

As a result of the foregoing facts and arguments, the size limit has been removed in Alberta. It is now up to the biologist to look for any changes in stream population which may result from this move.

The Feeder Stream Theory

The belief that main-stream trout move into tributaries to spawn has led to the almost universal practice of keeping tributaries closed in the belief that they "stock" the larger rivers. Research in Alberta has shown that this is not true. River dwelling trout do not spend their youth in tributaries; while the parent trout may ascend tributaries to spawn the resulting young desert the tributaries as fry or fingerlings. Small fish commonly seen in tributaries are not younger than the fish in rivers; they are mature tributary-dwelling trout which grow more slowly than fish in the rivers.

Closed Seasons

Should sport fish be protected during spawning? There seems no logical reason for the answer to be yes. The custom of closing streams during spawning appears to have arisen from the conspicuousness of the gonads at spawning time; anglers note the ripe eggs and feel it a shame to kill a potential mother. However, the potential young lost by killing a fish in June are of the same quantity and just as dead as if they were killed in September (in, for example, a brook trout). As no Alberta sport fish guard their eggs or young no reason for protection is evident. Alberta is now trying year-round fishing on some waters. The values of such a policy are simplified law enforcement and the elimination of the opening day "beating" which streams formerly received; in general the distribution of fishing pressure is more even.

New Management Procedures

So far, on the prairies, the role of the biologist has often been the detection of fallacies in existing methods. He has ridiculed the hatchery and pulled management legislation to pieces. To be of real value, the biologist must contribute something constructive to sport fish management. It has already been suggested that it is up to the biologist to find out how to grow strong fish in hatcheries. It is also up to the biologist to search for and test new watershed management procedures. For example, a new scheme will be tried in Alberta beginning in 1952. The east slope has been divided into areas according to the growth rate of the fish. Slow growth areas are subdivided into thirds; one third will be open each year; in this way each third of the area will receive two years rest out of every three in the hope that natural reproduction and growth will restore an attractive angling population. Fast growth areas are divided into halves. Each half will be open one year and closed the next. By careful choice of areas it is hoped to provide maximum fishing in every part of the province without endangering future supplies.

Summary

Given the title "The Role of Research in Fisheries Management", it is necessary to write a paper of book-size to give anything approaching adequate treatment. But when the paper is one of nine others, all to be presented the same afternoon, adequate treatment is manifestly impossible. The discussion in this paper has, therefore, been confined to certain aspects of the commercial fisheries of the Prairie Provinces and to the sport fishery for trout on the east slopes of the Rocky Mountains in Alberta. The main roles of research brought out in the paper may be summarized as follows:

A. Preliminary survey of resources both sporting and commercial; based on the survey, tentative assignment of seasons, quotas, creel limits, etc. The recognition of major research problems and the laying of plans for their attack.

B. Commercial fishery research problems.

1. Research into the dynamics of fish populations designed to yield information on: proper mesh size of gill nets, thread size and thread material in gill nets; proper age composition of the commercial catch; effect of exploitation of favoured fishes on their less-favoured competitors; effect of fishing pressure on growth rates, mortality rates and recruitment.
2. The solution of the *Triaenophorus* problem.
3. The value of the commercial hatchery.
4. Wisest use of a fishery (conflicts between commercial fishermen, anglers, fur breeders.)

C. Sport fishery research problems.

1. How to rear hatchery fish that will survive in streams.
2. Search for new trout stream management methods to replace useless legislation on minimum sizes, closed feeder streams, protection during spawning.
3. The best use of reservoirs and impoundments created primarily for irrigation and/or power.

The Role of Research in Fisheries Management in Ontario from the Research Point of View

by

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The activities in fisheries research as carried on in Ontario may be broadly divided into three strata. The most fundamental and generalized attacks are made by the University groups of which there are five, one at each of the Universities and one at the Royal Ontario Museum of Zoology. These are supported by the Provincial Department of Education, the Research Council of Ontario, the Ontario Department of Lands and Forests and the National Research Council.

These University groups are engaged in unravelling the facts of life in the aquatic world. They are determining how many kinds of animals and plants there actually are in our waters. They are learning how these organisms live together in their aquatic communities. They measure the amount of sunlight, the sole and still mysterious source of energy for the maintenance of all life, that reaches the lake surface and penetrates into the depths below. They determine the amounts of the minerals which are essential to the life of animals, and plants, that leached from the watershed, circulate from one organism to another for a while and then are ultimately deposited on the bottom or pass down to the sea.

The second stratum of researches comprises those which are aimed at solving problems that have particular reference to a geographical region, the Province of Ontario. These are carried out for the greatest part by the Research Division of the Ontario Department of Lands and Forests. For example, the fisheries group in this division gather information on the life histories of our important game and commercial fishes. At the present time they are investigating the spawning of lake and speckled trout with particular reference to the conditions on the spawning beds and the effect of changes in water levels.

The effects of fishing on various stocks of fish are also being investigated. A large scale experiment on commercial and coarse fish is being carried out by the Research Division in South Bay, Manitoulin Island.

A third major project, which has occupied the Research Division in recent years, is a thorough test of the effects of commercial fertilizer on the growth of fish and the plants and animals which support them. These tests were particularly necessary from a regional point of view since our relatively infertile and ice-bound lakes present conditions greatly different from the southern ponds in which most of the original work on fertilization was carried out. It has turned out that fertilization according to recommended procedure is most unsuitable for our waters. In consequence, research here on this subject is seeking ways of modifiying fertilization practices to suit our special needs. At the present time attention is being given to liming of lakes in the lime-poor Precambrian Shield region.

The third division of research responsibility—that of more limited investigations of local situations to help in the immediate application of a management practice—is being dealt with in the following article, so will not be included here.

These three divisions of the responsibility for research appear to represent a very real and valuable outcome of the principle of division of labour rather than just the chance result of administrative convenience, for the results in each field as outlined find their practical application in the next. The results of fundamental research have their immediate practical application in higher education where they provide background which enables research workers engaged on regional problems to attack these in the most efficient manner open to their generation. The results of the regional investigations provide the local investigator with an outline of events which can often be rapidly modified to provide a full understanding of the local situation. Thus all steps are essential and all properly should be carried out by different personnel for it is the rare human who can operate on more than one plane of thought.

The Role of Research in Fisheries Management in Ontario from the Management Point of View

by

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In the consideration of this matter, which forms part of a symposium at the 1952 meeting of the Canadian Committee on Fresh Water Fisheries Research, we shall attempt in this paper to evaluate some past and present management practices employed within the province on the basis of their scientific justification. In this way we intend to reveal some of the important gaps in biological knowledge which are required for the development of a sound management programme. The procurement and analysis of the required data, we feel, should be to a large extent the responsibility of research organizations in the future.

As the following remarks pertain primarily to the Province of Ontario, it should be noted that the problem of fisheries management, formerly the duty of the Department of Game and Fisheries, has taken on greater significance since 1946 when it became the responsibility of the newly formed Division of Fish and Wildlife of the Department of Lands and Forests. This division, a management organization, may not be expected to undertake basic research although projects of a research nature pertaining to local management are undertaken from time to time. The pre-1946 staff of two fisheries biologists has been expanded some eightfold as an important step towards inauguration of an up-to-date management plan. Further expansion is anticipitated until sufficient field biologists are available to administrate local fisheries management throughout the province.

A number of the fisheries management tools which are employed within the province will now be discussed under the general headings of regulations, fish culture, and habitat improvement.

Regulations

Regulations, one of the earliest attempts at fisheries management, have been based to a considerable extent on pure supposition, or on laws used with doubtful justification in other provinces and countries. As a result, regulations have undergone continuous change in recent years and revision must continue as scientific discrepancies are proven through further research.

Among the oldest regulations are those governing creel limits, size limits, and closed seasons. Those imposing limit restrictions have been adopted largely on the false basis of public demand, rather than on the sound basis of a crop to be harvested by a known number of fishermen. The regulations covering size limits (or minimum lengths) are scientifically based for most species to the extent that in most waters the harvested fish are at least "one-time" spawners. The actual effect on the ultimate fish production has not been satisfactorily demonstrated.

The regulations setting creel limits may tend to reduce wastage resulting from excessive captures in certain waters but, as is the case with size limits, laws of these types cannot be justified until indices are provided through research whereby management officers can readily determine the productivity of waters.

Regulations concerning closed seasons are based on a knowledge of spawning characteristics of each species and appear basically sound in eliminating fishing pressure at a time when each species is concentrated and easily exploited. Again, the actual effect on fish production has not been proven to any extent and may be worthy of research. A point which should be considered is the utilization of species of fish generally available to the angler only during the spawning season, for example, pickerel and rainbow trout in the Great Lakes and tributary streams. To what extent should these species be utilized while on the spawning beds?

Alternate closure of lakes in Algonquin Park has resulted from research studies of the Ontario Fisheries Research Laboratory. This management tool has not been generally applied to other waters.

Fish sanctuaries have been set up in Georgian Bay and several other Ontario waters but the actual value is more-or-less pure supposition. This practice of permanent closures of areas of lakes inhabited by both coarse and game fish must be investigated and its value assessed.

Regulations governing commercial fisheries pertaining to mesh size are generally based on a combination of scientific fact and economic value. Facts are still lacking which would permit the management of commercial fisheries on a continuous yield basis.

Fish Culture

Through the years hatcheries have been sold to the public as a sound and necessary management tool. In recent years their value has been disputed by both scientists and laymen, but insufficient research has yet been completed to prove their positive or negative value to conscientious administrators.

The actual operation of hatcheries in Ontario has improved through the utilization of scientific data coupled with the experience of non-technical men in hatchery operation. Methods of handling eggs, young fish, control of hatchery diseases, and the like, have reduced mortality within hatcheries to a minimum. Further research into the development of cheap and nutritious foods is desirable.

The value of hatcheries as a management tool may be assessed only by the usefulness of its products. Failure to determine the effectiveness has to an extent been the fault of administration which, through a lack of trained personnel and an apparent lack of initiative until recently, has made little attempt to determine the results of either stocking new waters (introductions) or restocking waters with existing populations of the same species. At any rate, before the use of hatchery products may form a justified place in the provincial fisheries management programme, research must be undertaken to ascertain the survival of all ages of fish which may be stocked from eyed-eggs to yearling or even mature fish. These studies must analyse the effect of environmental or habitat conditions on survival, and must present the results in a manner which may be readily utilized by management officers. The Atlantic salmon study in Ontario has been a research of this type in demonstrating the importance of effect of habitat on survival.

The stocking of northern Ontario lakes from aircraft has been used advantageously Techniques in handling fish, particularly aeration, have been developed. The stocking of northern virgin lakes offers an excellent opportunity for needed survival studies.

In considering hatchery products, management officers are interested in the possibility of developing hybrid fish which are more adaptable to environmental conditions and of proven value to a fishery.

Habitat Improvement

Habitat improvement has not received the attention in Ontario which is found in neighbouring American States, although the first sound steps towards a province-wide control of pollution have been taken.

Undoubtedly stream improvement and watershed work in southern Ontario is desirable from the fisheries standpoint, but is too large a project to be undertaken alone and must develop through co-operation with other conservation agencies. Reforestation carried out under the Department of Lands and Forests for many years has made perhaps the greatest single contribution, but its overall effect on stream temperatures, flooding, erosion, and silting is scarcely felt.

Pertaining to lakes, little has been done other than the possible value of controlling water levels. Pertaining to streams, it has not been found practical or economical to undertake many of the improvement methods recommended in American publications until such time as their value has been clearly demonstrated. A limited control over the construction of new dams is aimed at preventing further obstructions to migrating fish.

Regarding pond management, trout ponds have been developed and improved through techniques such as coarse fish removal, weed control, and fertilization. However, a definite lack of knowledge concerning the development of farm ponds for warm water game fish, food fish, and minnows, under northern climatic conditions remains a serious gap in the southern Ontario fisheries management programme. Definite research studies are required and may well be a co-operative effort between research and management.

Included within the problem of habitat improvement must be the question of population manipulation, i.e., restoration and maintenance of the proper balance of species of fish in a body of water, and the eradication of undesirable species. Techniques in Ontario include netting, chemical eradication, and intensive angling. Although these methods are used with favourable results in the management of small trout ponds, the relatively extensive coarse fish removal programme carried out in larger bodies of water in various parts of the Province is based on little more than optimistic speculation. Research and management may well join in a study of this problem. Management officers are awaiting with interest the results of the experiment of this nature currently being conducted by our partner in Ontario, the Research Division, at South Bay.

General Conclusion

This paper has made no attempt to cover all current management practices, but rather has undertaken to stress a number of those procedures which have received more-or-less general acceptance in Ontario although the ability to predict their effectiveness is lacking.

From these considerations it must be concluded that most practices employed within Ontario under the guise of fisheries management tools do not enjoy the benefit of adequate scientific knowledge. The Fish and Wildlife Division, with its expanding staff of biologists, is now approaching a position where it may examine its own management procedures and assess the relative importance of research studies which may be undertaken. There is no reason to doubt that definite progress can be made through the adoption of a policy of continuous investigational management over a period of years. This demands the close integration of research and management organizations in the study of problems of mutual interest.

Future Prospects for Valuable Development in this Field

by

K. H. Doan

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To attempt to predict the importance in the next five years or so of fisheries research in the management of fish is to risk confusing forecasting with hope. The needs of the fisheries vary throughout Canada, and it has been very difficult to achieve a national picture. Information was sought by the questionnaire method and I am deeply obliged to those who assisted. Since this paper represents a synthesis of opinions, various persons may recognize some of their contribution as a direct quote. The questionnaire listed about 75 items grouped into ten categories, and these have been reviewed with no priority of order.

The planting of hatchery raised fish is conducted without serious question of results in some regions, while in others the whole procedure is shaded with doubt or has even been abolished. Hatcheries are useful if some estimate can be made of their economic value, i.e., of relating the cost of producing a fish to the actual recovery by the angler or commercial fisherman. Hatcheries may make significant contributions where fishing is intense, where new species are desired, where it is wished to re-establish a former species, or where no natural reproduction exists. The trend in hatchery plantings will continue towards larger fish but the techniques of planting and the results to be derived from the practice will come under increasing scrutiny. In British Columbia the rearing and planting of salmon is still in the discard as a general practice, but in special instances fry and eggs may be useful to supplement or rejuvenate runs. Fish physiologists would unanimously, I suspect, declare themselves favourably inclined towards fish hatcheries as a source of experimental material.

Interest in Fish Genetics

New species of fish may be useful for the occupation of waters whose native inhabitants succumbed to changed ecological conditions, but it is believed that the former activity in introducing exotics will not be equalled in the future. There is some interest in fish genetics, either to produce hybrids or to produce strains of regular fish which may be more amenable to harvesting or management. To be able to alter the age at which fish migrate, to destroy the urge to migrate, to increase fecundity, growth rate, etc., might be desirable for some species in some regions. Only in the prairies and in Ontario have transfers of wild fish been made to any extent, but this may be practiced more in the future for pike, perch, and smallmouth bass. Semi-artificial rearing in natural ponds or in impoundments has been mostly successful where tried, and only the lack of good locations may limit this in the future.

The efficiency of propagation has been insufficiently studied, so that knowledge of the optimum stock of spawners required to maintain a fisheries is inadequate, and legislation designed to achieve this is based mostly upon theory. The importance of

this matter varies locally and the need of extending spawning grounds by the removal of obstructions, the provision of fishways, regulation of water supply and level, and the artificial provision or culture of suitable bottom seem to be more important for trout and salmon than for other fish. Although expensive, it is believed that the preservation and extension of natural spawning grounds will contribute much to propagation. Seemingly conflicting interests—lumbering, canals, hydro-electric power, drainage, irrigation, sewage disposal and fisheries—must work together more harmoniously in the future if the best water use is to be achieved. Although sometimes small in monetary value, the fisheries are often important, but difficult to evaluate as in the tourist industry. Sometimes obstructions can have a positive value, such as preventing undesirable fish like the carp from gaining access to new range.

The reduction of over-population of fish is only of local application, since it is believed that in most of our accessible fresh waters the harvest is adequate or could be increased without trouble. The use of nets to reduce crowded stocks of fish is not very effective. Poison is sometimes better but more expensive and will probably not be applied on a large scale in the near future.

Research on methods to increase the survival of young, the growth of fish, and the total production of lakes and rivers will be of importance where there is a proven lack of natural fertility of the water such as in northern areas. Some research upon the fertilization of water by the use of chemicals has been done but the results have been limited, and the need of additional facts is indicated. Such practice, more effective in southern climates, may have limited results in our colder climate. The effects of controlling predators and competitors upon the increased survival of the desirable fish are not generally very clear-cut and controlled experiments will be required to clarify predator-prey relationship. This practice, if and when developed, may give good results for some fisheries, such as British Columbia salmon, and elsewhere against sea lamprey, eels, etc. Increased survival may also be attained by the removal of obstructions which limit the passage of young fish to their growing areas or future fishing grounds.

There would seem to be a field in the future for methods of utilizing fish which are now insufficiently harvested, such as by the development of new sports, and new methods of fish preparation, by-products, and markets, so that all kinds of fish may be taken from the water at a rate commensurate with their ability to produce, rather than having selective fishing for only a few desirable species. There will be slow progress in educating anglers to fish more for sport and less for food, and to refine their tackle, but this doubtless will receive more attention.

In the matter of quality there have in the past been arguments over the relative merits of native versus hatchery fish for planting. Although some tests have been made that showed an inability of hatchery fish to compete with and survive against wild stocks after planting, it is likely that more such experiments will be undertaken. Perhaps hybrid strains with greater vigour may be developed in the hatcheries. The whole matter of fish parasites and diseases has generally been considered unimportant in nature, although the hatchery manager must be skilled in these matters. A notable exception is a tapeworm infection in whitefish which occurs in some lakes in central Canada, and is a matter of considerable economic importance still requiring research into such practices as population manipulation, chemical treatment, and fish processing

by filleting, canning, etc. In wholesale modifications of fish populations more research is needed on their ecology, and there is still room for the development of chemicals for the treatment of natural waters if comparison is made with the proliferation of insecticides that have arisen from research in economic entomology. Besides new processing methods for the elimination of parasites, every effort towards the production of high quality fish (by the industry) should be encouraged.

Detailed Knowledge Lacking

The field of environmental control offers one of the greatest opportunities for fish management, yet when any factor is examined closely a dire lack of detailed knowledge is soon evident. No methods of environmental control can be developed thoroughly without research upon the reactions of fish to various environmental factors. The maintenance of satisfactory water temperatures in nature, of erosion and bank stability for turbidity control, of high water tables in the soil, and the prevention or alleviation of floods, are all directly related to forest cover and water use. Parts of Canada that are still "new" have suffered little alteration of natural conditions, but in more highly developed sections of the country, man's activity in agriculture and industry have wrought extensive changes in the conditions under which fish must survive. It is believed that efforts towards the maintenance and restoration of natural conditions are essential to ensuring stocks of fish. Perhaps in only local and extremely valuable fisheries will there be much application of artificial structures such as low dams, current deflectors, artificial cover, rip-rap, mechanical and chemical control of turbidity, removal of excess aquatic vegetation, snow removal and pollution control. There is a definite trend towards experimental biology and towards the study of behaviour patterns, and these must be elucidated before they can be synthesized with environmental variables into management methods. Worthy of note are the steps that have been taken, and will continue to be developed, to preserve natural waters amid Canada's expanded oil industry.

Regulation of the catch, usually by legislation, has long been a favourite administrative procedure, but it would appear that research interest will be directed towards this more than in the past. There was almost unanimous opinion that accurate measures of catch are essential for attaining optimum yield in commercial and sport fisheries. There is considerable open-mindedness amongst fishery biologists about mesh size in commercial fisheries, and it is to be expected that more experiments will be conducted to see what effects smaller meshes may have upon stocks and yields of fish. Even in sport fishing, there is some inclination to review critically the efficacy of catch, size, and season limits with perhaps a view towards liberalization or elimination of these. Such limitations are now in effect without any sound factual basis. It might eventually be shown that maintenance and improvement of environment has more to do with fish production than limitation of catch. Some experiments are already under way to study the effect of the simultaneous harvesting of fish by commercial and sporting interests, but the full practice of this may perhaps not be brought about locally because of political factors.

Just as the banding of waterfowl has led to sound knowledge of their migrations, so will the tagging and marking of fish contribute towards our knowledge of their movements in a medium where they are largely invisible to us. Recovery data will

contribute to a knowledge of fish mortality so that the effect of man's take may be properly assessed in the natural cycle. This should lead to a more intelligent approach to the regulation of catch, and will perhaps indicate the necessity, or not, of such regulation. Correlated with currents and temperatures, the tagging studies may develop into one of the most important tools of fish management, and undoubtedly they will help in the interpretation of environmental effects and other influences upon fish production. Aside from this review, it has been noted that more emphasis is swinging towards study of the relationship of oceanography to fish movements and availability.

Only in densely settled portions of Canada does there seem to be any problem over access to fishing waters, since elsewhere in Canada the lakes and rivers are predominantly located on Crown Lands and in parks to which the public has access. The management of a few special fisheries may require the increased development of fishing sites, docks, camps, etc. This applies mostly to fisheries of recreational value, but the provision of harbours might be regarded as part of the management of commercial fisheries.

The general observation may be made that much of the past research in fisheries has been largely along lines of academic interest, and that with the limited resources for research we would be well advised to choose lines of research which are, perhaps, of less academic interest but of much more practical application. This practical application, however, must be predicated upon more factual knowledge, as noted in the discussion on environmental control. The rapid expansion of fisheries in recent years, both commercial and angling, has brought on a tremendous increase of fisheries problems and the realization by the fisheries authorities that their research background is remarkably shallow when direct questions are asked on the effects of various developments. The warning has been sounded that one cannot judge the value and practical significance of any factor affecting the production of a fish until it has been carefully studied or evaluated, particularly in relation to the whole early life-history, i.e., prior to the catching of fish. Some factor in the early life history might seemingly cause heavy loss and reduce the populations very appreciably. Its correction might seem a "must" yet there may be some factor, perhaps predation, coming to bear at a later stage which may very appreciably reduce the overall effect of the eradication or control of the previous limiting factor. Until then, when one has put together all the segments of the picture, one cannot too accurately assess the significance and importance of any one factor or phase involved in fisheries management.

The administrator, that is the fisheries manager, has at his disposal an array of facts which might be grouped in four classifications:—

(1) *No factual information*, but the setting up of a management plan on the basis of what appears to be a reasonable common-sense philosophical consideration of the case in point. If data or statistics are maintained and other regular and planned observations carried out on the management, this management programme in itself may constitute a basis for assessing its own value.

(2) *A limited amount of factual information arising from general or superficial investigation.* The sparse information employed in such a programme may arise from the early stages of a management programme set up on a theoretical basis or may be information of recorded or verbal nature arising from investigations carried out elsewhere in a similar field.

(3) *Factual information limited in character arising from a rather general type of ad hoc research.* This is perhaps the picture for the most advanced work in fisheries at the present time. The data arising from this category of research are probably very incomplete and may in fact be only a half-truth or less. A successful management programme based on research facts of this category will serve to substantiate the information, but some judgment must be exercised in using only data which promise some degree of success.

(4) *Facts arising as the result of basic research.* The spread between the approach to basic research and the approach to management is so wide that the results from any single unit of basic research have probably no value to applied management, and it is only as the result of a general accumulation of facts arising from basic research and their final integration and interpretation, that information from this source may be applied with value to management practices. It is important to emphasize that, in the final analysis, progress in fish management depends to a very great measure, if not completely, on this category, i.e., on basic research and the facts which arise from basic research.

One contributor to this review expressed the thought that streams and freshwater lakes, when compared to the oceans, are individually and collectively very young, and that, therefore, the organisms found in them are essentially pioneer stock which do not, as yet, approach the full utilization of the biological potential of their environment. In future fish management, there might be room for the development of new strains of the existing pioneer stock and the introduction of "immigrant" marine colonies, so that freshwaters might be made to produce higher yields than they do at present.

Throughout Canada nearly all known fish management practices are in use, but mostly locally, and their use is on a purely theoretical basis which presumes that by their nature they should be of value. In few cases are there any facts to strongly support the practice, and in fewer cases are there any facts in the form of numerical data. It seems to be a safe assumption that fisheries management will have a very dim future indeed unless research is vigorously organized and driven to produce the many necessary facts and improved techniques on which sound and increasingly productive management must be based. Without successful long-term research there will be no successful long-term management. The prosecution of research which will supply these facts can only be accomplished with more trained men and money.

Acknowledgments

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Transfer of Anaesthetized Adult Lake Trout by Means of Aircraft

by

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Chief Limnologist, Canadian Wildlife Service, Ottawa

For stocking and restocking bodies of water, fish eggs, fry and fingerlings have been moved by a variety of means. Pack horses, packs on men's backs, railroad, steamship and aircraft have all been utilized. Aircraft, for example, have been extensively used in the Province of Quebec and in the states of New York and California. In the case of adult living fish, trucks and railroad cars equipped with water-filled tanks have been used most frequently as a means of transportation.

The Province of Manitoba transferred by air from Clearwater Lake to Cormorant Lake 1,100 and 1,000 adult lake trout in 1947 and 1948 respectively. These fish were moved over a distance of approximately 25 miles in Norseman and Husky aircraft equipped with water-filled tanks. These transfers necessitated 10 or 11 trips. An additional transfer of 1,000 adult lake trout was made in 1948 from Clearwater Lake to Manistikwan Lake; the distance between the two lakes is 50 air miles. (Information supplied by Mr. G. E. Butler, Department of Game and Fisheries, Province of Manitoba.)

Operation of 1951 Transfer

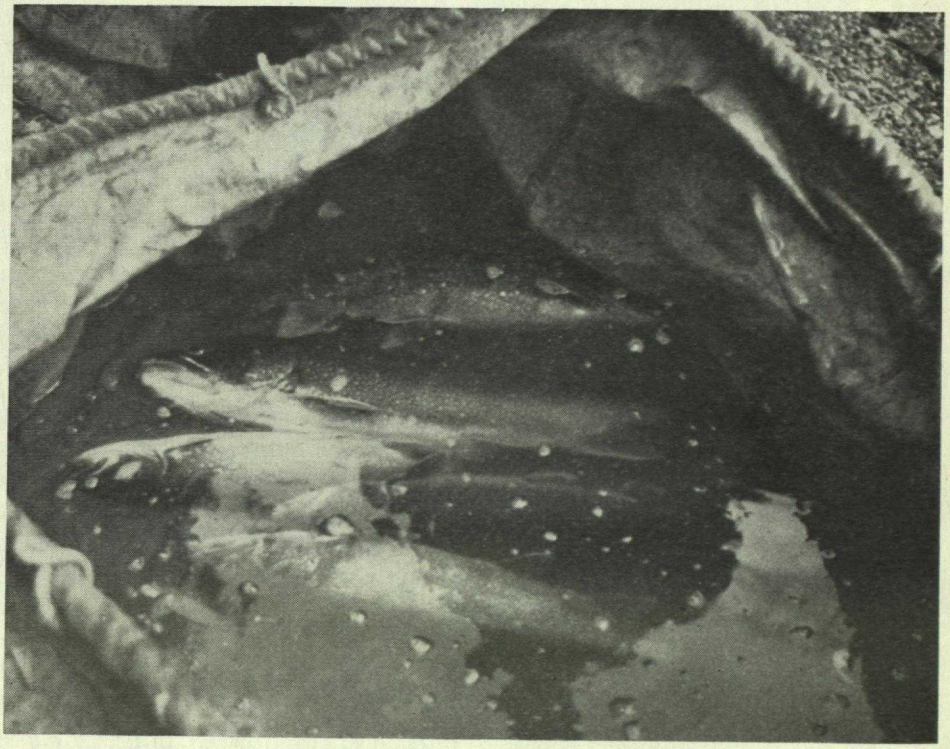
During the summer of 1951 a transfer of a large number of adult lake trout was carried out in Prince Albert Park, Saskatchewan, by the limnology section of the Canadian Wildlife Service. The background and the operation itself are discussed in this paper.

Investigations and reports indicated that an unbalanced population of lake trout, consisting of specimens weighing more than 10 pounds, was present in Crean Lake, Prince Albert National Park. As an attempt to re-establish a proper balance which would improve angling, it was recommended in 1949 that 400-500 adult lake trout each of about five pounds in weight should be released in Crean Lake. In Prince Albert Park, adult lake trout could be obtained only from Kingsmere Lake, or from Wassegam (Clearwater) Lake. There is no road connection with Crean Lake, so it was suggested that the fish be moved by aircraft.

An experiment was devised to investigate the possibility of moving fish anaesthetized and iced, rather than in water-filled tanks. This was based on the knowledge that fish can be kept alive when placed on ice under saturated oxygen conditions, that cold reduces the respiration rate of fish and that anaesthetic drugs reduce the activity and oxygen consumption of these animals. This experiment was carried out at Jasper National Park during the summer of 1950 with the assistance of the hatchery superintendent, Mr. W. C. Cable. Seven eastern brook trout of approximately three pounds each in weight were anaesthetized in a two per cent solution of urethane, placed in a wooden box with chopped ice covering the fish, particularly the head region, and subjected to a 75-minute trip over paved and gravel roads. When they were returned to the hatchery, the fish were placed in a tank with running water.

All seven fish recovered from this trip. It was then decided that the lake trout transfer scheduled for the following autumn could be performed with anaesthetized fish packed in ice in a wooden container, thus permitting the transfer of a maximum number of fish with the appropriation available for this project.

Wassegam Lake was selected for the capture of lake trout. This lake is located near the northeastern corner of Prince Albert National Park; it is practically inaccessible during summer and autumn except by air. According to Mr. Alex Pease, competent park guide who fished this lake commercially in 1928 and 1929 and accompanied



Lake trout under anaesthetic in relay tank.

anglers during recent years, and according to surveys carried out in the autumn of 1950, Wassegam Lake was inhabited by a dense unexploited population of lake trout.

Plans were made during the summer of 1951. Operations began when a party of five, flown to Wassegam Lake, started extensive netting and angling for lake trout on September 17. Gill nets ranging from 1½-inch to 5½-inch stretched mesh were used.

At first the nets were visited, weather permitting, at frequent intervals throughout the entire 24-hour period. It was soon found that the largest catches of lake trout by gill nets were made between 6:00 p.m. and 12:00 p.m. The 1½-inch and two-inch mesh nets were the most successful in catching lake trout in the excellent condition required for survival in reservoirs and retaining pots. Large-mesh nets were abandoned after a few days because of the large number of fish that were being killed or seriously injured.

Nets Set in Shallow Water

The capture of lake trout by setting nets in shallow water, eight to 12 feet deep, was possible because these fish habitually feed in such depths in the latter part of September, when the spawning period is approaching. The lake trout caught ranged from one pound to 40 pounds (the latter being caught in a 1½-inch-mesh net). Most of the fish seemed to be mature. The average weight of the fish released in Crean Lake is estimated at approximately five pounds, the greater number weighing between three pounds and 10 pounds. Chicken-wire enclosures, wooden reservoirs, and retaining

Transferring lake trout from relay tank into boxes for loading on plane.

pots made of coarse twine were used to keep the lake trout alive. Because of wind and wave action, it was found that retaining pots were the most suitable. When the number of fish in captivity approached 500, a radio message requesting the plane for a definite date was sent to the park superintendent at Waskesiu.

A Norseman aircraft was chartered from the Saskatchewan Government Airways for the transfer. The entire operation may be described as follows:

Two canvas-fibre relay tanks were filled to a depth of six inches with an aqueous solution containing about three per cent urethane. The lake trout were then transferred with a dip-net from the retaining pots to a wooden reservoir near the shore. When required, they were caught by hand in the reservoir and placed in a galvanized wash-tub, in which they were carried quickly to a relay tank for anaesthetization.

From 20 to 25 trout were treated in a relay tank at one time. Adequate anaesthetization required four to five minutes. When lake trout were anaesthetized, they were rapidly placed, one by one, in a wooden box and covered, particularly the heads, with layers of chopped ice. The box was then placed on the plane. In the meantime lake trout transferred to the other relay tank had become anaesthetized and were ready for packing and loading. The empty tank was filled with another group of fish after the solution had aerated. When the loading was completed the plane was flown from Wassegam Lake to the south end of Crean Lake, an air distance of about 20 miles. At Crean Lake the plane was unloaded and the boxes were placed in shallow water. As each fish was transferred to a large wooden floating reservoir, the upper tip of the caudal fin was clipped. Some lake trout were also tagged with aluminum tags placed around the maxillary bone. When the fish in the reservoir started to swim, the offshore end of the reservoir was sunk with a few rocks, so that the fish could leave freely. The time for recovery was found to be from 30 minutes to somewhat less than two hours. Most of the fish had escaped from the reservoir within one hour.

In spite of wind and rough water, which were experienced when most of the transfers were being carried out, the average time required for a complete trip was approximately 75 minutes, measured from removal of the fish from the retaining pot at Wassegam Lake to the transfer to the reservoir at Crean Lake.

In seven flights 1,231 adult lake trout were transferred from Wassegam Lake to Crean Lake. Of this number, 1,110 trout recovered and were released. Losses amounted to 10 per cent of the fish moved. Total loss of fish caught in Wassegam Lake amounted to approximately 26 per cent, but this could be reduced, as a result of experience, in any such operation in future.

On October 7 operations were brought to a close and the party and equipment were flown back to Waskesiu.

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The author wishes to thank the Prince Albert National Park superintendent for his interest in the project and his co-operation in planning and preparing the necessary material for the operations. Thanks are also extended to Messrs. H. Harrison, Alex Pease, T. Beale, J. Hiltz, and A. Boudreault, who took part in the operation. Special gratitude is due to Mr. Allen Hartley, pilot for the Saskatchewan Government Airways, for his co-operation in transferring the fish in the shortest time possible under the conditions that prevailed on these occasions.

Numerical Relations Between Abundance of Predators and Survival of Prey

by

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Fisheries Research Board of Canada

There is growing interest in control of predators as a tool in fishery management. Assessments of its usefulness will come only from repeated trials under varied conditions. A relatively small number of situations have already been examined. Some have given negative results; others show much promise. Even though the final answer must come from an actual trial, there are some simple theoretical considerations which will assist in assessing in advance the prospects of success. Used intelligently, they will help in selecting predation situations where control seems likely to be of real value.

Three Types of Predation

It is convenient to distinguish three types of numerical relationship between predators and a species of prey which they attack.

A. Predators of any given abundance take a fixed number of the prey species during the time they are in contact, enough to satiate them. The surplus prey escapes.

B. Predators at any given abundance take a fixed fraction of prey species present, as though there were captures at random encounters.

C. Predators take all the individuals of the prey species that are present, in excess of a certain minimum number. This minimum may be determined in different ways: (1) There may be only a limited number of secure habitable places in the environment, so that some prey are forced to live in exposed situations where capture is inevitable. The number of such secure niches may be partly governed by territorial behaviour of the prey. (2) The maximum "safe" density of prey may be the one at which predators no longer find it sufficiently rewarding to forage for them, and move to other feeding grounds.

The three situations above tend to intergrade, of course, but it is useful to keep their differences in mind.

Situation A

This is likely to occur when a prey species is temporarily massed in unusual numbers, for example, adult herring in spawning schools, or newly-emerged fry of pink and chum salmon going downstream. The main characteristic of such situations is that the number of prey eaten depends on the abundance of predators, but not on the abundance of prey. Hence such situations cannot last long, and the predators cannot make the prey in question their principal yearly food; otherwise they would almost surely increase in abundance and the situation would change to type B or type C. If a type A situation persisted for long, it would come to an abrupt end with the extermination of the prey.

Situation B

Here the number of the prey species eaten is proportional to the abundance of predators and to the abundance of prey. Unlike A, this type of predation can easily

occur over long portions of the year; and the prey species may comprise the larger portion of the predators' annual ration. This situation was observed at Cultus Lake, British Columbia, for predation of squawfish, char, coho and trout upon fingerling sockeye, over a wide range of abundance of the latter (Foerster and Ricker, 1941).

Situation C

The classical example of this situation was described by Errington for bob-white in Iowa, where a given range would winter safely a fixed number of birds, practically independently of the number which were present in autumn, the surplus being taken by predators. Studies conducted from the Atlantic Biological Station of the Fisheries Research Board of Canada, St. Andrews, N.B., suggest that in some rivers predation upon Atlantic salmon parr tends toward type C, because a marked increase in the number of young fish planted was followed by only a relatively small increase in number of surviving smolts (Elson, 1950). In type C situations the predators must tend to have ample alternative foods, and they are often mobile so that they can leave an area where the food supply has been "cleaned up" for the season.

Relation of Abundance of Predators to Mortality Rate and Survival Rate in "Type B" Situations

Consider a prey species which is subject to type B predation over some part of its life history. Assume first that predation causes the whole of the mortality that the prey is subject to during that period. Then the prey species decreases in abundance according to the well-known exponential formula

$$N/N_o = e^{-it}, \qquad (1)$$

where: N_o is initial abundance, N is abundance at time t, $e = 2{\cdot}718\ldots$, and i is a statistic representing the fraction of the prey which would be eaten in a unit of time if its abundance were held constant for that long; i is often called the instantaneous mortality rate.

Under the conditions postulated, instantaneous mortality rate is directly proportional to the abundance of predators. This can be illustrated by considering a situation where predators attack a prey population of 1,000,000 individuals under type B conditions, and they inflict losses corresponding to $i = 0{\cdot}8$, where the unit of time, t, is the whole season that predator and prey are in contact. Equation (1) indicates that in, for example, 1/1000 of the season, the predators will eat $i/1000 = 0.0008$ of the prey present, or 800 fish. During the next thousandth of the season, the predators eat $i/1000$ of the surviving prey, or $999{,}200 \times i/1000 = 799$ fish. The following interval they eat $998{,}401 \times i/1000 = 799$; then $997{,}602 \times i/1000 = 798$. This continues until all the thousand time-intervals have elapsed, at the end of which there are:

$$1{,}000{,}000(1 - 0{\cdot}0008)^{1000} = 472{,}400$$

survivors, or 47·2 per cent. What happens if the number of predators is doubled? In that event, during the first thousandth of the season twice as many fish will be eaten, i.e. 1,600, leaving 998,400. In the next thousandth the fraction eaten is likewise double, namely 0·0016; multiplied by the number of survivors this gives 1,597; and so on. At the end of the season $1{,}000{,}000(1 - 0{\cdot}0016)^{1000}$ survive, which is 201,900, or 20·2 per cent.

Thus doubling the number of predators doubles the instantaneous mortality rate (which is true generally), but it increases actual mortality by only $27 \cdot 0/52 \cdot 8 = 51$ per cent (which is true of only this particular example).

The general relation between predator abundance and actual mortality, or survival, is most conveniently expressed as:

$$\frac{p_2}{p_1} = \frac{\log s_2}{\log s_1}, \qquad (2)$$

where p_2 and p_1 represent two levels of predator abundance, and s_2 and s_1 are the corresponding survival rates for the prey. This expression can easily be derived from (1), since p is proportional to i, and $s = N/N_o$ when $t = 1$.

Formula (2) indicates that survival does not change in a simple inverse relation to number of predators. For example, in a situation where predators have been reduced to half ($p_2/p_1 = 1/2$), some typical values are shown below:

Original survival rate (s_1, as %)	Ratio of new to old survival rate (s_2/s_1)
0·01	100·
0·1	31·5
1	10·0
5	4·46
10	3·15
25	2·00
50	1·41
90	1·05
100	1·00

Schedules like this make it possible to estimate the beneficial effect of any given degree of predator reduction for type B situations. The principal lesson they teach is that predator control is more likely to be economically successful when survival rate is small to begin with (over the span of the prey's life history on which the predators in question operate). An easy assumption might have been that, by halving a predator population, we should double the survival of the prey. As matters actually stand, this much benefit will be gained only if mortality from predation is at least 75 per cent in the beginning ($s_1 = 25$ per cent). However if the initial mortality rate is greater than 75 per cent, then reducing the predators by half will more than double the number of survivors.

As a matter of fact, when mortality is initially great and survival small, quite startling improvements in survival can be achieved by means of very moderate reductions in predator population. Again using formula (2), we obtain the schedule below:

Original survival rate	Reduction in predators necessary to double survival rate
0·01%	7·5%
0·1	10·0
1	15·0
5	23·2
10	30·1
25	50·0
50	100

Presented in this manner, it is encouraging to discover that when survival is in the "medium" range from 1 to 10 per cent, it requires a reduction of predators by only one-third or less in order to achieve important benefits. This, in fact, is the range involved in Canadian attempts at increasing salmon production by predator control. In the sockeye salmon experiment mentioned earlier, the investigators were at first surprised at the magnitude of the improvement effected by quite a moderate decrease in predator abundance. However, this can have a discouraging as well as an encouraging aspect. For if a small decrease in predators results in important gains, then, equally, those gains can be wiped out by a subsequent small increase in predators, which might come from improved survival conditions for the young of the predators themselves.

Another general principle illustrated by the schedule above is that great fecundity is apt to be accompanied by a natural instability in population size, and particularly by marked variation in year-class strength. For example fish like the cod, which produce pelagic eggs to the number of 1,000,000 or so per female, may easily suffer average predation losses of the order of 99·9 per cent during their development and larval life. At that level, a 10 per cent decrease in abundance of predators causes a 100 per cent increase in strength of the year-class at the end of larval life.

The relationships above apply of course only when the whole of the prey's mortality is caused by predation. To the extent that other causes enter the picture, any given reduction in number of predators has less effect in increasing survival.

Control of Predators in Situations of Types "A" and "C"

The considerations developed above for type B situations apply equally to type A. There is an apparent difference arising from the fact that whereas, with type B, survival rate (s) is invariable from year to year for any given abundance of predators, in type A survival rate varies with abundance of prey. However, this does not change the nature of the effect which any given reduction of predators will have upon survival. Equation (2) will apply, whatever numerical value of s would be anticipated at the level of prey abundance existing in any particular year.

In type C situations, obviously the mathematical relations above do not apply at all, as long as they remain type C. The definition of C implies that changes in abundance of predators have no effect upon survival of prey; and for predator control to become effective it must first reduce the predators to the point where predation begins to change toward type B. This may be entirely feasible. In Elson's Pollett River experiment, removal of mergansers and kingfishers by shooting was sufficiently thorough to increase the survival from a heavy planting of young salmon four- or five-fold. This must mean that the predation situation had been changed; from one close to type C, it became type B or even type A, for whatever few birds managed to hang on or occasionally wandered into the area.

If we look at predation from the point of view of the predator rather than the prey, a broad distinction can be drawn between the warm-blooded and the cold-blooded carnivores. The former have a fairly constant food requirement, and hence are more likely to become involved in predation situations of types A or C. The great mobility of birds, and to a less extent of mammals, enables them to move quickly to localities where food is temporarily abundant (type A situations). At the same time they require a steady food intake to maintain body temperature and will quickly

leave an area where food abundance is depressed so far that foraging does not provide their minimum needs (thus creating type C situations). Predaceous fishes, by contrast, have a much lower minimum ration per unit body-weight, and much greater flexibility in the amount of food they can consume and still live normal lives. Many of them must set up type B situations, in which they can take whatever food they encounter as often as they encounter it, and rarely find prey so abundant that any must be refused.

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Two Poisoning Projects in Manitoba

by

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In the streams and lakes of southern Manitoba, speckled or eastern brook trout, rainbow trout, or brown trout are not present in the wild or natural state, although two creeks flowing into George Lake in the Whiteshell Provincial Park now have eastern brook trout established through the planting of fish hatchery stock.

In Northern Manitoba eastern brook trout is native to many streams, including the Nelson, Weir and Limestone Rivers, Ten Shilling Creek, God's River, Island Lake River and perhaps at other places at present not well known. In south-eastern Manitoba there are waters which appear to be well suited for eastern brook trout habitat, and it would be most desirous to extend the range of this and other species of trout, by seeding with fish hatchery stock. However, repeated stocking with trout fingerlings from the Whiteshell Trout Hatchery, in lakes with natural fish populations, has produced to date only three known successful introductions. Contrasting this, in a small pond made by the building of a grade across a gully near the Whiteshell Trout Hatchery, speckled and rainbow trout have established themselves; have, according to observations of the fish hatchery staff, successfully reproduced, and have made excellent growth. The initial plantings in this case were from fry or fingerlings which appeared to be weakly when in the hatchery troughs.

Analyses of the stomachs of small northern pike taken in the creek near the hatchery have shown this species to be very partial to trout fingerlings. In almost every pike stomach examined, trout fingerlings, either speckled, rainbow or brown, or the remains thereof were found. This would indicate that certain lakes and streams might permit trout to grow to maturity but for the predator population of piscivorous fishes.

Telford Pond

With this knowledge as a base, a lake in a disused gravel pit situated near Telford, 91 miles east of Winnipeg, was chosen for an experiment with the use of derris root powder to eliminate the fish population with a view to planting trout when the poison subsided. The lake at the gravel pit has a surface area of approximately 5·5 acres and a maximum depth of 19 feet. It is spring-fed, or at least there is an underground seepage, and one outflowing creek, connected to the Whiteshell River system, flows both winter and summer. On June 11, 1947, 141 pounds of derris root powder was applied to the lake in paste form over the whole of the surface. Distribution was made with the use of a fire fighting pump and hose mounted on a barge which was towed from end to end of the lake. The pump was operated continuously and with the circulation of water and pressure of water from the nozzle of the hose, a good distribution of derris was made. The kill appeared to be complete and after the poison subsided, 5,400 brown trout fingerlings were planted in the lake on October 23, 1947. Tests with a seine net on August 10, 1948 showed that brown trout survived, and five specimens from 4 to $4\frac{1}{2}$ inches in length were captured in two drags of the net. A more recent test, August 31, to September 3, 1951, resulted in the capture of eight brown trout including a female with fully developed ovaries.

Camp Lake

A second and somewhat more extensive experiment was conducted on August 8 and 9, 1950, at Camp Lake situated in the Whiteshell Provincial Park, in Sections 22 and 25, Township 9, Range 17 E.P.M. A map of Camp Lake showing depths of water is attached.

There are no roads which would permit driving to Camp Lake. It is approximately one-quarter of a mile north of Falcon Lake at the point where the portage road connects the two bodies of water. The portage rises steeply from Falcon Lake for the first 100 yards or so after which the upward slope is gentle to Camp Lake.

The area of Camp Lake is approximately 70 acres, its greatest depth, 46 feet and the greater part of the lake is between 32 to 40 feet in depth. The water is clear, the shores mostly precipitous granite rock with coniferous and deciduous trees growing to the water's edge. Water temperatures on August 10, 1950, were as follows: Surface 73·5° F., at depth of 35 feet; 50·0° F. in muck bottom—36 feet deep 43·0° F.

The quantity of powdered derris root required for Camp Lake was based on a formula prepared for Telford Pond by Dr. K. H. Doan. For Camp Lake the figures are as follows: Area, approximately 70 acres or 3,049,200 sq. ft.; volume (based on soundings), approximately 109,771,200 cu. ft.; weight of water, approximately 6,851,700,000 pounds; rotenone content of available powdered derris root quoted at 4·4%; concentration of available derris root powder required, based on 5 per cent rotenone content using 0·5 parts per million parts of water, 0·5684 parts per million; weight of powdered derris root required, 4,280 pounds.

When the order of 4,200 pounds of powdered derris root was received, it was described as Cube Powder with the following formula:

Active ingredients, including rotenone	5·73%
Other extractives	14·17%
Inert ingredients	80·10%

Thus the intended concentration of 0·5 parts per million of powdered derris root with a five per cent rotenone content may have been slightly increased.

All equipment for the work had to be portaged over from Falcon Lake. This included the carrying on the backs of eight or more willing workers of five canoes, 800 feet of lumber, two 3 h.p. gasoline engines, three 5 h.p. outboard motors, two $1\frac{1}{2}''$ centrifugal pumps, one large tent, 100 feet of hose, one cement mixer, 4,200 pounds of derris root in 75 pound sacks, eight 40-gallon barrels, 20 gallons of gasoline and many other smaller items. Portaging was completed and all material and tools were at Camp Lake before the operation started. The day before the application was made, August 7, two rafts were built having two canoes for each raft, binding them together with 2 by 6-inch planks, 14 feet long, and then building a 16-foot top on each pair of canoes, using 1 by 8-inch lumber.

Building raft on two canoes at Camp Lake.

When the flat-top rafts were completed, a 3 h.p. engine and a centrifugal pump were set up on each, together with the necessary hose connections. The plan was to have on each raft two 40-gallon barrels of derris root powder in paste form, and a second barrel to which the intake of the pump was connected. Into this barrel, water and derris root paste were bailed in equal proportions to permit the solution to pass freely through the pump.

On the day of application, eight men participated in the work, six on rafts and two ashore. On each raft one man operated the outboard motor to propel the raft, one operated the nozzle end of the hose, spraying and spreading derris root solution as the raft slowly moved over the surface of the lake. One bailed water and derris root paste into the 40-gallon barrel connected to the pump, filling the barrel as fast as the pump lowered the derris liquid. When the two barrels of derris root paste were emptied, the rafts returned to shore base where a fresh supply of paste was ready to be loaded on to the raft.

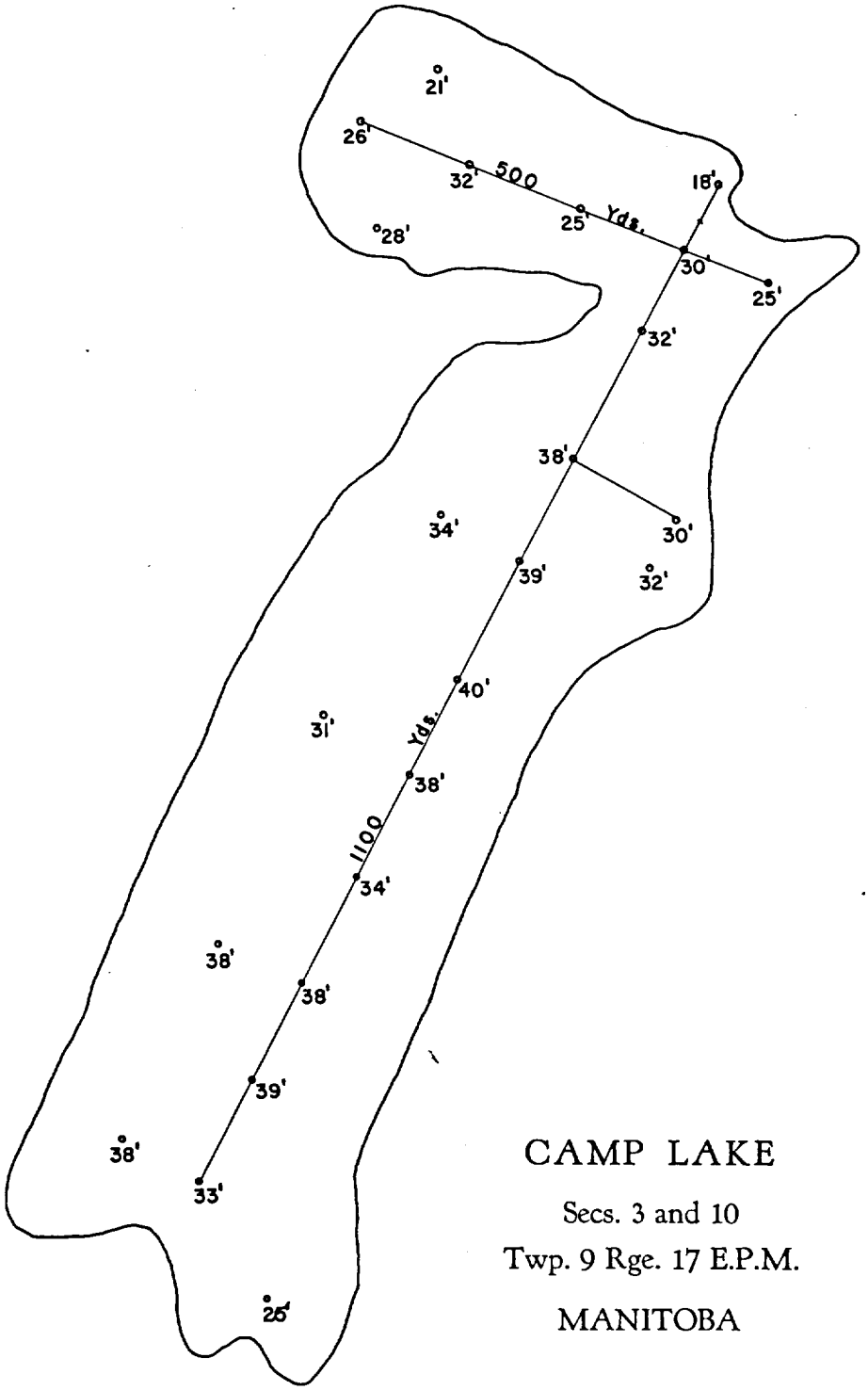
Immediately after the surface of the lake had been covered with derris solution, application at depth was made by trailing 50 feet of one-inch hose to which was attached a 20-foot length of $\frac{3}{4}$-inch iron pipe with $\frac{1}{4}$-inch holes bored through it at intervals of one foot. By trailing the iron pipe from the moving raft with the pump operating, a fairly effective application of derris root was made in the deeper parts of the lake. The application was completed in two half days.

Very shortly after the first spraying of derris solution, fish began to rise to the surface and drift ashore. They were mostly yellow perch, rock bass, pearl dace, spot-tail minnows and white suckers. Apparently no pike were present in the lake. When the application was made to the deeper waters, tullibee in dead or dying condition came to the surface in fairly large numbers.

Deep water poisoning outfit.

One week after the poisoning of the lake, two gill-nets were set without result. Later, on August 29, a gill-net, 35 feet deep, 112 yards long, was set from surface to bottom and in it overnight two white suckers were taken. From these tests it would appear that the kill has been fairly complete, although there were a few white suckers left in the lake.

Tests were next made with trout fingerlings enclosed in wire screen cages, to determine the toxic condition of the water. On September 22, nine rainbow trout fingerlings were submerged to a depth of 10 feet in Camp Lake. On September 25 the cage was lifted and five trout were living.



CAMP LAKE

Secs. 3 and 10

Twp. 9 Rge. 17 E.P.M.

MANITOBA

Surveys Br., Dept. M. & N. R., Winnipeg, July, 1951

63736—3

On October 18, 1950, sufficient time had elapsed for the toxic properties of the derris root application to be completely dissipated and 40,000 rainbow trout fingerlings were planted in Camp Lake.

The next test was made on February 20, 1951, when 100 yards of $4\frac{1}{4}$-inch mesh gill-net and 100 yards of $3\frac{1}{2}$-inch mesh gill-net were set under the ice and left for 48 hours. When these two nets were lifted, the total catch of fish was five white suckers, two being taken in the $4\frac{1}{4}$-inch mesh and three in the $3\frac{1}{2}$-inch mesh. On July 1st, 1951, two gill-nets, each 100 yards long and $2\frac{7}{8}$-inch mesh size were set in Camp Lake. After an overnight setting the nets were lifted. One net caught three rainbow trout and two white suckers, the other net one rainbow trout. The age of the four rainbow trout was 14 months, and the rate of growth was most satisfactory. Figures showing length and weight are as follows.

Specimen No. 1	Length 10″	Weight 290 grams (10·2 ozs.)
Specimen No. 2	Length $9\frac{7}{8}$″	Weight 240 grams (8·4 ozs.)
Specimen No. 3	Length $10\frac{3}{8}$″	Weight 300 grams (10·5 ozs.)
Specimen No. 4	Length 9″	Weight 204 grams (7·2 ozs.)

During the summer and fall of 1952, from May to October, numbers of anglers visited Camp Lake and enjoyed the catching of rainbow trout in southern Manitoba. In late summer specimens measuring 18 inches in length were taken which weighed from $1\frac{3}{4}$ pounds to two pounds.

Conclusion

The cost factor for the Camp Lake poisoning project worked out at 71·1 cents per acre foot according to the following figures:

No. of acre feet—2,660	
Cost of 4,200 pounds derris powder	$1,646.92
24 man days labour	192.00
Cost of 8 barrels	24.00
20 gallons of gasoline	8.40
Hauling and trucking	20.00
Total	$1,891.32

Cost per acre foot—71·1 cents

Where it is desirable, where the cost factor will permit and the environment is suitable for trout, the removal of all other fishes in a small lake by poisoning and restocking with trout of suitable species is a procedure warranted in fish cultural practices in Manitoba, and derris root powder and other forms of rotenone are, therefore, most valuable fish cultural tools.

Additional Information on Eastern Brook Trout x Lake Trout Hybrids

by

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The successful hybridization of eastern brook trout (*Salvelinus fontinalis*) and lake trout (*Cristivomer namaycush*) has already been reported by the author (Stenton 1950). It is now desirable to present an account of further hybridization between these species and the available data on morphological characteristics of the hybrids.

The original cross male eastern brook trout and female lake trout was repeated during the autumn of 1948, and, in addition, the reciprocal cross was made. The percentage of fertilization and hatch in the first cross was as high as that of a true species, with no deformed fish appearing. The reciprocal cross also showed a large percentage of fertilization and hatch, but a large number of deformed fish were observed.

During the autumn of 1950 the original cross, male brook trout and female lake trout, was again carried out to obtain fry to plant in a virgin lake. Again the efficiency of reproduction was similar to that of the true species.

Early in November 1950, the hybrids of 1947, then in their third year and being held at the Banff hatchery, showed signs of having reached maturity and were observed to be digging redds in preparation for spawning. On November 8, an attempt was made to strip some of these fish and some eggs and milt were obtained. A further attempt was carried out on November 14, and more eggs and milt were secured.

Fifteen Mature Hybrids Fertile

Fifteen mature hybrids, out of 25 held at the Banff hatchery, were stripped and all appeared to be fertile. The remaining ten fish were not checked, but there is no reason to think that they were not fertile. Among the specimens used, 60 per cent were males and 40 per cent females.

It has been shown by earlier workers, Roosevelt (1880) and Green (1881), that a cross between the Pacific salmon, species not known, and the eastern brook trout produced good specimens but on examination all were found to be females. These two investigators, working independently and each unaware of the other's work, obtained strikingly similar results.

The fact that the hybrids held at the Banff hatchery have proven fertile is very encouraging, since most early workers who produced hybrids found them to be usually sterile (Foerster, 1935; Day, 1884, 1885 and 1886). As previously stated, the cross between male brook trout and female lake trout was repeated in the autumn of 1950, and eggs were secured from the hybrid fish. Data on eyeing and hatching of these eggs were collected. They are presented in Tables I and II. Temperature units, shown in these tables, are calculated on the average temperature and based on the formula of one temperature unit per day for each degree of temperature above 32°F. This system was formerly widely used by fish culturists, but Embody (1934) has

shown it to be somewhat misleading and it is not now in general use. However, for the convenience of those still using this formula, the figures are included.

Data collected on losses incurred during incubation period and during the first free swimming stage are presented in Table III. The total loss among eggs and alevins is much higher among the hybrids F_2 than among hybrids F_1. About 30 per cent of the loss among hybrids F_2 is due to deformity in the development of the notochord.

Table I

Time and temperature data from fertilization to eyed stage of eastern brook trout x lake trout eggs, first generation (F_1) and of the hybrid eggs, generation (F_2)

Date of fertilization 1950	Generation	Appearance of first eye spots		Temp. to eyed stage	
		Date 1950	Number of days from fertilization	Average (°F.)	Number of units
Oct. 23	F_1	Nov. 27	36	41·6	345·6
Nov. 8	F_2	Dec. 16	38	41·6	364·8
Nov. 14	F_2	Dec. 22	38	41·6	364·8

It is to be noted that the natural hybridization of the two species is improbable, even if their spawning periods overlap, because of the great difference in their spawning habits.

It appears that the spawning of the hybrids follows the reproductive trend of the male parent (brook trout) in that they spawned in their third year of life, which appears normal for brook trout in this locality. On the other hand the lake trout (female parent) in this locality seldom reaches maturity under ten years of age. The ova, although not measured, were obviously of similar size to those of brook trout and were very much smaller than those of lake trout. The hybrids were observed to be digging redds, a characteristic of the brook trout not generally apparent in lake trout. The fact that these hybrids were confined to shallow hatchery ponds prevents any statement as to whether they would have migrated into spring surges or flows as do the brook trout or whether they would have spawned in deep still water as do the lake trout.

It is unfortunate that the progeny of the reciprocal cross, female brook trout x male lake trout, were disposed of since it would have been of great value to be able to determine if the genes of the male parent were dominant in this cross. Both Roosevelt (1880) and Green (1881) found, when the male parent was the larger species, that the ova of the hybrid females were too large to be normally extruded and that the vent had to be cut before they could be taken artificially. It would have been interesting to determine whether they would have proved to be sterile, or, if not, at what age they reached maturity. Green (1881) reported on such a cross but listed the male parent as a Lake Ontario salmon trout which leaves some doubt as to its true genus. He stated that these hybrids successfully spawned in their third year; however, Bean (1889) has cast some doubt on Green's work, which leaves this statement still unconfirmed.

Table II

Time and temperature data from fertilization to eyed stage of eastern brook trout x lake trout eggs, first generation (F_1) and of the hybrid eggs, second generation (F_2)

Date of fertilization 1950	Generation	Beginning of hatch		Temperature to beginning of hatch		Completion of hatch		Temperature to completion of hatch		Duration of hatching
		Date 1951	Number of days from fertilization	Average	Number of units	Date 1951	Number of days from fertilization	Average	Number of units	Period (No. of days)
Oct. 23	F_1	Jan. 2	71	41·3	660·3	Jan. 12	82	41·8	803·6	11
Nov. 8	F_2	Jan. 18	71	41·1	646·1	Jan. 28	83	41·4	780·2	11
Nov. 14	F_2	Jan. 25	71	41·6	681·2	Feb. 8	87	41·4	817·8	14

Table III

Losses during incubation and alevin stages of first (F_1) and second (F_2) generation hybrids (eastern brook trout x lake trout)

Date of fertilization 1950	Generation	Number of parents		Eggs obtained	Losses of eggs and fry			Number of fingerlings surviving
		Males	Females		During incubation	In alevin stage	Total	
Oct. 23	F_1	6 (a)	2 (b)	5,700	227 (4%)	1,198	1,425	4,275
Nov. 8	F_2	3 (c)	2 (c)	1,500	1,840 (27%)	1,480 (22%)	3,320 (49%)	3,410
Nov. 14	F_2	6 (c)	4 (c)	5,230				

(a) = eastern brook trout; (b) = lake trout; (c) = hybrids.

Note = "Alevin stage" here denotes the period from hatching until absorption of the yolk sac and commencement of free swimming.

Preparing to Spawn Again

In early November of 1951, the adult hybrids at the Banff hatchery were preparing to spawn again. Thus they follow the tendency of the male parent (brook trout) in that they apparently spawn every year, unlike lake trout, which in some northern lakes appear to spawn only every second or third year (Miller 1947).

The general colour of the first-generation hybrids between brook trout and lake trout, when three years old, may be described as follows: the back is dark olive-green with numerous pale vermiculations; the sides are bluish-silver and the belly white. There are numerous lemon-yellow and pale pink spots along the sides above and below the lateral line. The leading edges of the paired fins and of the anal fin are white, and the remainder of these fins are pale orange in colour, with the pectoral fins being dusky towards the forward edge. The dorsal fin is dark and heavily spotted. The tail is truncate as in the brook trout, but the body is elongated as in the lake trout. From the foregoing it becomes apparent that both parent species have left undeniable marks on the coloration and form of their progeny. The red spots and blue halos common to the brook trout are absent. Figure 1 illustrates the pattern of the vermiculations and the side spots.

Taxonomic measurements given in Table IV, made on four specimens of each of the parent species and four specimens of their F_1 hybrid progeny, show that the hybrids have a slight leaning towards characteristics of the lake trout female parent. Ten out of twenty-three of the measurements and counts favour the lake trout while six favour the brook trout side; the balance, nine, appear as intermediate between the parent species.

The vomerine teeth have the same location in all specimens examined, i.e. on the head of the vomer bone only.

The maxillary length, as shown in this table, is used instead of the upper jaw length as recommended by Hubbs and Lagler (1947), as the measurements shown refer only to the maxillary and not the total length.

Table IV

Counts and proportional body measurements of lake trout, eastern brook trout and hybrids

$$\text{Body parts} = \frac{\text{Body measurements}}{\text{Fork length}} \times 1000$$

	Species		
	Lake Trout (1)	Eastern Brook Trout (2)	Hybrid (3)
Fork Length (mm.)	346·25	326·0	345·5
Weight—ounces	14·25	12·75	14·0
Proportional Measurements			
Caudal Peduncle Length	6·4	6·3	6·1
Caudal Peduncle Depth	14·1	11·3	14·0
Body Depth	5·0	4·5	5·3
Head Length	4·1	4·6	4·3
Snout Length	14·6	14·2	15·7
Orbit Length	19·0	23·7	23·0
Eye Length	24·3	27·7	26·6
Maxillary Length	10·0	9·3	9·3
Maxillary Extends Beyond Eye	173·1	40·8	34·6
Length of Dorsal Fin Base	9·9	8·4	9·5
Length of Longest Dorsal Fin Ray	7·5	8·5	8·0
Length of Anal Fin Base	11·8	9·6	11·8
Length of Longest Anal Ray	11·3	11·9	12·1
Length of Longest Pelvic Fin Ray	8·9	9·4	8·6
Length of Longest Pectoral Fin Ray	6·0	7·1	6·4
Predorsal Length	2·2	2·4	2·2
Width of Tail Spread	3·6	3·8	5·8
Counts			
Number of Dorsal Fin Rays	11·0	10·0	11·0
Number of Anal Rays	11·0	9·0	10·0
Number of Gill Rackers	17·3	14·0	14·0
Number of Branchiostegal Rays	14·0	10·0	11·0
Number of Pyloric Caeca	105·5	31·8	76·0
Number of Lateral Line Scales	194·5	227·8	210·8

(1) 4 specimens = 2 males and 2 females; age: 3 and 4 years old.
(2) 4 specimens = 2 males and 2 females; age: 2 years old.
(3) 4 specimens = 3 males and 1 female; age: 3 years old.

The alevin stage of the brook trout-lake trout hybrids was completed on February 7, 27 days after hatching. Feeding of this group began on February 8. On February 28, after 21 days of feeding, this group showed an average length of 31 mm. and were feeding vigorously.

The alevin stage of the hybrid progeny was completed on February 26, 18 days after hatching. This group began to feed on February 27. On March 19, after 21 days of feeding, this group showed an average length of 22 mm. The alevins of the second generation hybrids appeared weak and puny in comparison with the first generation hybrids; close inspection however, showed them to be about the same size as the alevins and fingerlings of true brook trout.

The last measurements taken, on May 8, 1951, showed that the first generation progeny of brook trout and lake trout parents, averaged 38 mm. in length, and the second generation progeny of hybrid parents, averaged 28 mm. in length. Both groups were feeding well at this time.

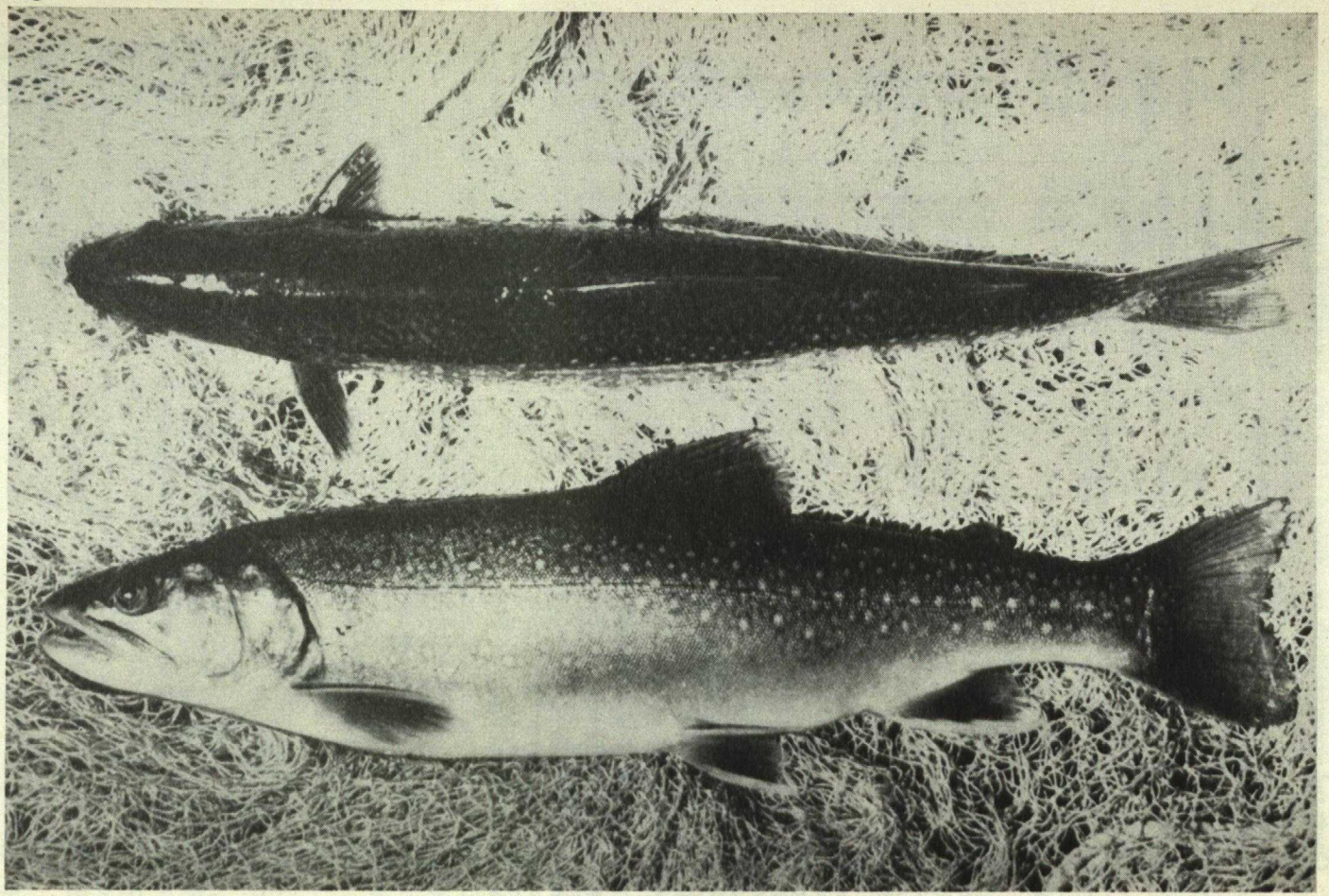

Figure 1. Lake trout-eastern brook trout hybrids. Fish Hatchery, Banff National Park, July 22, 1950.
Top: male immature; 13 inches, fork length; weight, 15 ounces. Bottom: male mature; 13·5 inches, fork length; weight, 15·5 ounces.
(Photo. by J.-P. Cuerrier)

Acknowledgments

My sincere thanks to the following persons: Mr. A. C. Colbeck, Superintendent, Banff Hatchery, and his staff who made the hatchery data available; Dr. R. E. Foerster, Pacific Biological Station, Nanaimo, B.C., who lent old literature pertaining to hybrid trout; Dr. D. S. Rawson, University of Saskatchewan, Saskatoon, Saskatchewan, for the loan of literature, for age determinations of lake trout, brook trout and hybrid and for helpful criticism and suggestions; Jean-Paul Cuerrier, Canadian Wildlife Service, Ottawa, for reading and criticising the manuscript.

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Moricetown Falls Biological Survey—1951

by

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Moricetown Falls, B.C., long regarded as an obstruction in the path of the salmon and steelhead runs, attracted the attention of the local Fisheries Inspector as early as 1928. The inspector who visited the falls in early autumn noticed that the water levels were low enough to hinder the upstream migration of salmon over the middle of the falls and that only a small number were able to ascend the side channels without being captured by the Indian fishery. The inspector further noted "There are, however, quite a number of sockeye above the falls and I do not wish you to think that the grounds will not be seeded on account of the falls at Moricetown, but I do believe a good deal of improvement could be made there, and in a case such as at present, where the water level is very low, possibly a number of sockeye that come late would more easily reach the spawning grounds."

As a result of this report a portion of the falls was blasted out in an effort to ease the situation. However, the efficiency of this remedial measure was never fully ascertained.

No further investigations were conducted at Moricetown Falls until the Fisheries Research Board of Canada set out to study the falls as part of the Skeena River Salmon Investigation. For three years, from 1945 to 1947, water levels were recorded, the Indian fishery observed, tagging experiments conducted and the behaviour of each species at the falls noted.

From the investigation it was shown by Milne* that the falls delayed the migration of all four species of Pacific salmon indigenous to the Bulkley River system, the degree of blockage varying with each species and increasing in severity with the advent of low flow conditions. Of the three years studied, water conditions in 1945 were the most adverse, particularly after August 20, and it was found that the sockeye salmon were delayed an average of 6·7 days and the coho salmon an average of 27·4 days. The spring salmon, which arrive at the falls early in the season, encounter little difficulty in ascending the crest of the falls but the pink salmon, later arrivals, are faced with the most adverse flow conditions and it was observed that only a few of the earliest arrivals succeeded in surmounting the obstacle.

The report concluded by recommending the provision of suitable fishways to facilitate the passage of salmon during the low water periods.

Plans Made for Two Fishways

This report was studied by engineers of the Department of Fisheries of Canada, following which plans were drawn up for the construction of two fishways that would (1) pass fish successfully at all levels at or below the critical low water periods, (2) be

*Milne, D. J. "Moricetown Falls as a Hazard to Salmon Migration." Bull. Fish. Res. Bd. of Can. 86: 1-16, 1950.

sufficiently large to accommodate the peaks of the runs and (3) be of a type that would not require the fish to jump.

Another factor which had to be considered was the possibility that future power developments would affect the headwaters of the Morice River to such a degree that the flow of water in the river would be reduced considerably. This reduction in flow would in turn lengthen the critical low water conditions at Moricetown Falls and further delay the upstream migration of the salmon for an average of ten days each year. This factor helped influence the decision to construct the fishways and so assist the salmon over the falls.

By October 1950 construction crews had assembled their equipment at Moricetown and commenced the building of the fishways. This work continued throughout the winter and was completed a few days before the spring freshets covered the fishways with the heavy spring run-off.

With the 1951 runs of salmon being able to take advantage of the fishway facilities it was decided to test their efficacy by duplicating as closely as possible the tagging experiments conducted by the Fisheries Research Board during the years 1945-47. In addition it was anticipated that during the period of low flow in August and September water conditions would permit the actual observation of salmon ascending the fishways. With this view in mind a survey crew was established at Moricetown Falls early in July, 1951.

Methods

The salmon were obtained for tagging by means of dip nets operated at the various locations shown in Figure 1. Dropping water levels throughout the tagging period necessitated the occasional relocation of the netting sites.

Petersen type tags were attached below the dorsal fin by means of a non-corrosive nickel pin. In addition to the tag number and date of capture, the length (fork), sex and condition of the salmon were recorded and a scale sample taken.

Water levels were recorded daily by means of a graduated line lowered from the traffic bridge to the surface of the water.

A maximum-minimum thermometer was installed below the falls from which daily readings were taken.

During the early part of the sockeye run a number of salmon were tagged and released above the falls for the purpose of estimating the population of this species that spawn in the upper reaches of the Nanika River tributary to Morice Lake. The silty nature of this river and the lack of a suitable trapping site had effectively prevented a tagging programme for such a study during the preceding two years. It had been decided therefore to combine the testing of the fishways with an analysis of the Nanika population, the tags to be retrieved on the spawning grounds during the spawning period September-October.

In conjunction with the tagging programme white flash or counting-boards were installed at the exits of both fishways as an aid in observing those salmon that had ascended. Frequent spot counts were made at these two stations and on August 17-18 a complete count of all salmon passing through the left-bank fishway during a 24-consecutive-hour period was carried out.

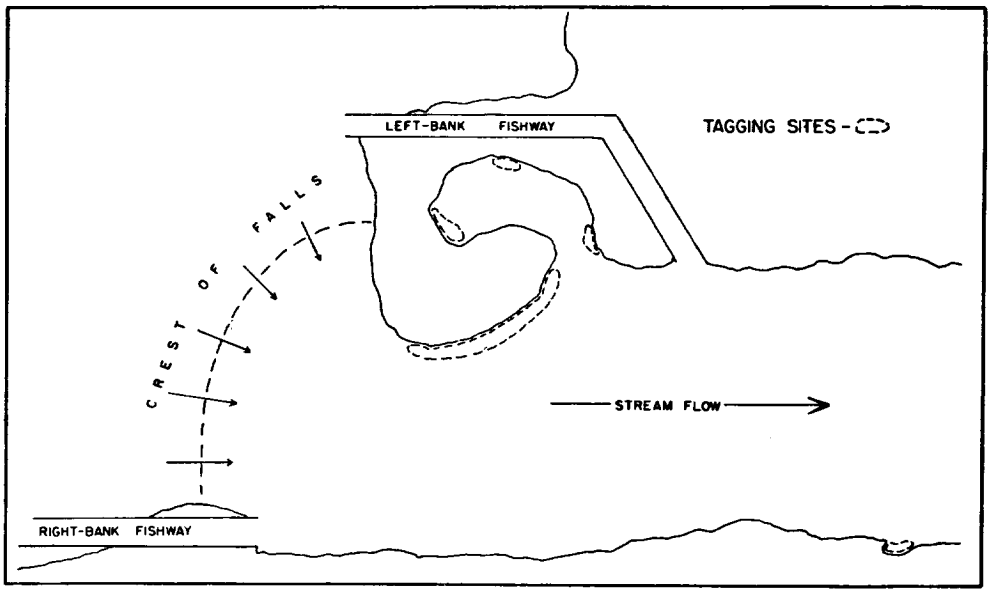


Figure 1. Salmon-tagging sites at Moricetown Falls

Since the return of tags from below the falls indicates only the relative periods of delay a trap was installed at the left-bank fishway exit for the purpose of trapping the tagged salmon and thereby ascertaining the absolute period between tagging and ascent of the fishway. Unfortunately this device proved unsuccessful due to the fact that the salmon would not pass through but rather tended to accumulate below it and finally returned back down the fishway. A total of nine tagged coho, however, were recovered by this method before the trap was removed.

To eliminate selective gaffing for tags by the Indians no reward was paid for their return. The Indian fishery was kept under close observation, however, and all tagged fish gaffed were examined and the numbered tag retrieved. The Indians proved very co-operative in this respect and it was felt that all tagged fish caught by them were examined.

Results

From July 17 to August 31 a total of 1,685 salmon were tagged and released at Moricetown Falls. Of these, 763 were released above and 922 below the falls. The number of each species of salmon tagged, the location of release and area of recapture is presented in Table I.

Of the 474 sockeye released below the falls 35 or 7·6 per cent were recovered at the falls either by the Indians or the tagging crew. Of the 761 sockeye released above the falls 12 were recovered at the falls, indicating that a certain number of these sockeye released above dropped back below the falls again.

There were 11 sockeye tags recovered at points other than at Moricetown Falls or the Nanika spawning grounds. Five were from the vicinity of Hazelton (30 miles below Moricetown), on the Bulkley River; one from the main Skeena River; one from

Table 1

Number of Salmon Tagged at Moricetown Falls, 1951, where released and recovered

Species	Number Tagged	Released		Recovered					Total Recovered
		Above Falls	Below Falls	At Falls		Below Falls[1]	Above Falls	Spawning Grounds	
				By Indians	By Taggers				
Sockeye	1,235	761	474	35	12	7	4	190	248 (20·1%)
Coho	441	2	439	6	5	1	9[2]	0	21 (4·76%)
Pink	9	0	9	0	0	0	0	0	0
Totals	1,685	763	922	41	17	8	13	190	269 (15·9%)

[1] *Below falls refers to recoveries from areas below Moricetown village.*
[2] *These nine Coho were captured in a trap at the left bank fishway exit.*

Table II

Sockeye Tagging Returns at Moricetown Falls, 1951

Date	Number Tagged	Number Recovered	Number of days out														
			0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
July 15	10	0															
16	11	3		1	2												
17	44	0															
18	45	5				5											
19	11	0															
20	21	1		1													
21	20	1							1								
22	53	3				1		1		1							
23	71	2		1			1										
24	47	0															
25	110	0															
26	142	1				1											
27	165	2			1				1								
28	123	13		2	2	6	1		1			1					
29	114	11	3	1	4	1		1			1						
30	45	1										1					
31	33	0															
Aug. 1	7	0															
2	17	0															
3	41	0															
4	31	0															
7	5	1															1
11	4	0															
13	3	0															
14	17	2				1				1							
15	15	0															
17	18	1			1												
18	1	0															
19	1	0															
20	1	0															
21	7	0															
26	1	0															
Totals	1,235	47	3	6	9	16	2	2	3	2	1	2	0	0	0	0	1

a pool below Moricetown Canyon; one in Kathlyn Creek (15 miles above Moricetown); one in the Telkwa area (40 miles above the falls); two in the Morice River near Owen Creek (70 miles above Moricetown).

With reference to the sockeye tags recovered at the falls, Table II shows the number of sockeye tagged daily, the number recovered and the number of days between tagging and recovery for each tag. These data are also illustrated graphically in Figure 2.

A comparison between the days out for sockeye during the period 1945 through 1947, before installation of the fishways, and 1951, when the salmon could make use of the fishway facilities, is shown in Table IV. Included also in this table are data relating to the duration of the run plus the date of critical low water levels during the four years.

The 24-hour count of all fish ascending the left bank fishway was started at midnight August 17, and terminated midnight August 18. It was found that with the white flash board in place at the outlet of the fishway there was sufficient illumination to enumerate all salmon ascending the ladder. A graph showing the number of salmon per hour that ascended the fishway is presented in Figure 3. Additional 24-hour counts were planned but unfortunately turbid water conditions precluded this. However, several counts of from one to five hours duration were made on both fishways. In all, a total of 2,028 salmon were counted through the right bank fishway in a total of 24 hours and 2,958 counted through the left bank fishway in a total of 72·5 hours.

Of the 439 coho released below the falls 11 (2·4 per cent) were recovered at the foot of the falls either by the Indians or the tagging crew. The two released above the falls were not recovered.

Table III

Coho Tagging Returns at Moricetown Falls, 1951

Date	Number Tagged	Number Recovered	Number of days out														
			0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Aug. 14	9	2							1	1							
15	50	3			1		1		1								
16	0	0															
17	46	1									1						
18	64	3			1	1								1			
19	36	2			1										1		
20	12	2		1				1									
21	38	1	1														
22	21	2				1	1										
23	5	0															
24	29	1	1														
25	46	1			1												
26	34	1				1											
27	8	0															
28	13	0															
29	20	1			1												
30	0	0															
31	10	0															
Totals	441	20	2	2	4	3	2	1	2	1	1	0	0	1	1	0	0

Table IV

Comparative Tagging-Recapture Intervals at Moricetown Falls Prior to and Following Fishway Installation, with related data

Year	Species and size of sample	Duration of run	Critical low water level	Average time between tagging and recapture[1]	Authority
1945	Sockeye 153 Coho 12	June 26-Aug. 27 Aug. 13-Oct. 5	Aug. 20	6·7 days 27·4 days	Fisheries Research Board
1946	Sockeye 164 Coho 8	June 27-Sept. 3 Aug. 26-Oct. 10	Sept. 3	5·1 days 13·0 days	"
1947	Sockeye 101 Coho 27	July 3-Aug. 23 Aug. 13-Oct. 5	Critical low not reached	5·5 days 10·0 days	"
1951	Sockeye 47 Coho 11	July 9-Aug. 26 Aug. 1-Sept. 13	Aug. 3	4·1 days 3·7 days	Dept. of Fisheries Fish Cult. Dev. Br.

[1] *The interval is that between tagging and recapture at the tagging site below the falls.*

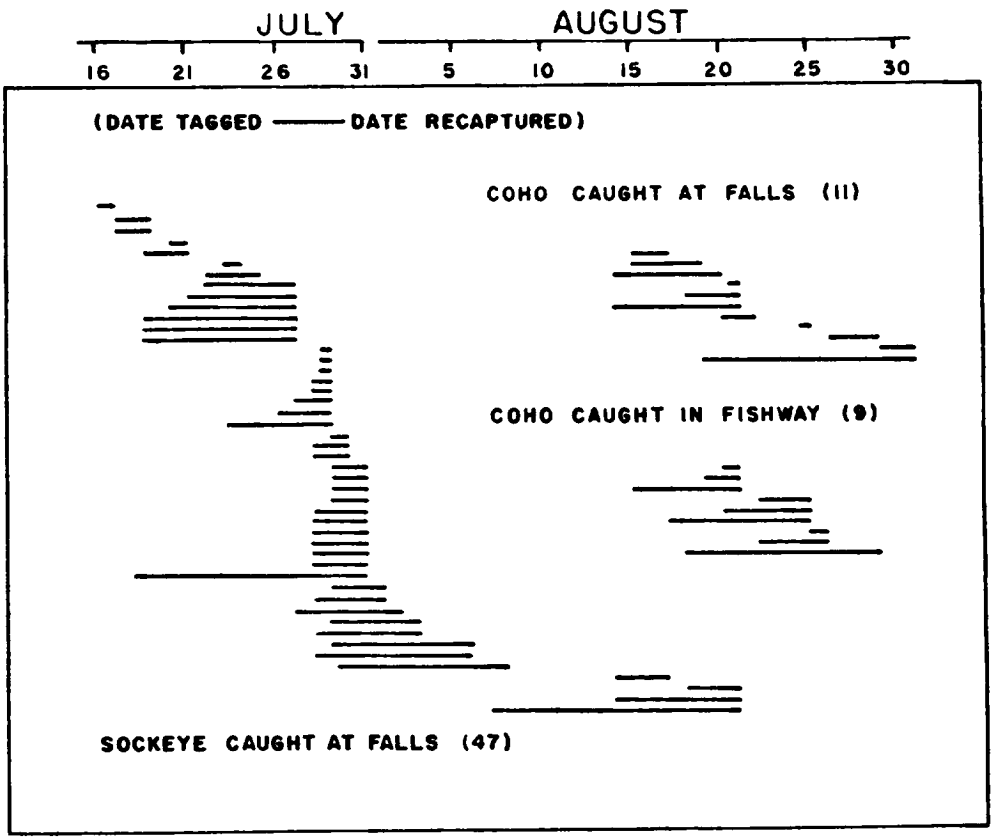


Figure 2. Number of days out for sockeye and coho salmon tagged at Moricetown Falls in 1951

There were ten coho tags recovered at points other than the foot of the falls. Of these, nine were taken at the exit of the left-bank fishway and one at Mission Creek (25 miles below Moricetown). These data are tabulated in Table I.

With reference to the tags recovered at the falls, Table III presents the number of coho tagged daily, the number recovered and the number of days between tagging and recovery for each tag. These data are also illustrated graphically in Figure 2.

A comparison between the days out for coho during the period 1945 through 1947, before installation of the fishways, and 1951, when the salmon could utilize the fishways, is shown in Table IV.

No recoveries were made of the nine pink salmon tagged and released below the falls. This species was not present at the falls in any large numbers during the period of tagging, the peak arriving some time later thereby accounting for the small number tagged.

The water levels during the 1951 tagging period, recorded by lowering a graduated line from the traffic bridge to the water surface, have been converted to water surface elevations with reference to a datum established in the canyon by the Department of Fisheries, and are presented in Figure 4. Dr. Milne's report had shown that water conditions during 1945 were the most adverse of the three years studied, so for purposes of comparison gauge heights during this year are also illustrated in Figure 4.

The mean daily water temperature at Moricetown Falls during the 1951 tagging period is presented in Figure 5.

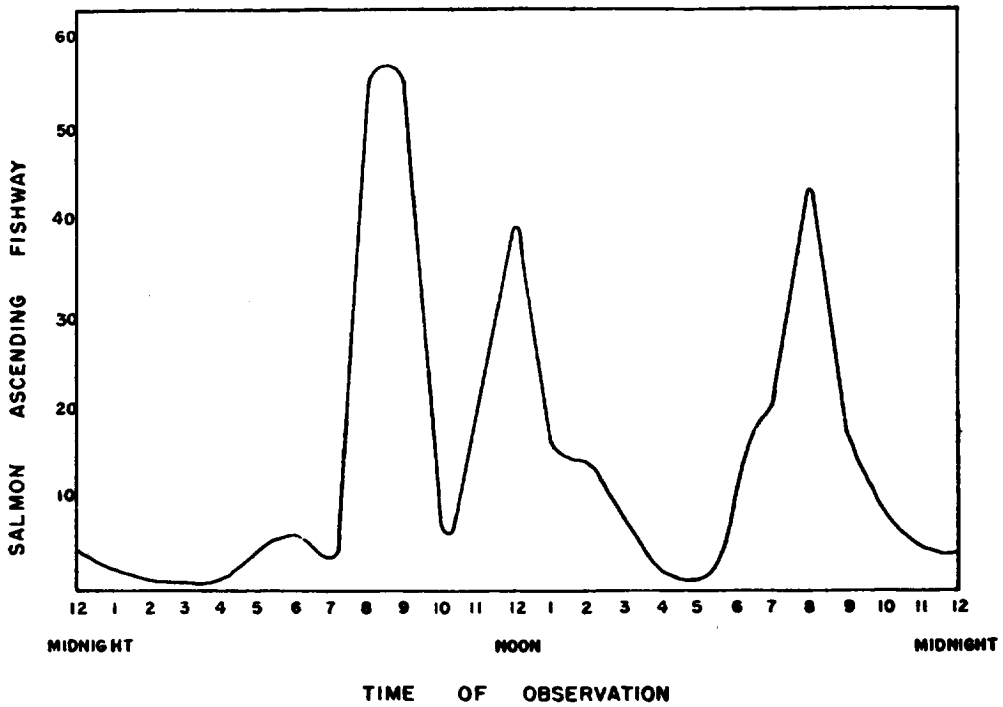
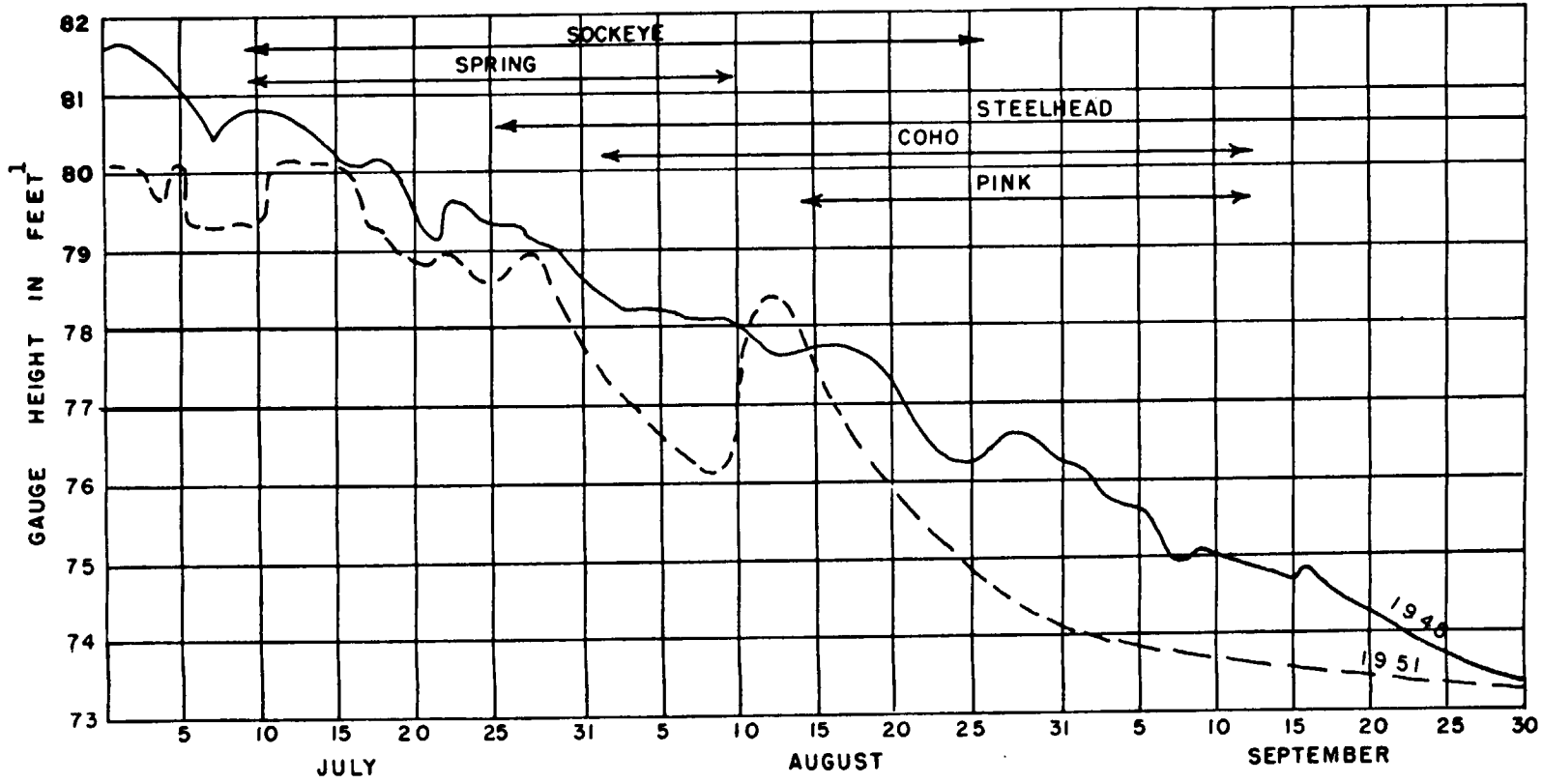


Figure 3. Number of salmon per hour ascending the left-bank fishway at Moricetown Falls during a 24-hour period August 17-18, 1951



[1] *Gauge heights calculated with references to datum established in the canyon by the Department of Fisheries.*

Figure 4. Gauge heights at Moricetown Falls, 1945 and 1951, and period of salmon and steelhead migration, 1951

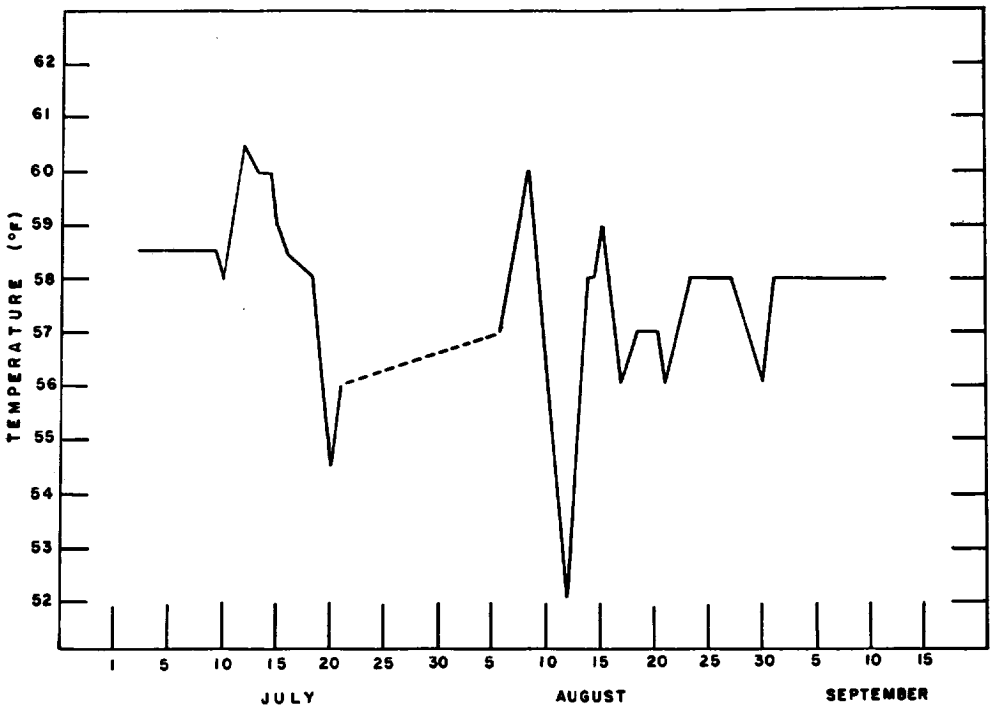


Figure 5. Daily mean water temperatures at Moricetown Falls in 1951

Discussion

The success of the fishways in easing the passage of sockeye salmon at Moricetown Falls is illustrated in Table IV which compares the average time between tagging and recapture for the four years during which tagging was carried out at this location, viz.: 1945-47 and 1951. It will be noted that the average of 4·1 days in 1951 is the shortest period of the four years studied. Figure 4, which compares the river elevations in 1945 and 1951, illustrates this point more graphically for it will be seen that in 1951 flow conditions at the falls were considerably more adverse than in 1945, the worst year recorded by the Fisheries Research Board surveys. If the fishways had not been in operation in 1951 there could be little doubt that the flow conditions during the latter part of the sockeye migration would have caused considerable delay at the falls.

The recovery below the falls of 12 of the 761 sockeye released above the falls indicated that a certain number of this group dropped back after release. While the fish were released into relatively quiet water some "fall backs" were expected since handling during tagging excites the fish to a considerable extent. The fact that 1·4 per cent of those released above were recovered below whereas 7·9 per cent of those released below were recovered below, would indicate that the majority of sockeye released above continued their upstream migration.

The results obtained from the coho tag returns offer further proof of the assistance rendered by the fishways in easing the passage of fish at Moricetown Falls. Although water conditions were worse in 1951 compared to 1945 the average time between

tagging and recovery was 3·7 days in the former year compared to 27·4 days in the latter year. This period is considerably less even than the average of 13·0 and 10·0 days delay recorded in 1946 and 1947 respectively, when water conditions were considerably better than in 1945. The bulk of the coho were tagged subsequent to the occurrence of water levels which were considered critical in 1945, yet the returns indicate little delay.

The recovery of nine coho in the trap in the last pool of the left-bank fishway in the average time of 4·5 days after tagging is a measure of the absolute period between tagging and ascent of the fishway. When it is considered that these fish were tagged during the period of adverse water conditions at the falls, then the fishways definitely facilitated their passage past the obstruction.

A further point of interest is a comparison between the percentage of tagged sockeye and coho salmon returned by the Indian fishery during the years 1945-47 and in 1951. In the former years 15 to 25 per cent of the tagged sockeye and 6 to 18 per cent of the tagged coho were returned by the Indians, whereas in the latter year 5·7 per cent of the tagged sockeye released below the falls and 1·6 per cent of the tagged coho were returned at the falls. While it is not possible to compare the relative fishing intensity, nevertheless, it is an indication that the fish were not schooling-up below the falls where they would be susceptible to gaffing.

With reference to pink salmon, considerable numbers were reported spawning above the falls in 1951 whereas in former years relatively few of this later running species were able to surmount the obstruction.

The 24-hour count of salmon ascending the left-bank fishway (Figure 3), indicated two pronounced peaks of activity, one in the morning and one in the evening, with considerable activity exhibited during the noon period. The periods of least activity occur during the early morning and late afternoon.

The following data on the condition of the salmon tagged was obtained. Out of 1,235 sockeye 9 per cent bore gaff marks, 7·4 per cent net marks and 3·1 per cent miscellaneous scars and bruises. Out of the 441 coho salmon tagged, 4·1 per cent bore gaff marks, 2 per cent net marks and 5 per cent scars and bruises.

The mean daily water temperature records illustrated in Figure 5 indicate that no abnormal temperature conditions were encountered by the salmon throughout their migration period. The mean high of 60·5 degrees Fahrenheit recorded on July 12 is well below the upper temperature tolerance limit of Pacific salmon.

The sockeye salmon population was estimated at 53,600. This estimate was derived from the return by the Indian fishery, of 35 (5·7 per cent) of the 1,235 sockeye tagged. In arriving at this figure a correction was made for the number of sockeye that were released above the falls, but which dropped back below and were therefore available for capture by the Indians.

Summary and Conclusions

A tagging programme was carried out by the Department of Fisheries of Canada at Moricetown Falls during the period of salmon migration in 1951. The purpose of the programme was to test the efficiency of the newly completed fishways installed as a result of an investigation during the years 1945-47 by the Fisheries Research Board of Canada from which it was determined that the falls delayed the migration of salmon.

Sockeye, coho, and pink salmon were tagged and released below the falls and in addition, a number of tagged sockeye were released above the Falls in conjunction with a study of the Nanika River spawning population.

Water level and temperature records were maintained for comparison with similar records compiled during the period 1945-47 by the Fisheries Research Board investigation.

The average time between tagging and recovery for sockeye salmon in 1951 was found to be 4·1 days. During the years 1945-47 this period was found to be 6·7 days, 5·1 days, and 5·5 days respectively.

For coho salmon the average time between tagging and recovery was 3·7 days in 1951. An average period of 27·4, 13·0, and 10·0 days respectively was determined for coho salmon during 1945-47.

Of the three years studied by the Fisheries Research Board water levels in 1945 were the lowest and conditions during this year were considered the most adverse for passage of salmon. The 1951 water levels were found to be lower than in 1945, particularly during the period of the coho migration.

During the years 1945-47 the Indians returned 15 to 25 per cent of the tagged sockeye salmon and 6 to 18 per cent of the tagged coho salmon. In 1951 the Indians returned 5·7 per cent of the tagged sockeye released below the falls and 1·6 per cent of the tagged coho salmon.

It is thus concluded that the fishways were successful in assisting the migration of salmon past Moricetown Falls, particularly under conditions of low flow in the Bulkley River.

Fertilization and Predator Control to Improve Trout Production in Crecy Lake, New Brunswick

by

M. W. Smith

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A study conducted over a number of years on eight Charlotte County lakes, of which Crecy is one, showed that the annual yield of trout (*Salvelinus fontinalis*) to the anglers averaged only 0·58 pounds per acre, and that introduced hatchery trout contributed little to this low yield (Smith, 1952). By virtue of drainage from an area of non-productive soils, the supply of nutrient salts in the waters of these lakes is poor. The infertility of the waters is viewed as a primary and obviously important factor in determining the low yields of trout.

The extent to which the yield of trout to anglers might be improved by overcoming, even if temporarily, the deficiency in the supply of nutrient salts by means of artificial fertilization has been explored at Crecy Lake. In the course of the investigation there was evidence that beneficial effects of the fertilization upon the yield of trout were being masked by bird, mammal and possibly eel predation. Apparently such predators of fish as the loon, kingfisher, otter and others were being attracted to Crecy Lake by a consistent annual stocking with trout which provided as good, if not better, fishing than found by these predators in neighbouring lakes. These observations led to an extension of the Crecy Lake programme on fertilization to include measures of predator control.

This article is preliminary in character. An account of the effects of fertilization upon the limnological conditions in general and a more complete presentation of the action of the fertilization and predator control upon the yield of trout in particular will be presented at a later date. Other preliminary reports have already been published (Smith, 1948a, b).

Crecy is a headwater lake on the Bocabec River system, Charlotte County, southwestern New Brunswick. It has an area of 50·4 acres (20·4 hectares) and a mean depth of 7·8 feet (2·4 metres). Since the maximum depth is only 12·5 feet (3·8 metres), the waters of the lake are subject to mixing throughout by winds of even moderate velocity. The lake has a volume of $17 \cdot 18 \times 10^6$ cubic feet ($0 \cdot 49 \times 10^6$ cubic metres). Additional limnological data for this lake may be found in a previous publication (Smith, 1952).

Actions Taken

1. *Annual Creel Census*

A man has been stationed on the lake for this purpose during each angling season since 1943 with the exception of 1945 when the lake was closed to fishermen. Data have been obtained upon the number of marked and unmarked trout killed, the number of anglers, the time spent in angling whether trout were taken or not, and the length, weight and sex of the fish. Almost all fishing has been from boats that landed at one point, which arrangement has favoured a thorough census.

2. Stocking with hatchery-reared trout

Since the stock of native trout in the lake was limited, additional trout were introduced to assure as complete utilization as possible of any improved trout-producing capacity that might result from the fertilization. Yearling trout, marked by fin-clipping, were planted in 1944 and 1945, and both marked yearlings and fingerlings thereafter annually. The hatchery trout have been planted sufficiently late in the season so that they have not been subject to angling until the following year. These trout have been supplied by the Fish Culture Development branch of the Department of Fisheries of Canada from the hatchery establishment at Saint John, N.B.

3. Fertilization of the lake

On June 19 and 20, 1946, one ton of ammonium phosphate fertilizer (11-48-0) and 500 pounds of potassium chloride (60 per cent K_2O) were spread over the surface of Crecy Lake, principally over the littoral areas. The application amounted to 6·5 pounds of the fertilizers per acre-foot, or 0·39 mg. of phosphorus (P), 0·21 mg. of nitrogen (N) and 0·27 mg. of potassium (K) per litre of water. The total phosphorus (P) content of the water just prior to fertilization averaged 0·016 mg. per litre. The fertilizers were donated by the New Brunswick Resources and Development Board.

4. Erection of fish barrier and trap in outlet of lake

Of the yearling trout (675) planted in Crecy Lake in the late fall of 1944, anglers captured 12 individuals during the following season in a small pond on the outlet of the lake. When the yield of trout fell off markedly in 1948 (Table I), movement of planted trout from the lake was considered as a possible factor contributing to the decline. To obviate this factor a fence of galvanized wire ($\frac{3}{8}$-inch mesh) was placed across the outlet immediately below the lake in July, 1948, before the annual stocking was made. A year later a trap was incorporated into the barrier to assess the number of trout that might attempt to leave the lake. The fence and trap have been maintained effectively throughout all seasons of the year.

Only nine yearlings and one fingerling of the stock planted in 1949 attempted to run from the lake. Of the introductions made in 1950, 2·5 per cent of the fingerlings (168) and 6·1 per cent of the yearlings (41) were taken in the trap. These observations suggest that migration from the lake was not a prominent factor in the disappearance of the planted trout before the barrier was erected. It is pertinent that the yield of trout continued to decline in 1949 (Table I) although escape of trout from the lake was prevented.

5. Control of fish-eating birds and mammals

The diminishing yield of trout to the anglers from 1947 to 1949 was associated with an increase in the number of visits made to the lake by fish-eating birds and mammals. Attempts to curtail the activities of these predators were initiated in early August, 1949. Control measures have consisted of shooting and trapping under permit as many predators as possible and, failing this, frightening them from the lake, in either case before they have had the opportunity to feed. The control has increased in effectiveness with time. To be as effective as it has been, constant attention has been required from a technician resident on the lake.

6. Trapping of eels in the lake

The capture of 897 eels in the trap in the outlet during the fall of 1949 disclosed a greater abundance of these fish in Crecy Lake than was formerly appreciated. (A good proportion of these eels would doubtless have left the lake in 1948 if they had not been prevented from so doing by the fence.) The eel is the only piscivorous fish in the lake aside from the trout. To determine if their number could be reduced appreciably and thereby the control of trout predators extended, a programme of trapping eels in baited traps set in the lake was begun in 1950. The numbers of eels taken in this manner were 369 in 1950 and 78 in 1951. These captures, although they comprised quite large numbers when consideration is given to the size of Crecy Lake, by no means depleted the stock of eels in the lake. This is shown by the following numbers of eels which were taken in the outlet trap when they attempted to migrate: 105 during the fall of 1950; 55 during April, 1951; 357 during the fall of 1951. The eel is catadromous, and limnetic populations of the species are primarily recruited from the elvers that annually enter fresh waters from the sea; accordingly the best eel control would be to prevent the entrance of the young into the lake. A barrier dam was erected in the outlet in the spring of 1951 with this objective. The efficacy of the measure has not yet been demonstrated and in any case its action has no bearing upon the data presented here.

Results of Fertilization

The yield of trout and the rate of their capture from Crecy Lake were appreciably greater in 1947, the year following fertilization, than had been experienced previously (Table I). Much of the improved yield may be ascribed to the excellent growth made by the introduced fingerlings. From September, 1946, to May and June, 1947, these trout increased in mean fork length from 3·2 to 8·5 inches (8·2 to 21·7 cm.) and were accordingly a suitable size for angling when yearlings (Table III). Of the 425 trout taken in 1947 by the anglers, 254 (60 per cent) were from this planting.

Since no marked fingerlings were introduced into Crecy Lake prior to 1946, a direct comparison of the growth rate of this size of stock before and after fertilization is not possible. There is good evidence, however, that the fertilization resulted in a decidedly faster growth rate by the fingerlings than would have been realized normally.

Table I

Yield of trout to anglers from Crecy Lake

Year	Number caught	Number per rod-hour	Pounds per acre	Kilograms per hectare
1943	166	0·45	2·2	2·5
1944	148	0·5	1·45	1·6
1946	139	0·6	1·4	1·6
1947	425	1·0	3·55	4·0
1948	110	0·3	1·6	1·8
1949	39	0·15	0·9	1·0
1950	264	0·6	2·9	3·2
1951	1,441	1·4	6·4	7·2

Table II

Percentage survival of planted trout to anglers' creels

Year planted	Stock	Number planted	Number subsequently caught	Per cent survival to anglers
1944	yearlings	675	6*	0·9
1945	yearlings	812	83	10·2
1946	yearlings	659	111	16·8
1946	fingerlings	6,701	286	4·3
1947	yearlings	675	26	3·85
1947	fingerlings	6,684	52	0·8
1948	yearlings	675	12	1·8
1948	fingerlings	6,575	5	<0·1
1949	yearlings	674	201	29·8
1949	fingerlings	6,633	129	1·9
1950	yearlings	675	306	45·3**
1950	fingerlings	6,750	1,333	19·7**

**12 additional individuals were taken from pond on outlet of Crecy Lake.*

***to June 16, 1952.*

Fingerlings from the same hatchery stock that was planted in Crecy Lake in 1946 were also introduced during that year into Gibson Lake, which lies in the same area of Charlotte County and in many respects of morphology and character of water is similar to the former lake. Gibson Lake was not fertilized and there the growth in length of the introduced fingerlings from August, 1946, to May, 1947, was only from 2·9 to 4·4 inches (7·4 to 11·1 cm.). It is also significant that no yearlings were found among the 453 trout taken from Crecy Lake by the anglers in 1943, 1944 and 1946, before fertilization. The assumption is made that, as yearlings, trout were not large enough to be taken, or if taken were not retained by the anglers. This situation was found to obtain generally in Charlotte County lakes (Smith, 1952).

An improvement in the growth of trout planted as yearlings also followed the fertilization (Table III). However, the improved growth rate by the planted fingerlings to the point that they were of suitable angling size during the year following their introduction is considered the more important result of the procedure. Introductions of hatchery trout to overcome deficiencies in stocks of native fish is most economical when good returns to the anglers are realized from planting fingerlings. It develops all too frequently, however, that because of various adverse conditions the survival of planted fingerlings to fishermen's creels is discouragingly poor. Recourse may be had to rearing the trout to angling size under artificial conditions before distribution on what is largely a put-and-take basis, relegating the natural aquatic environment to a holding rather than a producing area. The fertilization of Crecy Lake resulted in a sufficiently better growth of fingerling trout to shorten appreciably the period during which they were subject to natural mortalities before being cropped by the anglers. Of the fingerlings planted in 1946, 4·3 per cent were subsequently captured by the fishermen. This percentage in itself is small but viewed as a survival of planted fingerlings to anglers' catches is noteworthy for waters of the area, as well as elsewhere (Shetter, 1939; Smith, 1952).

Table III

Growth of planted trout

Stock and year of planting		Mean fork length in centimetres (Number in sample in brackets)				
		When planted	When angled 1st year after planting	Increment in one year	When angled 2nd year after planting	Increment in two years
Yearlings.....	1944	28·3 ± 1·79 (41)	— *		31·2 (5)	2·9
	1945	19·2 ± 2·19 (77)	25·6 ± 1·63 (66)	6·4	32·3 ± 2·10 (12)	13·1
	1946	21·3 ± 1·54 (108)	28·9 ± 1·27 (111)	7·6	—**	
	1947	21·4 ± 1·61 (53)	31·0 ± 1·92 (26)	9·6	—**	
	1948	16·2 ± 1·30 (60)	30·2 ± 3·46 (11)	14·0	—**	
	1949	18·7 ± 1·82 (60)	26·8 ± 1·71 (181)	8·1	36·5 (7)	17·8
	1950	18·5 ± 1·83 (239)	25·0 ± 2·45 (278)	6·5	32·7 (2)	14·2
Fingerlings.....	1946	8·2 ± 1·09 (49)	21·7 ± 1·30 (244)	13·5	32·4 ± 1·87 (25)	24·2
	1947	7·4 ± 0·95 (76)	23·5 ± 1·95 (32)	16·1	33·3 ± 1·67 (15)	25·9
	1948	6·1 ± 0·84 (175)	21·4 ± 1·95 (23)	15·3	30·6 (2)	24·5
	1949	6·6 ± 0·79 (67)	19·0 ± 2·16 (60)	12·4	25·9 ± 3·09 (68)	19·3
	1950	8·4 ± 1·29 (55)	17·0 ± 2·06 (905)	8·6	23·3 ± 2·51 (287)	14·9

Lake not open to angling in 1945.
**None captured.*

Results of Predator Control

The better yield of trout to anglers which was realized in 1947 did not persist, and in 1948 and 1949 the anglers' catches fell off markedly to below pre-fertilization levels (Table I). The survival of both the planted fingerlings and yearlings to the anglers was poor (Table II). (There was evidence from gill-netting and from the carry-over of planted trout into the second year from their introduction that the poorer yields in 1948 and 1949 reflected correspondingly lower trout populations in the lake.) Yet as may be seen in Table III, the growth of the fewer trout captured by the anglers was good, for the most part an improvement over those taken in 1947. The beneficial effects of the fertilization were no doubt still being experienced, but also contributary to the continuing fast growth of the trout was less competition for a common food supply.

As we have already noted, the declining yields of trout in 1948 and 1949 were associated with an increased predation by fish-eating birds and mammals, and perhaps by eels as well. Attempts at predator control, which these observations prompted, were begun in 1949 and the first stocks of planted trout that could have been affected appreciably were those introduced into the lake in that year and initially subjected to angling in 1950. It is shown in Table II that a greater percentage of these trout, especially those planted as yearlings, survived to the anglers' creels. With a continuance of bird and mammal control at a more effective level and extension of the programme to the trapping of eels on the lake in 1950, still better results were obtained with respect to both survival and yield of hatchery trout. Of the yearlings put into the lake in 1950, 45·3 per cent were subsequently taken by the anglers (Table II). We consider it more noteworthy, however, that 19·7 per cent of the fingerling stock survived to the fishermen.

Coincident with a greater survival of planted trout, the growth rate was depressed (Table III). It would appear that a condition of over-population had almost been reached—over-population from the viewpoint of the desirability of having planted fingerlings attain a suitable size for angling during the next year, i.e. as yearlings.

Discussion

However effective fertilization may prove to be as a procedure to improve trout production in natural lakes in certain situations, there are difficulties and definite limitations to its general application.

1. Fertilization is obviously of no value if applied to a lake that presents an adverse chemical environment for trout.

2. So far as we can visualize at the present time the cost of the fertilizer limits the size of the lake that can be treated, even if there were assurance that a given dosage would result in an improved trout production. Interpretation of what is a reasonable cost is subject to a divergence of opinion, but it should be borne in mind that we are primarily concerned with a sport fishery whose value cannot be gauged by the worth of the fish as food.

3. Unwanted fish in a trout lake will also benefit from any increase in the fish-producing capacity. On the one hand there are species that are competitors and predators of trout and, on the other, forage fish that are trout foods. In many Maritime lakes yellow (*Perca flavescens*) and white (*Morone americana*) perch, eels (*Anguilla rostrata*) and certain other species are inimical to trout. Control of such fish is indicated in order to realize at all fully the beneficial effects upon trout production that may accrue from artificial fertilization.

4. A sufficient supply of young trout to capitalize upon a higher productive level after fertilization is prerequisite. Where because of poor spawning facilities young native trout are scarce, transplantations from other waters or plantings from hatchery stocks are required and may on occasion present difficulties.

5. Fertilization to be effective implies creating or intensifying a condition of eutrophy, even if no more than temporarily. Blooms of phytoplankton occur where they have not previously been noted (Smith, 1948; Langford, 1950). Decomposition of the increased amounts of organic matter increases or causes hypolimnial deficits in

dissolved oxygen and depressions of winter values at all levels when lakes are ice-bound. A marked reduction in the amount of dissolved oxygen may be helpful to the phosphorus exchange in some lakes by presenting conditions suitable for the reduction of ferric to the more soluble ferrous phosphate (Einsele, 1938; Hayes, 1951), but this is no compensation for depletion of oxygen to the point that fish are killed. Almost complete winter-kills of fish were experienced in fertilized lakes in Michigan (Ball, 1950). However, at Crecy Lake the mean dissolved oxygen content was reduced to a low of only 6·8 ml. per litre (71 per cent saturation) during the winter following the fertilization. A greater but yet not severe deficit was found two years later at the end of a winter season with greater ice and snow cover on the lake. On March 29, 1949, the mean content was 5·8 ml. per litre (62 per cent saturation). Fertilization to attain maximum eutrophication without too serious reduction in dissolved oxygen is a nice manipulation of the limnetic environment which is certainly not yet fixed by prescription.

Physical difficulties involved in patrol and costs, increasing with increasing size of lake, present the most serious limitations to control of fish-eating birds and mammals. However, something quite short of complete control may prove worthwhile. Our experience at Crecy Lake demonstrated that to approach complete control close attention was required, and that patrol on the ordinary workaday basis would have been ineffective since so many of the predators visited the lake in the early daylight hours and to a lesser extent in the evening.

A scientific permit is required to destroy throughout the year those fish-eating birds that come under the protection of the Migratory Birds Convention Act.

Conclusion

Notwithstanding the considerable number of technical and biological problems involved in the development and practical application of artificial fertilization and predator control as means of improving trout angling in natural lakes, the results obtained at Crecy Lake are encouraging. The improvements in the anglers' catches of trout that followed both fertilization and predator control on that lake are sufficiently clear-cut to warrant further application in other similar non-productive waters.

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Abstract

by

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MEYER, P. F. 1951.
Ein neuartiges Impulsgerat fur die Elektrofischerei.
Der Fischwirt: Nr. 3.

This article describes brief tests with a new model of electric fishing apparatus designed for use in ponds and streams. The device makes use of a fluctuating D.C. current and operates from a 12-volt battery. The advantages stated for the apparatus are its lightness (approx. 15 lbs. without the battery, 50 lbs. with battery, dry cells may be substituted for the storage battery to reduce the weight) and its safety from an electrical standpoint. The apparatus is stated to be equal in effectiveness to a 3 to 5 K.W. apparatus of the types formerly available. Its sphere of effectiveness is 10 to 15 feet. The fish are attracted to the positive pole and are removed by a dipnet as they become narcotized. Three or four day's fishing may be carried out without recharging the battery. The apparatus is built by Messrs. Kreutzer-Peglow, Hamburg 8, Postfach 1281.

Three trials are reported: in a pond three feet deep, a stream about 15 feet wide and five feet deep, and a pond 16 feet deep. All were successful. The major disadvantage encountered was that the larger fish may be harmed if allowed to approach too close to the positive pole, a thumb switch is installed on the electrode rod to guard against this. When fishing over deep water, it is necessary to be able to see down at least five feet since fish swimming up to the electrode are stunned and will sink before they can be seen if the water is not sufficiently transparent.

A copy of the article abstracted above is on file in the library of the Ontario Fisheries Research Laboratory.

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Correspondence should be addressed to the DIRECTOR, INFORMATION AND EDUCATIONAL SERVICE, DEPARTMENT OF FISHERIES, OTTAWA, CANADA.

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HON. JAMES SINCLAIR, M.P.
Minister of Fisheries

The Effects of Regulatory Selectivity on the Productivity of Fraser River Sockeye

by

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The International Pacific Salmon Fisheries Commission was created, under a Convention ratified in 1937, because of a serious decline in the Fraser River sockeye population and because of the prevailing belief that competitive fishing by the nationals of the United States and Canada had contributed to that decline. The stated purpose of the Convention was to protect, preserve, and extend the sockeye salmon fishery of the Fraser River system. Through an accepted understanding it was decreed that eight years of scientific investigations by the Commission should preclude the exercise of regulatory powers over the fishery, and that the allowable catch should be divided equally between the fishermen of the two signatory nations. By these clearly defined terms of reference, fisheries scientists, appointed by the Commission and functioning under it, were obligated both to determine the cause or causes of the decline in the Fraser River sockeye population and to develop practical methods for restoring it to a maximum sustaining size. The seriousness of this obligation is best illustrated by the fact that the total pack of Fraser sockeye declined from 2,400,000 forty-eight pound cases in 1913 to 143,000 cases in 1921, only two reproductive cycles later.

Principal Cause of Decline

The investigations which revealed that the Hell's Gate obstruction, lying between the fishery and the major spawning grounds of the Fraser sockeye, was the principal cause of the decline are now a published record. The fishways constructed to overcome this obstacle became operative in 1945, one year before regulatory power over the fishery was granted to the Commission.

During the course of the Hell's Gate investigations it was shown that the obstruction was impassable to sockeye only at certain water levels and, as a consequence, the obstruction had a varying effect from year to year and also a varying effect on different individual races in the same year. The term "race" as used here assumes that homogeneity exists in each population spawning in a particular area which is subject to the same general reproductive environment. Extensive tagging operations both in the sea and at Hell's Gate roughly indicated the time of passage of each race as the individuals passed any given point enroute to their particular spawning grounds. The difference in the time of passage of the individual races correlated with the annual water level at Hell's Gate indicated in general the reason

The papers presented in this issue formed a symposium on "The Effects of Protective and Regulatory Legislation upon Fisheries" presented at the meeting of the Canadian Committee on Freshwater Fisheries Research held at Ottawa in January, 1953.

for the variation in the decline of the individual races. It explained, for instance, why certain late-spawning races were producing at a high level of productivity in spite of the Hell's Gate obstruction while earlier migrating races were almost exterminated. The investigations further substantiated the "home stream" concept.

In 1946, one year after the fishways became operative, the Commission was faced with the necessity of formulating its first fishing regulations designed to rehabilitate the Fraser River sockeye population. This population was known to consist of many residual races, some almost exterminated, others still existing in fair numbers. Certain spawning grounds were known to be entirely barren, and parts of other areas were not in use. The racial concept was well established as W. F. Thompson stated in his report on the Hell's Gate obstruction: "In the end, it is necessary to deal with a unit which is called a race, although it is not known what influences, external or internal, hold it together and perpetuate it, or whether it can be sub-divided still further. The persistent individuality shown by each such race forces its recognition in a practical sense as a unit known by its 'home' stream, whatever its genetic background".

Unfortunately, in 1946 little was known concerning the character of the racial migration except that it started at any given point at a given time and was finished at a later time. Attempts to identify the racial origin of adult sockeye in the fishery met with failure. Tagging failed to show the normal peak time of passage accurately because of inadequate sampling in relation to time. Nevertheless, the available yet elementary knowledge of the racial migrations combined with the awareness of the general depletion of all the early races made it possible to close certain periods in order that a greater escapement might reach the spawning grounds via the fishways at Hell's Gate.

Available Knowledge Utilized

The available knowledge of racial migration was utilized also to solve the problem of maintaining the fishing industry during the period of restriction on commercial fishing. Whenever possible, seasons were set to permit the total or increased escapement of those races most seriously depleted while allowing fishing on the races previously affected the least by the Hell's Gate obstruction and still existing in numerical strength.

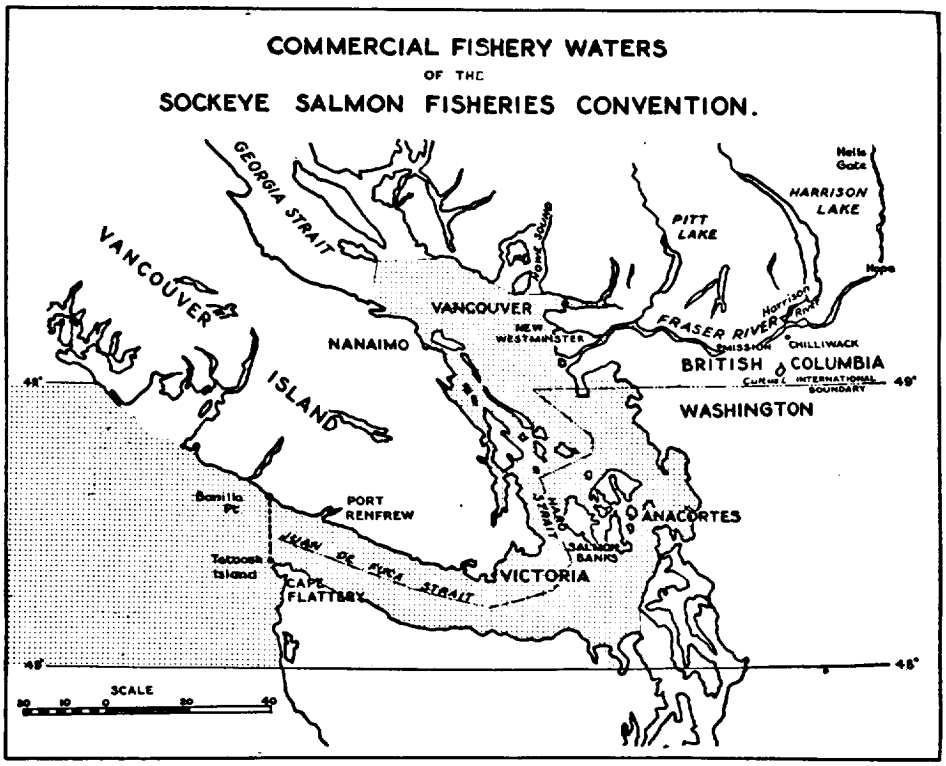
In 1946 the sockeye migration season was closed until July 25 in United States waters and until August 8 in Canadian waters. This closure afforded either complete or increased protection to all races except those which had been unaffected by Hell's Gate. This practice was followed for five successive annual cycles ending in 1950.

It is not suggested that these regulations were without fault, but the increased knowledge regarding the racial segregation of the Fraser River sockeye population made it possible to accomplish the needed increase in specific racial escapements without seriously curtailing the annual catch. Escapements to the seriously depleted reproductive areas increased from 200 to 2,900 per cent in each of the first four years during which severe restrictions were enforced, yet the total pack for the same four-year period was 961,000 cases as compared with 998,000 cases for the preceding four-year unregulated period. Thus the economy of the fishery was maintained at a high

level while at the same time the few thousand sockeye remaining of the seriously depleted and early migrating races were allowed to reach their spawning grounds unmolested to serve as seed stock for future rehabilitation. The increases in the escapement were caused not only by regulatory restrictions but also by the ability of the sockeye to pass the Hell's Gate obstruction through the fishways.

Regulation of the Fraser River in the early years of the fishery prior to 1915 provided for a closed season from August 25 to September 15 to obtain escapement for *all* of the races. With the current knowledge of racial migrations it can be proved that the majority of the races received no benefit from this closure because these races had pressed through the fishery prior to the date of the closure. The weekly closed season for many years was of 48-hour duration. Current findings indicate that 98 per cent of the migrating fish are taken during the open period of fishing and that little escapement occurs until 30 hours of closure have elapsed. The river gear is so effective that the bulk of the escaping fish must migrate from the lower part of the Fraser River, a distance of approximately 40 miles below the upper fishing deadline (Figure 1). Current weekly closed periods are of 76-hour duration. These points

Figure 1



are not made in a criticial sense but are presented here as evidence that the regulation of the fishery must be based even in the most elementary way on the consideration of each race as a unit. As it is destroyed—so must it be protected.

In 1951 the exploitation of all races was allowed for the first time since 1945. Restricted fishing was permitted on all races at a level which, calculated on previously indicated productivity levels from escapements which had passed through the fishways, would allow for some catch while still permitting any needed increase in escapements. That this concept of regulation proved effective is shown by the following table.

Table I

1951 Cycle Escapements for Certain Sockeye Races Periodically Affected by Hell's Gate Obstruction Prior to 1945

District	1943	1947	1951
Seymour River	200	10,000	24,400
Raft River	4,000	8,000	8,500
Chilko River	13,546	55,000	118,600
Nechako River	9,188	55,642	97,500
Stuart River	3,000	14,260	63,300
Bowron River	6,215	23,945	22,000
Total Escapement (fish)	36,149	166,847	334,300
Estimated Total Catch (fish)	105,000	10,000	1,337,200
Estimated Total Run (fish)	141,149	176,847	1,671,500

In regard to the above table, 1943 was a normal fishing year prior to the construction of the fishways. Severe restrictions were placed on the fishery in 1947, and the increased escapement was unobstructed in its migration because of the fishways. It should be noted that the rate of productivity of the escapement using the fishways was twice that of the escapement passing the Hell's Gate obstruction prior to the operation of the fishways. The increase in both the catch and the escapement in 1951 is justification for maintaining a continuing assessment of racial productivity.

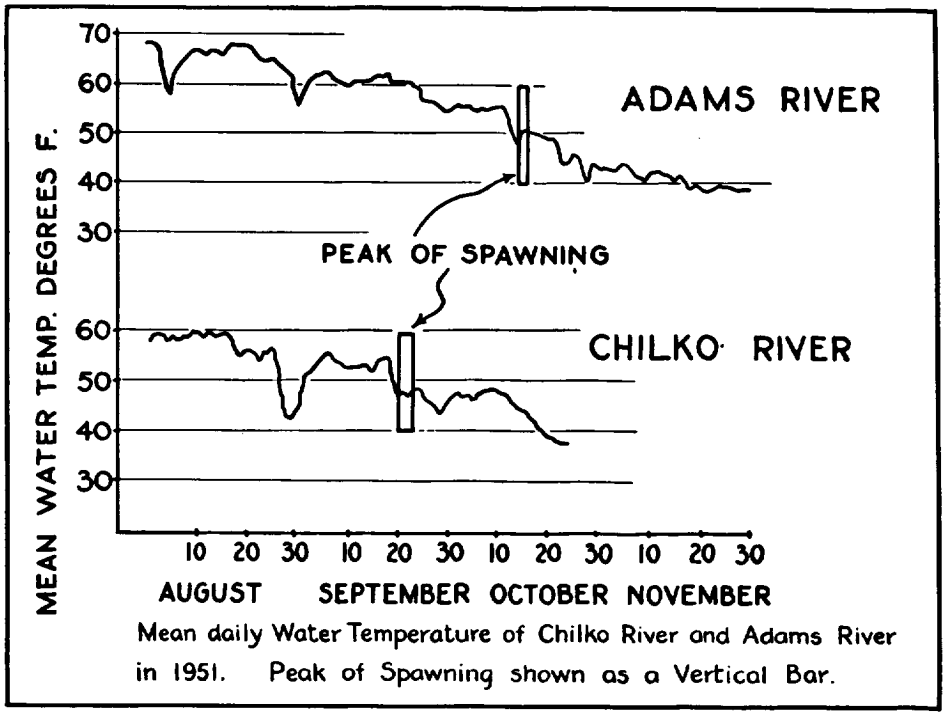
Problems of Management

With the return of certain racial sockeye populations in increasing numbers all of the difficult problems of management arise. The Hell's Gate fishways are merely a means of permitting the allowed escapement to reach the spawning grounds in a normal manner. Total closures merely increase the escapement to a reproducing area by eliminating interference from the fishery. Both the construction of the fishways and closures of the fishery during racial migrations have been major scientific accomplishments in the management of the Fraser River sockeye, and both were based on lengthy and sound scientific investigations. However, they do not involve the detailed knowledge of the dynamics of racial sockeye populations that may be required to restore extinct racial populations by substitution or maintain existing racial populations at the highest level of productivity while subjecting them to one of the most intense and complicated fisheries in the world.

Upon the elimination of the budgetary strain caused by the investigations centered at the Hell's Gate obstruction and also by the investigations designed to determine adequate methods for enumerating spawning populations, an intensive search was started in 1949 for knowledge regarding the dynamics controlling racial functions

and productivity. An analysis of a great mass of water temperature data taken during the spawning periods of various races indicated that all of the races tended to spawn on the falling portion of the annual water temperature cycle as controlled by the solar cycle and at a water temperature ranging between 55° F. and 45° F. Peak spawning usually occurred at 50° F. (Figure 2). The timing of the migration of each

Figure 2



Mean daily Water Temperature of Chilko River and Adams River in 1951. Peak of Spawning shown as a Vertical Bar.

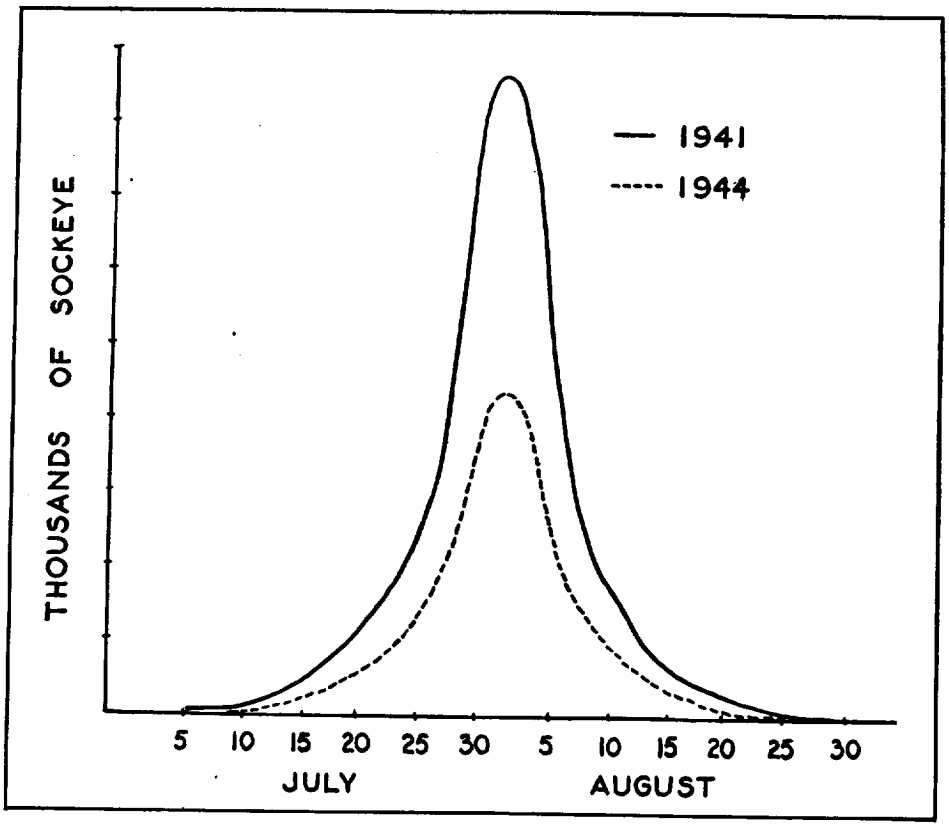
race appeared to be closely related both to the timing of the environmental cycle in the reproductive area and to the distance of the latter from the sea. Field observations indicated that temporary and local variations in weather conditions which resulted in abnormally high water temperatures caused extensive mortality in unspawned adults. This mortality normally occurred in the early part of the spawning season. Further, controlled temperature experiments revealed that a high mortality resulted when eggs were incubated at low temperatures. Thus water temperature was indicated as one of the major limiting factors, if not the exclusive limiting factor, in the timing of spawning. A thorough search of the historical records of the daily Indian catch dating back to 1822 also revealed a remarkable consistency in the timing of the annual and cyclic racial migrations to specific areas.

From the above two obvious facts and from information associated with them a concept was evolved that "The character of the migration of a race is related to the character of the environmental cycle in the reproductive area, the timing being controlled indirectly by the solar cycle, hence the maintenance of maximum productivity in a fishery depends upon the maintenance of normalcy in the character of the escapement."

Research Necessary to Substantiate Concepts

Availability curves of time and numbers approximated from the catch of numerically strong racial populations when the catch of other races was obscured by their small size indicated rather smooth curves with a long horizontal base but with extremely steep and fairly narrow vertical crowns (Figure 3). Thus was

Figure 3



Availability of 1941 and 1944 Chilko runs as approximated from the catch and partially verified by scale reading.

evolved a second concept that "only the main part of the racial availability curve is properly related to the normal reproductive cycle, and the tails of the curve consist of abnormalities not properly timed with the reproductive cycle." Naturally a great amount of research is required to substantiate both of these concepts, although they were both conceived from a great mass of factual information.

One of the first investigations initiated to substantiate these concepts consisted of new explorations to determine the racial identity of adult sockeye in the fishery. This was necessary in order to determine the true character of the availability curve of each race as it entered the fishery, and also to obtain an accurate measure of the fishing mortality by areas and thus determine the change in the character of the curve as it passed through a very extended and intensive fishery influenced by weekly closed

periods. If the fishing mortality could be measured, the sum of this estimate and the number of spawners, as established by well-founded methods of enumeration, would give a measure of total racial productivity under recorded environmental conditions. Various methods already used in an attempt to identify the racial origin of individuals in the fishery had proved unsatisfactory. Tagging, fat determinations and meristic characteristics had already been tried with very limited success. As a last resort the number of circuli in the freshwater nuclear area of the scale was used, the thought originating with Dr. C. H. Gilbert. Temporarily at least, the method is proving very successful in the isolation of some of the races each year. It is hoped that eventually the tendency for consistency in the timing of migration every year will permit a calculation of fishing mortality, on the basis of known escapement as related to a known fishing intensity, in those years when particular races cannot be separated.

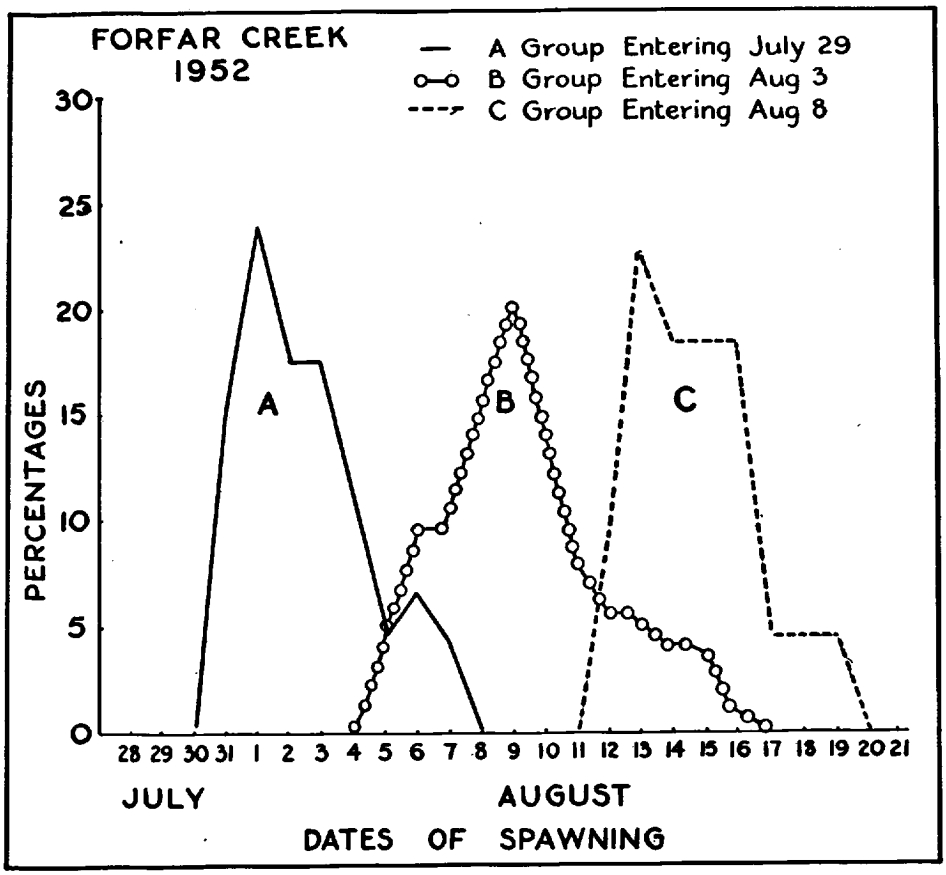
As well as ascertaining the true character of a racial migration regarding timing and the degree of consistency of that timing from year to year and cycle to cycle, we must determine whether the individuals retain their identity in relation to their position in the availability curve from the time they enter the fishery to the time of spawning and ultimate death. If their position is not retained, controlling the character of the fishery to avoid interference with the apparent normalcy of the escapement might be of little value in maintaining the maximum rate of productivity. Previous salt-water tagging of fast moving races gave meagre information that the individuals did retain their identity in the availability curve, but many intervening artifacts in other tagging experiments indicated the opposite. Through using the calculated rate of migration from the Fraser River fishery to the spawning grounds, based on tagging experiments in some cases involving a distance of over 500 miles, and projecting the curve of daily arrival on the spawning grounds back to the fishery it was found that the weekly closed period escapement held its identity throughout the period of migration. In some cases this period exceeded 25 days. Thus where migration is not interfered with and does not hesitate at any point it is indicated that there is a negligible amount of mixing of individuals in relation to time.

The next step was to accurately determine the variation, if any, in the time of spawning and death of the individuals arriving at the spawning area in fixed sequence from the fishery. To accomplish this a large area was fenced off in one of the streams farthest removed from the fishing area. Three lots of fish were isolated, tagged, and placed in the fenced area. One lot of 100 adults, divided equally as to sexes, was taken from the first arrivals, a second lot from the peak arrivals, and a third from the last arrivals. In each case the lots maintained a sequence of activity from arrival at the spawning area through the period of spawning (Figure 4).

Thus, with no indication of a significant mixing of individuals of a given race from the fishery to spawning, and with a known consistency in the timing of their annual and cyclic migration and a measured consistency in the timing of the environmental cycle, we can assume without further proof, although such proof is certainly desirable, that any change in the character of the escapement caused by the fishery may have a detrimental effect on productivity although numerically the escapement might appear adequate for the physical limitations of the spawning area. If the numerically and

physically adequate escapement is obtained from either the beginning or end of the run, such an escapement may have a low rate of productivity since it may not be timed with the optimum reproductive environment.

Figure 4



Percentage Frequency Distribution of Spawning as Determined by Manual Examination of Confined Female Sockeye

Fixed Physical Factor

Both of the concepts concerned with timing and productivity appear logical and are based on sufficient fact that regulations for escapement are now predicated, within practical limits, upon the requirement that the maximum portion of each racial escapement must come from the peak of the run of that specific race. Engineering surveys combined with observations on the distribution of spawners have indicated the approximate physical limits of those spawning grounds producing the current large runs. This spawning limitation is a fixed physical factor, and while productivity may still fluctuate with local and temporarily abnormal environmental conditions, the numerical size of the required escapement for each spawning area does not vary. Emergency changes are now made in the regulations if a certain run, as it enters the

fishery, is found to be more or less than the size expected to provide the required escapement from the peak of the run. This type of emergency regulation was made during the Adams River run in 1950 and during the Chilko run in 1952. Just what effect this has had on productivity of the escapements to the above areas will not be evident until the return of the surviving populations. However, unmeasured and unknown factors could intervene and cloud the results. Nevertheless, if the size of a racial population can be determined in the fishery and the spawning limitations are fixed it would be an economic waste to allow too few or too many fish to reach the spawning ground. The only added feature not yet completely substantiated is the effect of predetermining the character of the escapement by regulations regardless of its size.

The ability of regulatory measures to select the escapement from a given portion of the migration curve may have possibilities in restoring sockeye to certain portions of spawning ground now unused by sockeye since the decline commencing in 1913. As Thompson stated, "We do not know what influences hold a race together or perpetuate it, or whether it can be subdivided still further". We do know that as a population approaches its physical spawning limitations, individuals will spawn elsewhere regardless of the difference in environment or the suitability of the adopted spawning area. In many cases of such "slop-over" there is evidence that there is no survival, particularly when the environment of the adopted area is significantly different from that of the usual spawning area. Conversely, where the environmental cycle of the adopted area is similar to that of the usual spawning area evidence is available to indicate that the new area may become productive with returning runs established.

Three Subdivisions in Spawning Area

In the Horsefly River, the main spawning area of the once great Quesnel run, there are three subdivisions in the spawning area as determined by three different water temperature cycles. Originally all three areas were populated. Now only one of these, the upper area, is producing, and since the environmental cycle is early in this area, the current rapidly rehabilitating run is earlier in its timing than was the main portion of the original migration. A run may return in 1953 of sufficient size that a large escapement could not physically spawn in Area I (the upper area). If this proves to be the case the last of the escapement may find it desirable to spawn below in Areas II or III (the middle and lower areas). Since the last of the run is not properly timed with the environmental cycle of Area I but is timed with the environmental cycle of Area II, it might produce at a maximum instead of at the expected minimum level. In this way a subdivision of a race would be created which migrates at a later date but which nevertheless produces at a maximum rate. If this supposition be true, regulatory selection of a large portion of the latter part of the run for escapement would be desirable in this case. This course of action is being followed to some degree for the runs to both the Quesnel and Stuart Lake areas in the proposed regulations for 1953 and will be continued unless it proves to be valueless for the purpose intended. If the supposition is not true and adjustment to the new area is an evolutionary necessity it may take many years for these now barren areas to return to full productivity. Fortunately, the indication so far is that the result will be positive rather than negative.

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Quadrennial Dominance

The decline in the racial populations of sockeye reproducing above Hell's Gate destroyed what is commonly referred to as the "quadrennial dominance in productivity". Originally all of these races had a quadrennial dominance in productivity in the same cycle to the extent that far more sockeye were produced in one cycle than in the other three cycles combined. Quadrennial dominance was a stable thing, for the historical records show that it existed on the same cycle for at least 90 years. Only the Hell's Gate slide was sufficiently severe in its effect to destroy the great runs of every fourth year.

Coincident with the destruction of the dominant year and the current increases in escapement, the problem arises of whether or not large racial escapements should be permitted every year regardless of the size of the run, or whether fishing pressure should be equal every year regardless of any indicated variability in the annual productivity and escapement. From 1946 through 1950 regulations were formulated on the basis that the few tens, hundreds, or thousands of sockeye on the spawning grounds, if they existed at all, should be allowed to increase in number each year.

The practice of regulating to exert even fishing pressure was initiated in 1951. In the first case little was known about the cause of quadrennial dominance, and the racial escapement in most instances was below that recorded for all years prior to 1913. In the second case the increasing escapements appeared to be producing at a dominant rate each year. In a sense each year class appeared to be struggling for supremacy. Two examples of returning quadrennial dominance already existed, each returning on a different annual cycle and each returning on a cycle different from the original one. Thus evidence was available to show that quadrennial dominance would re-form as the runs approached their original abundance and that it did not need to occur in all races on the same year. Evidence was also available to indicate that dominance would not re-form until at least one year class reached a size approaching the reproductive limits of the area. Whether that limit is on the spawning grounds or in the lake rearing area remains to be determined.

Whatever the specific cause of quadrennial dominance may be, and there are several theories existing on this subject, we may be assured that it will re-form itself in every case where it existed before. If it is quadrennial in occurrence the cause must be interrelated on this same cyclical basis. It is logical to assume, therefore, that large escapements brought about each year by unequal fishing pressure may upset the productive balance of the area, forestall the creation of true dominance, and actually result in a below maximum production over each four year cycle. Whether this logic is right or wrong will be determined in the next few years, for the survival of adults from four continuously large annual escapements to each of two spawning areas will start to return next year. In the future equal fishing pressure will be permitted by regulation as near as may be practicable although strikes and other factors may interfere. It should be noted also that the contemplated modification in the regulations during 1953, in an attempt to subdivide the late Stuart and Horsefly races, will allow an increased escapement of one other race migrating at nearly the same time. This latter race has already established its dominance on the 1952 cycle, hence the resultant increase in its escapement because of the special regulations designed for the protection of the Stuart and Horsefly races may not be desirable but is unavoidable.

Investigations Continue

Investigation into the possibe cause of quadrennial dominance continues with the hope that knowledge of the cause may provide a method for eliminating it and by doing so perhaps provide for a greater production of sockeye than had existed originally.

The selective time effect of the fishery on individual races and on parts of individual racial runs as caused by regulation has already been discussed. The selective effect of the fishery on size and sex has been measured also. The effect of this measured selectivity has not been completely determined so that no regulatory action has been taken up to the present time. Only a small amount of selectivity, if any, by size and sex exists on the early runs. Sex selectivity by the fishery exists on the late runs to the extent that a natural sex ratio of approximately 50 per cent males and 50 per cent females can be changed to a sex ration of 25 per cent males and 75 per cent females in escapement. First controlled experiments indicate a lowered rate of productivity in the latter case but the experiments should be repeated, particularly since the results are somewhat at variance with the data being obtained in Alaska. If the maintenance of a more uniform sex ratio is found to be desirable this can probably be accomplished by a simple regulation of the gillnet fishery which is responsible for the present condition in the escapement of the late spawning races.

One of the requirements of the Convention is that the allowable catch be divided as near as may be practicable between the fishermen of Canada and the United States. While this requirement is an economic and political necessity it is extremely difficult to fulfil under regulations designed to manage individual races. Rapidly changing efficiency and intensity of the fishing gear in the two countries likewise adds to the difficulty of the Commission maintaining the desired catch-escapement ratio while still maintaining an equal division of the catch between the fishermen of the two countries. At first the industry requested seasonal quotas, but with an understanding of the racial problem involved combined with knowledge of our inability as yet to accurately predict the size of the incoming population the request was subsequently withdrawn.

The current method of accomplishing division is meeting with considerable success, especially in later years. During the first seven years of regulation the total Canadian catch has been 9,703,000 sockeye as compared with 9,258,000 for the United States' fishermen. All of the above differential and more occurred in 1946, the first year of regulation. Prior to the advent of Commission regulation the catch fluctuated heavily in favour of one country or the other depending upon the intensity of fishing by each country.

Regulations for dividing the catch are based upon a rough prediction of the incoming population by races, the anticipated intensity of the commercial fishery, and the anticipated needs of the individual spawning grounds. As the runs appear in the outer fishing areas their size is noted through the tabulation of catch statistics from all areas within 24 hours, and consideration is given to whether or not the catch in each country is following expected trends. If it is not, emergency short closures or extensions in the fishing period are made in one country or the other depending on whether increased catch or escapement is desired. A continuing examination of the gillnet catch on the Fraser River before and after weekend closed periods provides a rough

approximation of the current escapement throughout the season. Our methods are not perfect but they are improving as additional studies are made. A special twenty-four hour closure of the Canadian fishery during the peak of the migration of the Chilko race in 1952 resulted in a badly needed escapement and provided an almost equal division of the catch between the two countries. The final sockeye catch figures for 1952 are 1,154,000 fish for Canada and 1,113,000 fish for the United States.

Much biological information is needed before the full requirements of regulation are known or understood. Perhaps we are still failing in part in our obligation to restore the Fraser River sockeye fishery. However, as in the case of all other fisheries, management must continue while it awaits the answers to obtain 100 per cent efficiency. We believe, however, that we have gained considerable knowledge regarding the needs of the fishery and that the record of increasing runs validates the majority of our protective and regulatory recommendations. Though we may eventually assess all of the scientific requirements of the fishery we may be thwarted in part by conflict between these very same requirements when applied to regulation or by the psychological impossibility of imposing overly complex regulations on a fishery involving many types of gear operating over approximately 200 miles of fishing area and many thousands of fishermen of two different nations. Much has been accomplished and more will be accomplished towards fulfilling the terms of reference of the Convention not necessarily due to the efforts of any individual or any group of individuals but because scientific research has been made an integral part of the management programme.

Effects of Protective and Regulatory Legislation upon the Pacific Herring and Halibut Fisheries

by

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Regulatory and protective legislation respecting fish stocks is designed to benefit fishermen and the fishing industry. It tries to accomplish this by making fish more abundant, or easier to catch, or more valuable, than they would otherwise be. The fisheries for herring and halibut on the Pacific coast are of the type which attack a series of age-groups, rather than only fish which are about to mature and die. The problem of estimating the effects of regulation upon such fisheries has two aspects. Firstly, we may look at the yearly supply of recruits to a fishery, and try to make regulations so as to use them to best advantage. Alternatively, or additionally, we may cast about for means to increase this supply of recruits. Measures which accomplish one of these objectives may also assist the other, or they may work against it.

Aspect I. Best Use of Recruits

The optimum use of a given annual supply of recruits is the easier problem. Its solution evolved during the North Sea researches of the first decade of this century, and received its definitive form in Baranov's great work of 1918. What is needed is an estimate of the growth rate and the natural mortality rate in the fishery. If growth is less than natural mortality, it will be possible to obtain a larger gross catch by fishing harder. If growth exceeds natural mortality, fishing *less* will produce a greater yield. There are complications introduced by the fact that (relative) growth rate tends to decrease as fish grow older, and natural mortality too may change with age. Growth rate at a given age may also change as stock density increases or decreases in response to less or more fishing, or for other reasons; but this means only that computations of the equilibrium position must be repeated at frequent intervals. Then too, the smaller fish in the commercial stock tend to be harder to catch, and may bring a lower price per pound. This, together with the rapid growth of smaller fish, may suggest the wisdom of computing the effect of a minimum size limit or a mesh regulation instead of, or in addition to, a restricted level of exploitation. However, these are merely details, and the job of computing the equilibrium yield from different levels of fishing effort is fundamentally simple—as long as recruitment does not vary.

Aspect II. Maximum Recruitment

The problem of obtaining greater yield through maximum recruitment presents greater difficulties, though the general picture of what must occur seems clear enough. Removal of adult fish from a stock very generally promotes a greater percentage survival of eggs and larvae, in a variety of ways. At or near the maximum density of stock, a removal of adults may even increase the *absolute number* of annual recruits. The rather scanty information available on stock and recruitment in various fisheries suggests that this may be the usual situation.

Under the circumstances just described, the first effect of fishing an undisturbed stock is to increase the number of recruits which enter that stock each year. Later, with intensified fishing, spawning stock may become reduced so that the number of recruits begins to decrease, and it may even fall to below the primitive average level. In that event two stages of the influence of fishing upon recruitment can be distinguished:

Stage 1. In this stage a decrease of stock increases recruitment, while an increase of stock decreases recruitment. Population size is still regulated mainly by natural controls.

Stage 2. In this stage decrease of stock decreases recruitment, while an increase will increase it. Size of population tends to be controlled mainly by the fishery, which, left to itself, will fish it down to the point where it yields average economic returns, or sometimes even less.

Obviously the effect of protective legislation depends upon which Stage the fishery is in. In Stage 2 it is certain to increase recruitment, and this is true no matter whether it is adults or young that are protected. In Stage 1, however, while protection of young will increase recruitment, though only to a degree and temporarily, protection of adults will always *decrease* recruitment.

Thus an important task in fishery management is to ascertain the relation between adult stock and recruitment, so that the stage of exploitation can be identified. This task is made much more complex by the existence of year-to-year variation in success of reproduction associated with environmental variability. Random or short-term variation is not so bad, because its effects tend to average out over a period of a decade or two. Long-term or cyclical variation is much more difficult, because it is always possible that any observed trend in recruitment is the result of unknown environmental factors, rather than the current change in stock size.

Fishery Administration

Thus a fairly clear picture emerges of what a fishery administrator would like to be able to do. To make best use of stock on hand, he will need to know the rate of growth and the mortality rate, particularly the *natural* mortality rate, of the fish stock, and how they change from year to year. To promote optimum recruitment, he will want to know how recruitment has varied over the years in relation to prevailing levels of stock; and in particular, whether recruitment will be expected to increase or to decrease if the current level of commercial stock is decreased. The principal possibility of conflict in the results of protective legislation will occur in respect to a fishery which is in Stage 2 of exploitation *and* in which growth of the commercial stock is less than the natural mortality rate. In this situation decreasing the amount of fishing will decrease yield from the existing number of recruits, but it will increase recruitment a few years later; and vice versa. The two trends must be balanced one against the other.

In addition to the biological information above, an administrator will also need to know the relative vulnerability of fish of different sizes, and their relative desirability as shown by market price. He must then decide upon the economic objective at which he is aiming. The three possibilities usually considered are: maximum total yield;

an adequate living for fishermen—that is, a certain minimum catch per unit effort; or a fishery in which the difference between cost of operation and sale price of the product is a maximum. The chosen goal and the anticipated reaction of the fish stock must then be fitted to the kinds of regulations which are available and are enforceable. In general, considerations of economics and public policy will play a large role in this final operation.

The discussion to follow will be restricted to the biological aspects of regulation of the two species assigned me, the herring and halibut of the Pacific.

Herring

The British Columbia herring fishery exploits a number of fairly discrete populations, these being demonstrable by average differences in vertebra number and by returns of tagged fish. The development of the fishery is described by Tester (1935) and more recent information is available from various sources (Tester, 1945, 1948; Stevenson *et al.*, 1951, and earlier papers of this series). The modern fleet of purse seiners, equipped with echo sounders, is an efficient means of capturing herring when they are concentrated prior to spawning time. Catches up to 300 tons per haul are not uncommon, and less than 50 tons per day constitutes poor fishing.

Regulation of this fishery has been of two types: closed seasons and catch quotas.

Closed seasons are set during the time of actual spawning. The reason is that herring are extremely vulnerable at this time, and inadequate spawning is feared if they are taken. In addition, the industry prefers to have fish taken prior to spawning, because oil yield is high early in autumn and decreases to zero at spawning.

Catch quotas were introduced at the time unlimited reduction of herring was first permitted, in 1937. The quotas chosen were set originally with an eye to past production of the Area in question. Quotas are quite often extended if fish still seem abundant when the limit is reached. On the west coast quotas have been removed since 1946–47, as an experimental measure for comparison with the east coast. However, the closed season remains.

Aspect I.

Natural mortality rate for recruited herring (age three and older) is estimated to be of the order of 50 per cent (Tester, 1948). On the other hand growth at age three is only about 25 per cent per year, and it decreases steadily at older ages (Tester, 1948, Fig. 6). Thus there is little question that better use of existing stock could be made by more intensive fishing than now occurs.

Aspect II.

To find a relation between *stock size* and *recruitment*, in herring, estimates of these two items are needed. Unfortunately neither is easy. Although tagging of herring is feasible and has yielded important information, the mortality involved has so far precluded any direct estimate of rate of exploitation, hence of stock size, in this way. Some idea can be obtained from a comparison of primitive and present survival rates, as shown by age composition of the stock; but this involves the assumption that it is fishing which caused the change, and anyway natural mortality may differ in the two

situations. Recently the size of post-fishing herring schools has been estimated by echo-sounding and compared with total stock (catch plus these schools), but this method is in its infancy. Up to now estimates of spawn produced have provided the only measure of stock size. The technique of spawning surveys has reached a considerable degree of refinement, and although it cannot be equated to number of adults with certainty, the figures obtained are of much use.

Relative size of individual year-classes is estimated by first computing the percentage of fish of each class present in the commercial stock each year. This is multiplied by an estimate of abundance—the catch per boat-day—and the sum of the occurrences of each year-class is taken (Tester, 1948).

For the west coast of Vancouver Island, a relation between the strength of each year-class and the amount of spawn which produced it is given by Tester (1948) as $r = -0.30$ for the spawning years 1931–43. This is not large enough to be statistically significant, and in later years it becomes numerically less. Using a more elaborate index of spawning for the years 1937-49, the correlation is -0.04 (Stevenson, MS). For the lower east coast of Vancouver Island, the 1937–49 relation is -0.18 (Stevenson), again a non-significant value. In this there is a complete absence of any indication that larger spawnings produce larger broods, and perhaps a suggestion that they tend to produce smaller broods. In terms of the analysis above, this suggests that these stocks have been near the boundary between Stage 1 and Stage 2 of exploitation, but probably closer to Stage 1.

Thus the indications available suggest that somewhat more intensive fishing of the herring stocks of age three and older would increase total long-term yield. The removal of quotas from the west-coast stock was of course designed to test exactly this proposition, and the experiment is being continued. It may soon become desirable to try the more drastic experiment of removing the closed season at spawning time, in order to ascertain the production of recruits by lower levels of stock than have been observed to date.

Halibut

From catch statistics, vessel log records, age studies, and tagging experiments, the scientists of the International Fisheries Commission in 1930–34 pieced together a picture of the history and present state of our two great Pacific halibut stocks, or groups of stocks, the "southern" and the "western". The latest published figures on catch and availability are given by Dunlop (1951) and by Bell *et al.* (1952). The southern stock consists of younger fish, has relatively fewer spawners, grows more rapidly, and has been more intensively exploited than the western one. The exact level of exploitation of these stocks at different times is subject to some uncertainty. The figures 40 per cent and 10 per cent are quoted for Area 2 and Area 3, respectively, in 1926 (Thompson and Bell, 1934). Results of recent tagging make it seem possible that the Area 3 figure was really somewhat higher than 10 per cent, and with the shortening of the fishing season in recent years the whole question of exploitation of different subdivisions of the stocks, and their contribution to the total catch, has become much more complex and uncertain.

Aspect I.

For the southern stock it was computed that, for any constant level of recruitment, reduced fishing would permit at least as great an equilibrium yield as was current in 1930, and possibly somewhat more. For the western stock it seemed that increase in equilibrium yield would come from more, not less, fishing (Thompson and Bell, 1934, p. 47).

Aspect II.

Direct evidence of the relation of stock size to recruitment was not available for either of the halibut stocks in the early 1930's. However, the level of abundance of the stock, and particularly of the mature stock, appeared to have fallen so far below its original magnitude that exploitation was assumed to have passed into Stage 2. An increase in recruitment was confidently expected from increased spawners in both stocks (Thompson and Bell, 1934).

The principal means of regulating the halibut fishery has been an annual quota imposed upon the total catch for each Area, beginning in 1932. Voluntary restriction had been in force a year or two earlier, and had been followed by increase in catch per unit of gear. The legal quotas were designed to continue this process. The benefits anticipated were: (1) that restriction would permit a greater accumulation of spawning stock, and hence, eventually, greater recruitment; (2) in the southern Area it would permit a somewhat better utilization of existing recruits, since the fish of this stock were thought to be growing somewhat faster than they decreased by natural mortality. The immediate effects upon the fishermen would be an increase in catch per unit effort, but a decrease in yearly catch and in total fishing done.

The adoption of this policy of quotas required considerable courage. The inevitable process of replacement of stock into the higher levels of the age structure meant that increase in availability from this cause would be slow at best. And this replacement would have to proceed far enough so that mature stock was substantially increased, before there could be much increase in spawning; after which there was to be another wait of 8 years or so before these larger broods appeared in the fishery in any considerable numbers.

The course of events has been somewhat different in the two stocks. In Area 3 the immediate increase in catch per unit effort, during the 1930's and early 1940's, was much greater than had been predicted on the basis of rebuilding the adult stock from constant recruitment; the difference has been computed by Burkenroad (1948, Fig. 5). Thus a phase of increasing recruitment must have been under way—an increase which began among broods produced by the small stocks of the late 1920's. During the later 1940's however, catch per unit effort in the western stock fell off to the level of the late 1930's, presumably because of decrease in recruitment from the denser stocks of 1936 and onward, but aided by a gradual increase in the catch quota. Recently catch per unit effort has started rising again.

In Area 2, the increase in catch per unit effort up to 1937 appears to have been about what would be expected on the basis of steady recruitment and stable growth rate. By 1947, availability had risen somewhat above the point that could have been supported by the old level of recruitment, suggesting that an increase in recruits had

occurred. In recent reports of the Commission, however, there are statements that the broods of 1943–45 on the Goose Island banks were much less numerous than those of 1939–42, and apparently this may be expected to reduce availability in the next few years.

As far as an outsider can judge, no interpretation of these various indications can yet be made with assurance. It might be argued that Area 3 has always been in Stage 1 of exploitation, since the low stocks of 1925–35 apparently produced more recruits than the increased stocks of 1936–43. But these differences might equally be "accidental", independent of stock density as far as present knowledge goes. In Area 2 increased stock was followed by some increase in recruitment, but it is now feared that a recession is in prospect, on some banks at least. Until there are better clues concerning the nature of these changes, the best policy may be to ignore them and base regulations upon the best utilization of whatever recruits come along, however unsatisfactory this may seem. Perhaps eventually the level of effort in one or other Area should be altered on a frankly experimental basis, but the procedure so far has in fact been an experiment that has provided some of the necessary information on the relation between stock size and recruitment.

One anticipated result of the quota regulation has been amply achieved—that of making fishing more successful. In part this results from increased stock density and in part from the greater vulnerability of the larger fish, which are now relatively more numerous. Whether it will ever appear desirable, or feasible, to translate the implied potential economic return into actual profits or royalties, by restricting the number of boats fishing, is a question of serious concern to the public and international policy of the two countries.

Summary

The biological information which is desirable for making fishery regulations includes (1) the relative size of the growth rate and the natural mortality rate in the population fished; (2) the relation between stock size and recruitment. Information on (1) permits a choice of the best level of exploitation for recruits on hand; information on (2) permits the choice of the level of stock which will yield a maximum number of recruits. Abundance of stock and recruits produced are often (not necessarily always) inversely related when exploitation is light (Stage 1), but become directly related when exploitation becomes sufficiently heavy (Stage 2).

British Columbia herring are not fished heavily enough to make most use of recruits on hand, and there is as yet no indication that even the smallest level of stock observed has produced less than the maximum recruits possible for the environmental conditions prevailing. In the Pacific halibut stocks, growth and natural mortality are so nearly in balance that no important change in long-term yield (from any given number of recruits) results from change in fishing effort, over the range observed so far. The relation between halibut stock size and recruitment is still obscure, although the lowest observed level of the Western stock produced more recruits than a subsequent higher level. The most striking effect of regulation has been to increase stock density and make fishing more successful during the curtailed fishing season.

Acknowledgments

The articles shown in the reference list have provided the factual material quoted in this paper, since the author has done no field work with either herring or halibut. Mr. H. A. Dunlop of the International Fisheries Commission, and Mr. J. C. Stevenson of the Fisheries Research Board of Canada, have very kindly co-operated by discussing the more recent findings of their investigations.

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The Regulation of Trout Fishing in Alberta

by

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For some years now the feeling has been growing among fishery biologists, particularly in the United States, that sports fisheries are over-regulated. This is especially true of warm-water fishes such as blue gills, crappies and various basses. In fisheries of this kind a common observation has been that fishing deteriorates to the catching of many small fish, below legal size, and of little interest to the sportsmen. Biological investigation of such fisheries usually has revealed a very large population of very slow-growing fishes. Representations from sportsmen formerly led to stocking these waters with even more fish, a procedure which merely aggravated the situation. To the biologist it was obvious that the fault lay in an insufficient catch; too many fish spawned and too many young survived. Soon the food supply was outstripped and stunting resulted. The remedy was clearly greater fishing pressure.

These simple facts proved to be very difficult to sell to the angling public. Biologists as a whole are condemned as either dangerous theorists or impractical fiddlers; any assertion which savours of the "balance of nature theory" is bound to be vigorously contested. The truth of the situation in these warm water fisheries had to be demonstrated to the public as proven, numerical facts. A great body of the required data was provided by Eschmeyer and his co-workers on the Tennessee Valley Authority impoundments. By marking large numbers of fish and recording returns to anglers they showed that the harvest was at best some ten per cent of the available catchable population. Similar data came from workers in Indiana and from the experiments of Swingle and Smith in Alabama. These latter men, through extensive work on small fertilized ponds, demonstrated convincingly the essential role of population balance in producing desirable fish.

As a result of these studies, Alabama, and later other states bordering on T.V.A. waters, were persuaded to liberalize regulations. The first step was to abolish the closed season on lakes and reservoirs. This idea has spread all through the south and even into some of the northern states. It is restricted largely to lakes but some states have no closed season on the larger rivers. Minimum size limits have been relaxed in a few places, but this regulation and the creel limits are still largely in force.

Trout Fisheries

The preceding remarks apply only to warm water fisheries where over-crowding is a common phenomenon. That the same arguments may apply to cold water or trout fisheries has been very little considered. Rawson has reported the decline of Kamloops trout fisheries in certain lakes in the National Parks. These lakes were devoid of fish; trout were planted and achieved phenomenal growth. After a few

years, however, the trout became thin, poor and small. While there is difference of opinion as to the reasons for this, I am inclined to agree with those who attribute it largely to overcrowding.

The phenomenal success of Mr. Pautzke's lake management procedures in Washington speak, I believe, against conventional trout management methods. The crux of the Washington scheme is to catch all the trout in each lake each year; if this is not done plantings with new trout fail more markedly the older the residual trout become. If all the fish are not removed by angling and poor returns from fresh plantings are experienced the lakes are poisoned and a fresh start is made.

A certain relaxation of traditional trout regulations has also taken place in Montana. In this state several trout-containing watersheds are open the entire year. Montana also permits the taking of five undersize trout (less than seven inches) per day out of the total 15 allowed.

In general, however, this continent continues to regulate its trout fisheries according to old established traditions. Let us subject these to a critical analysis in the light of our survey findings in Alberta.

Critical Analysis of Alberta Trout Regulations

The backbone of traditional trout management consists of four main regulations, viz., closed seasons, minimum size limits, permanent closure of "nursery" streams and regular hatchery planting. I propose to examine each of these in turn.

Closed Seasons

All Alberta angling waters were closed for part of each year; opening dates ran from May 1 to June 16 and closing dates from September 30 to October 31. Each year there was a considerable amount of discussion about these dates and they have evidently been regarded as important. The principal reason appeared to be to protect trout while they were spawning and the variations in the date were because of the different spawning habits of various species in different drainages. There seems to be little actual evidence of need for thus protecting fish during their annual spawning periods. In the first place, trout are not readily catchable by angling while they are spawning; furthermore, for the spring spawners, water conditions usually make angling impossible. The run-off dirties the water so that lures are not visible. In the second place, the spawning periods of the trout are both prolonged and variable. Rainbow and cutthroat may spawn from April to August, the beginning time and ending time change from year to year and from stream to stream. It is impossible to select an opening date which is satisfactory for more than one stream for one season.

Many commercial fisheries are carried on during spawning runs, for example, the Pacific salmon fishery and many Great Lakes fisheries. To kill a female fish when it is ripe destroys no more eggs than killing the same fish before it is ripe.

In summary, the evidence suggests that closed seasons for the protection of spawning fish on our east slope streams are actually unwarranted.

Minimum legal size

It has been illegal, in Alberta, to kill trout less than eight inches in length from nose to fork of tail. The chief purpose of this law has been to allow trout to grow old

enough to spawn, at least once, before being killed. There are two main reasons why this law is of doubtful value. First is the variation in growth rate; trout grow at different rates in different streams. In the McLeod River drainage rainbow trout grow very slowly; they mature and spawn at lengths of 5-6 inches and weights of 1·5 ounces. Few reach legal size. In the Oldman River we find the other extreme; here trout grow rapidly and reach a length of ten inches before maturing. The law permitted taking immature trout in these waters. Between these extremes exist all possible intermediate conditions; most of the smaller Bow River tributaries, for example, contain trout which mature under legal size; a few possess trout which just reach legal size at maturity. In the face of all this variation, it is clearly impossible to select a legal minimum of any value; no matter what length is selected, it will prevent the taking of mature fish in some areas and allow the taking of immature fish in others.

The second reason to doubt the value of the legal minimum lies in the rates of natural mortality among trout. Research on mountain streams in California that are, through altitude, very similar to our streams, has shown that, on the average, 60 per cent of the trout die each year from natural causes. At our research station on Gorge Creek we have conducted marking experiments on wild trout which have yielded the same figure, 60 per cent, for average annual mortality. The high mortality has considerable bearing on the legal minimum. Let us start with 1,000 fry in a stream; next year but 400 remain; next year only 160, next year just 64 are left. Suppose these 64 reached legal size (8 inches). The angler is forced to select for his creel from only 64 of the 1,000 fish, and these 64 are the brood stock of the stream. In many streams another year would be required to reach legal size; then the angler has a chance at only 25 out of every 1,000 fish. Surely it would be better conservation to take some of the smaller fish as part of the daily creel; many of them would die of natural causes anyway, before reaching legal size. In this way some angling pressure would be taken off the brood stock.

"Nursery" stream closures

Continuous closure of feeder streams is one of the angler's most firmly-believed management principles in Alberta. All the unnamed streams in the Forest Reserve were permanently closed. Many tributaries of the main rivers were also kept closed or only opened occasionally. Requests for closures of feeder streams still come from local Fish and Game Associations. This practice is based on two common observations; the presence of small trout in tributaries and the occasional use of tributaries by large trout for spawning purposes. These observations have led to the conclusion that large trout from the larger streams ascend the tributaries and spawn; the small trout in the tributaries are their young, which, in the course of time will descend to the larger rivers and grow into large trout. This conclusion does not bear close examination. The small trout in the tributaries are not all young fish; many are fully grown, sexually mature fish, which spend their whole lives in the tributaries. Numbers of these small streams have been investigated that contain trout 5–7 years old, weighing 2–6 ounces; a few yards away, in the larger rivers, are trout of the same age weighing more than one pound. It is impossible that these should be the parents of the trout in the tributaries. Furthermore, traps placed in the mouths of the

tributaries, beginning in May, fail to intercept any significant downstream movement of trout throughout the summer, that should occur if the theory is true. It is true that some of the trout in the larger rivers spawn in the tributaries, possibly prompted by a search for cleaner water, but it would be virtually impossible for this continuous accumulation of young fish to remain and compete for food with a resident population whose existence has already been established by age determination. This evidence would certainly suggest that the closure of "feeder streams" for the purpose of stocking rivers is a plain waste of fish. These small fish grow up, mature and die; they contribute nothing to other parts of the drainage and much of our present legislation forbids their capture. It would appear advisable to abandon the practice of closing these streams on anything resembling a permanent basis.

Hatchery plants

Regular planting of trout streams has been the backbone of trout management in Alberta. Much has been accomplished. The now famous Bow River trout arose from such plantings; brown trout and eastern brook trout in the Bow and the Red Deer and North Saskatchewan drainage have also been established by the hatchery. The hatchery has been proven to be an efficient tool in fishery management. Its value in establishing new species or in creating trout fishing where little or no trout existed before is unquestioned. But the value of planting trout among wild, breeding populations of the same species of trout is indeed questionable. This has been the major use of the hatchery in the last ten years. It is based on the theory that streams get "fished out" and require restocking.

The question arises, what is a "fished out" stream? A great many of them have been examined here and in the United States. In the large majority of cases plenty of fish are found in these streams. It is true that most of these fish are small; it is also true that it is next to impossible to catch them (although really skilful anglers can). But, if such streams are poisoned, or treated with electric shocks, an astonishing number of trout turn up, even a number of very large ones. It must therefore be concluded that a "fished out" stream usually means a stream where anglers can't catch fish; many of the large fish have been caught and the remainder have become too wary and wise to be catchable.

Now, is it good business to put hatchery-raised fish into such streams? Only a small percentage of the fish planted from a hatchery survive in the presence of wild fish of the same species. This has been proven over and over again in streams all across the continent. In our own experiments at Gorge Creek we have shown that survival of hatchery three-year-olds in a stream containing wild trout is from 0–3 per cent; these were fish larger than the wild population. We observed no survival at all from two-year-old hatchery fish. Therefore, the only purpose in planting these fish is so that they may be taken by the angler within a few weeks of the time they were planted. This is the practice in the United States where plants of legal trout are made during the open season, not to contribute to the brood stock (for they don't), but to contribute directly to the angler's creel. We don't think that this is what the Alberta anglers want when they ask for planting of "fished out" streams. They want these streams planted and then protected so that a new brood stock may develop. This will not happen. As stated a few lines back, these "fished out" streams are already well stocked with small fish, about the size that our hatchery normally plants.

We have now examined the basic principles underlying management as it has been practised up to the present time. They appear to be inadequate or incorrect. *To continue to follow them may lead to the kind of fishing now common in many places—following the hatchery truck.* This provides two-ounce fish, requiring no skill to catch, and tasting totally unlike a wild trout. No one will deny that it is desirable, at any cost, to avoid this eventuality. Consequently, a new management plan has been worked out and is being tried as an experiment in the South Saskatchewan drainage.

New Management Plan

The new plan is not really new in its entirety. Certain features, particularly the fallowing system were suggested, and tried out by F. E. J. Fry for Algonquin Park trout lakes. (See article by Martin and Baldwin.) The main features of the plan are:—

(1) Abolition of the minimum legal size.
(2) No permanently closed "nursery" streams.
(3) *Year around fishing in open areas.
(4) A system of staggered open seasons or fallowing of streams.

The principal feature is the "fallowing" of the smaller tributary streams. It is generally agreed that small streams which have been closed appear to provide good fishing for a short period after opening. Further, there is convincing evidence that streams that have been heavily fished and provide poor fishing often contain numerous small trout. Therefore, it appears reasonable that good fishing might be provided by alternately opening and closing all but the major streams. The closed period would allow time for small trout to grow larger; it might also permit the trout to lose the wariness which they acquire after a season's fishing. The closed period must not be too long, for natural mortality would then take too big a share of production; but it must be long enough so that some worthwhile growth is achieved. As growth rates are extremely variable, the closed season should, in theory, be different for each stream. As such an arrangement would be very difficult from an administrative point of view, some compromise is necessary. Thus, where growth is generally slow, the closed period has been set at two years (open every third year) and where growth is generally fast, the closed period is every other year.

To implement this plan, the east slope has been divided into four major areas. These are:

I. Athabasca drainage
II. North Saskatchewan
III. Bow River drainage } South Saskatchewan
IV. Oldman drainage }

In each of these major areas the main streams are regarded as too large to require management. These are in Area I, the Athabasca River, the McLeod River and the Pembina River; in Area II, the North Saskatchewan, the Clearwater and the Red Deer; In Area III, the Bow, the Elbow, the Jumping Pound, the Sheep and the

* *Except that it is illegal to fish through holes in the ice in streams.*

Highwood; in Area IV, main Willow Creek, main Oldman River, main Castle River. All these rivers would be continuously open. All other streams would be subject to alternate opening and closure.

At the time of writing the legal minimum has been abolished in all the areas beginning with 1951. The remaining features have been implemented only in the South Saskatchewan drainage where the fishing pressure is heaviest. The present season, 1952, is the first under the plan and it is too early for any deductions on the success or otherwise of the venture.

Effects of the Alternate Closure of Algonquin Park Lakes

by

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When highway No. 60 was completed through the southern portion of Algonquin Park in 1936, that area became much more accessible to anglers than in the past. A creel census initiated by the Ontario Fisheries Research Laboratory in 1936 soon provided evidence that in some of the more heavily fished lakes large proportions of the mature trout were being removed by anglers (Fry, 1939a). It was believed that if this situation continued, spawn production might be reduced to a point where it would limit the population of trout. In order to reduce the possibility of further deterioration in certain lake trout fisheries, closure to fishing in alternate years was proposed for lakes where fishing mortality was believed to form a large part of the total mortality and where mature trout were fully exposed to fishing pressure. In these situations the closure was to be undertaken to allow periodic strengthening of spawning stocks and encourage higher egg production.

Relatively heavy fishing pressure on the eastern brook or speckled trout population in Redrock Lake in 1936 and 1937 was followed by a marked drop in the quality of fishing. The lake was closed to fishing in 1938 and opened in 1939. The improvement in fishing (Fry, 1939b) resulted in the application of the closure plan to a number of lakes providing speckled trout fishing.

Some 21 of the more accessible lakes in the southern part of the Park were on the closure list by 1940 and by 1948 the total reached 36. No lakes with cottages or lodges on their shores were included. Lakes in the alternate closure system were grouped in pairs, one lake remaining open while the adjacent lake was closed and vice versa in the following year.

After 1948 further extension of the closure plan was considered because of the increase in air travel. In 1948 about 900 anglers were flown to lakes in the interior of the Park. It was suggested that these lakes, at one time accessible only by canoe, might require the same protection afforded lakes close to the highway, particularly, as it soon became evident that commercial aircraft operators were concentrating their fishermen year after year in the same lake. The closure plan was therefore extended in 1949 to include 106 lakes in the interior of the Park. While this extension may be judged premature, in so far as the effects of closure were still unknown, it was prompted by the fear that the increased fishing intensity brought to bear on the interior lakes by airborne anglers might damage a number of attractive sport fisheries. This action might be called "term insurance" to be carried until such time as adequate information on the effects of fishing was collected.

Methods

The Algonquin Park creel census has been used to study the effects of alternate closure. The information it has provided has been of two types. A general census in southern Algonquin Park from 1937 to 1950 has provided information on the average length of the fish taken and the catch per unit effort or availability in about 20 lakes. The catch reported by the census on these lakes is believed to be 30 to 80 per cent of the total catch.

In one group of five lakes a more complete census has been possible because fishermen in this area generally pass through one centrally located checking station. Examination of a major portion of the catch from these lakes has been possible and scale collections have allowed study of the age composition of the catch. The census in these lakes gives an estimated coverage of from 80 to 90 per cent of the total catch.

Results: Lake Trout

The quality of lake trout fishing has been given a numerical value or index (Fry and Chapman, 1948). This value for any particular lake has been calculated in the following manner. When availability or catch per unit effort is plotted against the average length of the season's catch for Algonquin Park lakes the points tend to fall within a profile marked by a curve which rises steeply at 14 inches, reaches a peak of availability at 16 inches and then falls off as the average length of the catch increases. Below the profile, which represents the best fishing that can be expected in these lakes, other curves can be drawn at equal intervals to represent lower levels of angling quality. The fishing quality in a lake in any year can therefore be given a single value dependent on both the availability and the size of the fish. These values generally vary from 10 to 90 but values of 110 occasionally occur when fishing is exceptionally good.

In Table 1, which is an extension of a table presented in a previous paper (Fry, 1949), angling quality in the more heavily fished lakes covered by the general census is shown. The data have been grouped to allow a rough comparison of the quality in those lakes incorporated in the alternate closure system, Group A, and those open to fishing in consecutive years, Group B. As yet there is no marked difference in the quality of fishing in these two groups of lakes. There is a possibility, however, that a difference may still develop for the following reason. The lake trout fisheries in Algonquin Park are, at the present time, dependent on those year classes spawned during the period 1942–1945. At this time fishing pressure on almost all the lakes in the area was comparatively light as a result of wartime travel restrictions. After 1945 fishing pressure increased. Year classes entering the fisheries in the next few years should reflect the effects of closure better than those year classes now in the fisheries.

In Table 2 the creel census returns of the three lake trout lakes to be studied in detail are compared with those of Lake Opeongo which has been statistically analysed previously by Fry (1949).

It may be seen that the fisheries of Happy Isle, Merchants, and Redrock Lakes have undergone marked fluctuations in the availability and size composition of the catch. In Merchants Lake in particular, the average length has varied over a range of four inches and the availability risen and fallen some 100 units. The total catch of lake

Table I

Quality of lake trout fishing in some accessible Algonquin Park lakes as measured against a standard profile of availability (see text)

Lake	Index of angling quality for years:													
	1937	1938	1939	1940	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950
Group A—														
Canisbay	—	50	30	cl	30	cl	50	cl	50	cl	30	cl	50	cl
Head	—	50	30	cl	50	cl	30	cl	30	cl	30	cl	30	cl
Little Island	—	—	30	cl	50	cl	30	cl	30	cl	30	cl	30	cl
Merchants	90	90	cl	50	cl	70	cl	30	cl	50	cl	30	cl	30
Ragged	70	cl	70	cl	50	cl	70	cl	50	cl	70	cl	—	cl
Redrock	30	cl	50	cl	50	cl	70	cl	30	cl	30	cl	30	cl
Average Index	63	63	42	50	46	70	50	30	38	50	38	30	35	30
Group B—														
Burnt Island	—	—	110	90	10	90	50	70	90	90	—	50	30	50
Cache	30	30	10	30	30	30	30	30	30	30	50	30	30	50
Louisa	70	110	70	50	50	90	90	50	70	30	30	30	cl	30
Opeongo	70	50	50	50	30	50	70	70	70	50	50	30	30	30
Smoke	50	50	50	50	50	70	70	70	50	—	50	50	—	70
Source	30	30	30	—	10	10	10	10	30	—	50	30	50	30
Tanamakoon	—	30	30	—	10	30	30	30	30	30	50	30	50	—
Two Rivers	30	—	30	30	30	30	50	50	50	30	10	10	—	—
Average Index	47	50	47	50	27	50	50	48	52	43	41	32	38	43
Average Index, all lakes	52	54	45	50	35	52	50	46	47	44	40	32	37	41

cl—closed to fishing.

Table II

Summary of creel census returns for lake trout from four Algonquin Park lakes, 1937–1952

Year	Opeongo			Merchants			Happy Isle			Redrock		
	Number of fish reported	Average length in inches	Fish per 100 boat hrs.	Number of fish reported	Average length in inches	Fish per 100 boat hrs.	Number of fish reported	Average length in inches	Fish per 100 boat hrs.	Number of fish reported	Average length in inches	Fish per 100 boat hrs.
1937	2,029	18·7	121	87	19·8	136	105	17·7	169	328	18·1	144
1938	1,304	18·4	101	441	20·3	122	264	17·7	113		closed	
1939	1,233	18·4	112		closed		73	18·5	120	331	18·1	113
1940	1,133	17·9	120	137	16·8	182	76	15·7	144		closed	
1941	885	17·4	97		closed		50	16·7	100	216	17·9	120
1942	504	18·5	111	97	17·7	201	77	15·9	183		closed	
1943	704	18·4	126		closed		75	15·0	139	87	18·7	153
1944	835	18·8	126	131	17·2	106	78	17·1	97		closed	
1945	1,139	19·7	101		closed		21	17·6	85	78	17·4	69
1946	976	18·8	70	476	18·9	112	78	16·6	118		closed	
1947	705	18·3	72		closed		13	15·0	70	177	17·6	81
1948	984	18·2	68	143	16·7	96	122	15·8	130		closed	
1949	1,133	18·4	74		closed		190	15·7	139	146	17·5	97
1950	1,343	18·5	62	452	16·7	95		closed			closed	
1951	1,208	17·9	58		closed		524	15·8	123	172	19·6	81
1952	994	18·8	70	803	16·5	152		closed			closed	

trout in 1952 in this lake was nearly that reported for Opeongo, a lake more than ten times its size. A similar fluctuation is apparent in Happy Isle Lake and to a lesser extent in Redrock. As will be pointed out such fluctuations are the result of uneven year class strength in these lakes. In Lake Opeongo on the other hand, there has been a consistent decline in the fishery since the early forties. No strong year classes

Table III

Percent age composition of the lake trout catch from Happy Isle Lake, Algonquin Park, 1938–1951

Year	Reported catch	Age group											
		4	5	6	7	8	9	10	11	12	13	14	15
1938	264	—	—	1	24	42	9	15	2	1	2	1	2
1939	73	No age data											
1940	76	—	—	4	68	21	4	4	—	—	—	—	—
1941	50												
1942	77												
1943	75												
1944	78	No age data											
1945	21												
1946	93												
1947	13												
1948	85	—	—	5	64	23	3	3	2	—	2	—	—
1949	190	1	1	10	63	13	7	1	1	—	—	1	—
1950	Closed												
1951	524	—	3	19	57	18	—	3	—	—	—	1	—
1938–1951		—	2	13	52	22	3	5	1	—	1	1	—

Table IV

Percent age composition of the lake trout catch from Merchants Lake, Algonquin Park

1939–1952

Year	Reported catch	Ages												
		4	5	6	7	8	9	10	11	12	13	14	15	16
1937	87	—	4	10	28	30	12	6	4	2	2	2	—	—
1938	441	1	1	—	10	27	24	11	10	6	5	3	3	—
1939	Closed													
1940	176	—	1	6	26	33	10	15	8	—	—	—	—	1
1941	Closed													
1942	97													
1943	Closed													
1944	131	No age data 1941–1947												
1945	Closed													
1946	477													
1947	Closed													
1948	143	—	2	14	52	18	8	3	—	3	—	—	—	—
1949	Closed													
1950	452	—	—	12	54	16	5	4	1	5	1	2	—	—
1951	Closed													
1952	803	—	1	6	45	33	10	3	1	1	—	1	1	—
1937–1952	2,807	—	1	6	32	28	14	7	5	3	2	1	1	—

Table V

Per cent age composition of the lake trout catch from Redrock Lake, 1937–1951

Year sampled	Reported catch	Per cent of catch in ages									
		4	5	6	7	8	9	10	11	12	13
1937	328	3	4	17	31	22	14	4	4	1	—
1938	Closed										
1939	331	—	8	23	42	15	2	2	5	—	2
1940	Closed										
1941	216	—	4	6	25	36	17	8	2	2	—
1942	Closed										
1943	87										
1944	Closed	No age data 1942–1946									
1945	78										
1946	Closed										
1947	177	2	4	25	35	24	9	1	1	—	—
1948	Closed										
1949	146	2	—	1	21	34	25	13	4	—	—
1950	Closed										
1951	172	—	1	2	14	25	22	24	7	5	1
1937–1951	1,535	2	3	11	24	26	17	11	4	2	—

have entered the fishery in this time. It has been pointed out by Fry (1949) that the intensity of the fishing in this lake which has a sparse population of trout, has reduced the spawning escapement sufficiently to adversely affect year class strength.

The percentage age composition of the lake trout catches in certain years is given in Tables 3, 4, and 5, for Happy Isle, Merchants and Redrock Lakes. These data are based on the examination of scale samples from 1,750 fish. Unfortunately scale collections are sparse for the period 1941–1944 so that only the material from the years prior to 1941 and the last five years has been adequate for analysis. The data presented show that since 1945 only a few lake trout are taken in the fisheries in their fourth or fifth year, about 10 per cent in their sixth while most enter at age seven at a length of about 16 inches.

It is interesting to note the difference in age composition between the 1938 catches when the fisheries were fished heavily for the first time and the catches in recent years. About 40 per cent of the fish in Happy Isle Lake in 1938 were nine years and over and about the same percentage in Merchants Lake in the same year were 10 years and over. In recent years these groups of fish have only made up about 10 per cent of the catch. In Happy Isle and Merchants Lakes the seven and eight year old fish have made up 70 to 80 per cent of the total catch since 1947 and in Redrock Lake about half of the fish caught were in these two age groups.

In Tables VI, VII and VIII the data have been organized into year classes which were based on spawning rather than hatching years. The treatment adopted for Lake Opeongo lake trout by Fry (1949) is used to compare the strength of year classes spawned in open and closed years. The complete contribution of any one year class to the fishery cannot of course be shown over the five years span covered by these tables. Part of the data represents the "tail ends" of preceding year classes in the fishery or the beginnings of new ones. However, as the major part of the fishery in each lake

Table VI

Year class contribution to the lake trout fishery in Happy Isle Lake, 1948–1951

Year of Capture	Year spawned											
	1934	1935	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945
1948	1	—	1	3	3	19	54	4	—	—	—	—
1949	3	—	—	3	3	14	24	118	19	3	3	—
1951	—	—	3	—	—	—	17	—	94	297	99	14
Total contribution to date	—	—	—	—	—	—	95	122	113	300	—	—

Table VII

Year class contribution to the lake trout fishery in Merchants Lake, Algonquin Park, 1937–40 and 1948–1952

1937–1940

Year sampled	Year spawned												
	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934
1937	2	2	2	3	5	10	26	24	9	3	—	—	—
1938	13	13	23	27	43	47	108	120	43	0	4	2	—
1939 Closed													
1940	—	2	—	—	—	—	12	20	13	45	35	8	2
Total contribution to date	—	—	—	—	—	—	—	164	65	—	—	—	—

1948–1952

Year sampled	Year spawned											
	1935	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945	1946
1948	4	—	4	11	26	73	20	2	—	—	—	—
1949 Closed												
1950	11	5	21	5	16	21	74	242	58	—	—	—
1951 Closed												
1952	—	8	4	—	4	11	22	78	264	366	48	4
Total contribution to date	—	—	—	—	—	105	116	322	322	—	—	—

Table VIII

Year class contributions to the lake trout fishery in Redrock Lake, Algonquin Park, 1937–1941 and 1947–1951

1937–1941

Year sampled	Year spawned											
	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935
1937.....	3	3	16	46	74	101	59	15	12	—	—	—
1938 Closed												
1939.....	—	8	—	17	8	8	49	141	74	25	—	—
1940 Closed												
1941.....	—	—	—	—	4	4	18	36	77	54	14	9
Total contribution to date	—	—	—	—	—	113	126	192	163	—	—	—

1947–1951

Year sampled	Year spawned										
	1935	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945
1947.....	2	2	16	42	61	44	6	3	—	—	—
1948 Closed											
1949.....	—	—	6	19	37	49	31	1	—	—	—
1950 Closed											
1951.....	—	—	1	9	11	41	38	43	24	4	1
Total contribution to date.....	—	—	—	—	109	134	75	—	—	—	—

is supported by two or three year classes, it is possible to estimate the total contribution of a year class even if it has not entirely passed through the fishery. In the tables the "Total contributions to date" represents 80–90 per cent of the complete totals. The total contribution of each of these year classes, apart from the 1942 and 1943 in Merchants Lake and the 1943 in Happy Isle has been of the order of 90–200 lake trout. Strong 1943 year classes in Happy Isle and 1943 and 1944 in Merchants Lake will each contribute over 350 lake trout to the fisheries of the respective lakes.

The sudden entrance of a year class into the fishery at seven years of age is demonstrated in 1949 when the 1941 year class appeared in Happy Isle Lake. The sudden disappearance two years later indicates an intensive fishery in 1951.

On the basis of the data in the foregoing tables, which are summarized in Table IX, there appears to be no evidence at the moment that alternate closure has been instrumental in providing stronger year classes of lake trout. In Merchants Lake, which has been closed in the odd years, the 1940 and 1941 year class contributions have been approximately the same as have the 1942 and 1943. The 1944 year class which first entered the fishery in 1952 as seven year old fish, is exceptionally strong (see Table VII). Although it was probably heavily exploited in 1952 it may still provide 400–500 trout to the fishery. In Redrock Lake, which has been closed in the even years, the little evidence at hand does not indicate stronger year classes in closed years. In Happy Isle Lake, where the closure was not put into effect until 1950, there has been a uniform year class production up to the 1942 year class of 100–130 trout. Apparently there are two very strong succeeding year classes in this lake, the 1943 which was the mainstay of the 1951 angling and the 1944 which began to enter the fishery in 1951 and which may contribute considerably to the fishing in 1953.

Table IX

Summary of year class contribution to the lake trout fisheries of Happy Isle, Merchants and Redrock Lakes, Algonquin Park

Year spawned	Number of fish of various spawning years contributed to the fishery		
	Happy Isle Lake	Merchants Lake	Redrock Lake
1928	—	—	—
1929	—	164	113
1930	—	65	126
1931	—	—	192
1932	—	—	163
1939	—	—	109
1940	95	105	134*
1941	122	116*	75
1942	113	322	—
1943	300	322*	—

* *Spawned in year closed to fishing.*

There does not appear to be any correspondence in the years when strong year classes are spawned in the various lakes, which suggests that the factors concerned in year class production are determined in each lake itself rather than being of an overall nature such as meteorological conditions.

Results: Speckled Trout

Four speckled trout lakes have been under the closure system since 1940. Only two lakes, Redrock and Proulx, have been well covered by the creel census and it is on these two lakes that the effects of closure on speckled trout fisheries are being studied. In these lakes the reported catch is estimated to be about 80 per cent of the total catch although somewhat better coverage was obtained in 1947 and 1949 for the fishing in Redrock Lake.

A summary of the information provided by the creel census is presented in Table X. Information on gill net catches appears as a footnote.

Table X

A summary of creel census returns for speckled trout from Redrock and Proulx lakes, Algonquin Park, 1936–1952

Year	Lake	Number of fish reported taken	Fishing pressure in boat hours	Fish per 100 boat hours	Average length in inches
1936	Redrock	555	347	160	11·7
1937	"	398	312	124	11·1
1939	"	631	297	212	12·6
1941	"	487	271	180	12·7
1943	"	352	189	186	13·1
1945	"	497	270	184	12·5
1947	"	346	286	121	11·7
1949	"	662	525	126	12·8
1951	"	480	424	113	13·2
1938	Proulx	138	67	206	12·3
1939	"	118	147	80	12·5
1940	"	107	96	112	12·4
1942	"	83	85	98	12·2
1944	"	336	295	114	12·6
1946	"	156	211	74	12·0
1948	"	373	256	146	11·9
1950	"	238	345	69	13·0
1952	"	282	297	95	13·6

156 trout averaging 8·1 inches taken in gillnets in 1947
36 " 12·8 " " " " 1949
5 " 10·0 " " " " 1951
31 " 12·0 " " " " 1950

According to the outfitters and guides in the area, Redrock was lightly fished prior to 1936. In 1936 and 1937 fishing pressure increased. The average size of the catch and the availability fell in 1937. After it was closed to fishing for a year it again provided fish of good size. The availability also rose. During the open years 1941-43-45 the lake was lightly fished and the size and availability of speckled trout remained high. In 1947 and 1949 fishing pressure became heavier and although the average size of the fish taken remained high the availability dropped to a lower level. A record catch of speckled trout for this lake was taken in 1949. A tagging experiment in the spring of that year (Baldwin, 1949) showed that about 75 per cent of the mature trout in the population were removed by angling. The results of the tagging experiments coupled with observations in seasonal changes in size of trout caught (Baldwin, 1948), and rough reciprocal relationships between fishing pressure and availability support the contention that Redrock was very thoroughly fished in the years 1947, 1949 and 1951. Theoretically therefore, the closure should be particularly beneficial to the speckled trout fishing now.

Proulx Lake, on the other hand, has probably been underfished. Although it is slightly larger than Redrock the catch has been smaller and the availability generally lower. The proportion of old fish in the Proulx catch has been higher than in the Redrock catch. Closure in alternate years would not on theoretical grounds, therefore, be as effective as in Redrock.

Since 1947 scale samples have been collected from the speckled trout caught in Redrock and Proulx lakes. The age composition of the catch from Redrock and Proulx lakes, based on the examination of scales from about 1000 speckled trout representing about half the catch, is presented in Tables XI and XII. Speckled trout enter these fisheries as two-year-olds and disappear from the fishery almost completely as six-year-olds. About half the catch in Redrock has been composed of three-year-olds while in Proulx four-year-olds have made the major contribution. This is believed to reflect the lighter fishing pressure in the latter lake.

Table XI

Percent age composition of the speckled trout catch from Redrock Lake, Algonquin Park, 1947–1951

Year	Reported catch	Age group					
		1	2	3	4	5	6
1947.....	346	—	34	30	33	3	—
1949.....	662	—	6	69	24	7	—
1951.....	480	—	18	47	29	6	—
1947–49–51	1,488	—	16	53	28	3	—

Table XII

Percent age composition of the speckled trout catch from Proulx Lake, Algonquin Park, 1950–1952

Year	Reported catch	Age group					
		1	2	3	4	5	6
1950.....	241	—	14	30	44	11	1
1952.....	282	—	23	33	35	8	1
1950–52....	523	—	18	32	39	10	1

It has been possible to build up Tables XIII and XIV showing the contributions to the fishery of four year classes in Redrock and two year classes in Proulx. The total contributions of the year classes spawned between 1944 and 1947 in Redrock range from 185 to 569 fish. The strongest year class recorded was spawned in 1945, a year open to fishing. The weakest year class recorded was spawned in 1946 after the lake had been closed to fishing for a year. In Proulx Lake the year class spawned in

Table XIII

Year class contributions to speckled trout fishery, Redrock Lake, Algonquin Park, 1947–1951

Year sampled	Method	Year spawned							
		1941	1942	1943	1944	1945	1946	1947	1948
1947.....	angling	11	115	102	117	1	—	—	—
	netting	—	2	8	84	62			
1949.....	angling	—	—	6	159	457	40	—	—
	netting	—	—	—	—	20	16	—	—
1951.....	angling	—	—	—	—	29	139	224	88
	netting	—	—	—	—	—	—	—	5
Total Contribution.....		—	—	—	350	569	185	224	—

Table XIV

Year class contributing to the speckled trout fishery in Proulx Lake, Algonquin Park, 1950–52

Year sampled	Method	Year spawned							
		1943	1944	1945	1946	1947	1948	1949	1950
1950.....	angling	3	27	105	72	34	—	—	—
	netting	—	—	—	16	15	—	—	—
1952.....	angling	—	—	2	24	99	93	64	—
	netting	—	—	—	—	—	—	—	—
Total contributions.....		—	—	—	112	148	—	—	—

the closure year was stronger than that spawned in an open year but no great significance should be attached to this limited information. There is no evidence yet that the closure is materially aiding these speckled trout fisheries by encouraging stronger year classes.

Discussion and Conclusions

Some limited conclusions can be drawn from the evidence collected to date. First, the quality of the lake trout fishing in the lakes on the closure plan has not differed materially from the quality in those lakes open to fishing in consecutive years. Secondly, there is no evidence that stronger year classes have arisen in closed years in three lakes during the period 1939 to 1943. Thirdly there is no evidence that stronger year classes of speckled trout have developed in the closure years in one lake during the period 1944 to 1947.

The data at hand for lake trout, however, reflects the effects of closure in a period when fishing pressure was relatively light. Whether this will change with

present fishing pressure, which is comparatively heavy, has yet to be seen. In the next four years the collection of census material should greatly improve our understanding of the effects of closure on lake trout for this information, coupled with that now on hand, will cover a span of years in which fishing pressure was first light, then heavy. The material collected by that time should justify fuller treatment than has been accorded it now.

Similarly, a study of the effects of alternate closure on speckled trout fisheries should be continued and an evaluation delayed until the 1948 and 1949 year classes of speckled trout have passed through the Redrock and Proulx fisheries.

It has not been possible to compare a group of speckled trout lakes on the closure system with a group not on the closure system. It may, therefore, be advisable to open either Redrock or Proulx or perhaps both to fishing in consecutive years in order to provide a comparison of the effects of closure on speckled trout fishing.

There are two things that the closure may have accomplished but which cannot be easily demonstrated. First, the closure system has interrupted the fishing habits of certain groups of anglers who, instead of returning year after year to the same lake, have in the last few years successfully fished a large number of lakes thus giving a wider distribution of angling pressure than might otherwise have occurred. Second, one of the angling attractions in the Park is the large size of the speckled trout taken in early spring. These spectacular spring catches would probably not occur as frequently if fishing in consecutive years was allowed.

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The History of Lake Minnewanka with Reference to the Reaction of Lake Trout to Artificial Changes in Environment

by

Jean-Paul Cuerrier

Canadian Wildlife Service
Department of Northern Affairs and National Resources, Ottawa.

Lake Minnewanka, located in Banff National Park, has been investigated on several occasions since 1936. Data have been collected by Dr. D. S. Rawson (1936, 1938, 1941 and 1943), by Warden J. E. Stenton (1945, 1947, 1949 and 1951), by Dr. V. E. F. Solman (1947), and by the author and his field party[1] (1952) with particular respect to lake trout, cisco and Rocky Mountain whitefish, plankton, bottom fauna, and the physical and chemical characteristics of the lake.

The lake trout population of Lake Minnewanka has suffered several ecological changes resulting from successive increases in the water level for electric power development. This lake, which was once popular for its lake trout angling, is now almost depleted of large individuals of that species and inhabited by a dense population of small lake trout. Since this lake is the largest body of water in the vicinity of Banff and the demand for angling is high, it is desirable to make attempts to improve angling prospects.

Lake Minnewanka is located about five miles from the town of Banff. At high water its surface lies at 4,840 feet above sea level. Surrounding peaks range in height from 7,000 to 9,000 feet. Under original conditions the surface level was 4,763.7 feet above sea level and the area was 3,464 acres. In 1911 and 1912, a small dam for electric power development was built across the Cascade River at the outlet of the lake, raising the level a maximum of 12 feet and adding 467 acres to the original lake area.

In 1941, a much larger and higher dam was built below the old one. This dam raised the water level an additional 64.3 feet and added 1,524 acres to the area of the former lake. The maximum draw-down of the water level is now 35 feet from the maximum level of 4,840 feet. At present, when the water in the reservoir is at its maximum level, the total area of the lake is 5,454 acres, i.e., 8.3 square miles. A new outlet diverts the water south through Two Jacks Lake, a new area of 96 acres, which flooded the former Summit Lake, and through a canal about $1\frac{1}{4}$ miles long. The draw-down of Two Jacks Lake is 16 feet, exposing nearly one-half of the lake bottom.

[1] *F. H. Schultz, Limnologist, Canadian Wildlife Service, and J. Shapiro, summer assistant.*

The average depth of Lake Minnewanka is about 170 feet at maximum water level, and the maximum recorded depth is 325 feet.

The duration of ice cover is approximately 120 days. The lake usually freezes over by the end of December and breaks up in early May. During the period prior to 1941, the lake trout population was considered normal and provided adequate angling for that species. The present status of the lake trout population is demonstrated by the fact that the catch of lake trout by angling or by netting consists almost exclusively of fish measuring less than the legal length of 15 inches. Trolling for lake trout has become increasingly rare during the last four or five years and the catch of good-sized trout has decreased drastically. Angling for lake trout by still-fishing is now limited to the lower end of the lake and to the vicinity of the Cascade River outlet. Gill net tests have shown the presence of an unbalanced lake trout population consisting of a small proportion of lake trout weighing more than one pound and of a very large proportion of smaller individuals. The rate of mortality seems to be very high when the fish have reached 12 or 13 inches in length. The ecological conditions which have developed since 1941 seem inadequate for the survival and growth of lake trout after they have reached that critical period in their life history.

Physical—Chemical Conditions

Data available on water temperature, oxygen and pH since 1936 indicate that physico-chemical conditions of Lake Minnewanka have not changed to any great extent from year to year. Differences are considered to be within the range of variations caused by one season being earlier, later, warmer, or colder than another.

Dr. Rawson obtained data on water temperatures during the months of February and March, 1944. Temperatures ranged from 0·8° C. to 1·4° C. from surface to bottom in mid-February, and a uniform temperature from surface to bottom of 1·5° C. was recorded in mid-March.

During the summer of 1952, the highest surface temperature, 17·7° C. was recorded on July 17. In deep water, at 50 metres, a temperature of 9·0° C. was recorded on August 5.

Dissolved oxygen is plentiful at all times and at all depths. In spite of the increase in water depth and the decomposition of woody debris, the dissolved oxygen concentration near the bottom exceeds the minimum needed for fish.

Plankton

Qualitative and quantitative samples taken in 1941 led Dr. Rawson to the conclusion that up to that time there had been no important change in the composition of the plankton population of the lake. The dry weights of samples collected in 1941 were similar to those of samples secured in 1936 and 1938. In 1943, the average quantity of plankton per total vertical haul was nearly five times greater than the averages obtained from previous samplings, because of a pulse of the diatom *Frigilaria*. The analysis of material collected during 1952, which is now in progress, indicates that the same species are still present in the lake and that the density of population, even if it fluctuates according to the time and location of sampling, is within the range of

averages obtained previously. The final figures are expected to indicate a slight increase in the plankton population. Like Dr. Rawson, the writer feels safe in saying that there is no evidence "that flooding has interfered with the plankton production and it may have resulted in some increase".

Bottom Fauna

Since fluctuations in the population of bottom organisms were forecast as a result of flooding, biologists who have investigated Lake Minnewanka have paid particular attention to the collection and analysis of this material.

As expected the construction of the new dam and the 64-foot raise in water level were followed by a decrease in the average number of bottom organisms to the acre and by a change in relative abundance of the constituent organisms as shown by Dr. Rawson's studies carried out in 1943. In 1947, six years after the construction of the dam, an increase in bottom fauna was recorded by Dr. Solman. Samples secured during 1952 seem to indicate that the bottom organisms are in the process of adaptation to the new environment and that their production per unit of area has further increased. Table 1 summarizes data on bottom fauna in Lake Minnewanka in the years 1936 to 1952.

Table 1

Year of Collection	Number of Samples	Per cent composition by number of		Average dry weight of organic matter per acre, in lbs.
		Chironomids	Sphaeriidae	
1936	42	52·5	38·6	6·5
1941	22	58·8	28·6	3·5
1943	64	92·7	2·7	2·9
1947	29	92·6	1·5	4·0
1952	40	93·5	4·6	5·1

Organisms usually found on or in the lake bottom include larvae and pupae of aquatic insects such as chironomids, mayflies and caddis flies, and also sphaeriids, gastropods, amphipods and oligochaetes. Samples collected in 1936 and 1941 indicated that chironomid larvae and sphaeriids were the main components of the bottom fauna. In 1943, a sharp decrease in sphaeriids and a sharp increase in chironomids were noted. In 1943 and 1947, chironomids constituted 93 per cent by number of the total number of organisms collected. The 1952 samples present the same high proportion of chironomid larvae. Amphipods have fluctuated between 1·7 and 3·1 per cent of the total number of animals during the period of 1938 to 1947, but oligochaetes, gastropods and larvae of insects other than chironomids are almost absent in recent samples.

The newly-flooded areas from which the water is withdrawn for almost five months of the year are not productive. Chironomid larvae are found in small numbers, and they are of a much smaller size than those collected at the same time in deep water.

It is believed that eggs laid by adult flies on the surface of the water fall to the bottom. When the water recedes they are left bare. The development of the eggs is delayed, therefore, until they are again in the water. Because of the possible annual fluctuation of 35 feet, the 645 acres left uncovered by water for part of the year will never permit the growth of aquatic or semi-aquatic vegetation and the bottom fauna in this area is expected to remain limited.

Among the species of fish inhabiting Lake Minnewanka, the suckers, the Rocky Mountain whitefish, and the lake trout, normally piscivorous, are bottom feeders. Cisco are generally plankton feeders. It is interesting to note that, in spite of the increase in the proportion of young lake trout which have been found to feed almost exclusively on chironomid larvae, the bottom organisms are increasing in number, thus indicating that the bottom fauna is not being fully utilized by the species of fish present in the lake.

Spawning Grounds for Lake Trout

In his 1938 report Dr. Rawson estimated that the 12-foot vertical variation in water level resulting from the first impoundment must have "profound effect on the spawning and development of the lake trout, if it does not altogether prevent reproduction". Because of annual plantings of lake trout fingerlings since 1914, catches of small fish could not be considered evidence of successful natural reproduction. These plantings were discontinued in 1938 because of the difficulty of securing eggs. After construction of the 1941 dam it was believed that lake trout spawning and early development was in danger. For this reason the licence issued on May 14, 1947, for the storage of water and the development of water power at Lake Minnewanka stipulated that the Company was to safeguard game fish in Lake Minnewanka and pay for the restocking of this lake.

Observations made with an underwater television camera have indicated that spawning grounds for lake trout are still available in deep waters and that eggs were laid at depths beyond the limit of lower water. It seems that the annual draw-down of water has not interfered with lake trout spawning activities, and, further, that the survival of eggs and fry is greater than before the construction of the 1941 dam. This condition might possibly be explained on the theory that the activity of spawners over spawning grounds before the dam was constructed may have resulted in low survival of eggs and that consequently production of young fish and return of adult fish were low. Similar observations made on Pacific salmon have shown that, if small runs of mature fish occurred in one year, large returns of spawners of that year-class were later recorded.

The Lake Minnewanka conditions could be compared with those described by Sven Runnstrom, who studied the Arctic char population in a regulated lake in Sweden. Runnstrom recalls that, when the dam was constructed at the outlet of Lake Torron, the fisheries biologist had forecast a reduction in the trout population, owing to failure of spawning and the destruction of eggs left dry in shallow areas by the water level variations. Observations made during a period of 13 years have shown that the total population of trout has not dropped in number and that the population has even grown

too big for the changed food conditions. With reference to spawning grounds, Runnstrom explains that char continued to spawn at the old spawning places during the first few years after the construction of the dam and that on the newly-flooded parts of the shore the stone and gravel bottom offered new suitable spawning places which were also occupied by the trout. Therefore the total area of suitable spawning grounds was considerably enlarged, permitting the spawners to disperse over the wide area and preventing over-crowding over a limited spawning ground. Runnstrom and also Fabricius, who made similar observations at Lake Storsjouten, Sweden, concluded that "it would seem that the spawning is more dependent on the nature of the bottom than on the depth".

Trout spawning in Lake Minnewanka appears to have considerably greater vertical distribution now than it had before 1941. When the draw-down occurs before the end of February, eggs then developing at depths of less than 15 feet fail to hatch; nevertheless, the rate of survival of eggs laid in deep water is so great that such losses are offset. It is therefore concluded that the construction of the dam in 1941 has not been detrimental to a potential production of an adequate lake trout population. It is also concluded that plantings of lake trout are not required.

Size Distribution and Growth of Lake Trout

Samples collected in 1936, 1938, and 1941 at Lake Minnewanka, by standard netting operations, indicated a normal population of lake trout where individuals of all sizes were well represented. In the 1943 sample, a scarcity of lake trout between 10 and 15 inches was noted. In the same sample the number of lake trout between 7 and 10 inches in length was greater than in previous samples, indicating that they had increased considerably. Since 1943, the increase in the number of fish of that size in the gill net catches has become more and more pronounced, and the catch of individuals of larger size has continuously decreased. In 1941, lake trout between 8 and 12 inches in length represented 17·6 per cent of the total catch by gill nets. In 1947 lake trout of that size range represented 65·1 per cent. For those between 16 and 20 inches in length the percentage dropped from 38·9 in 1941 to 6·7 in 1947. From samplings carried out during 1952, lake trout of the 8 to 12-inch length range represented 91 per cent of the total catch made by standard gangs of gill nets.

A detailed study of the length distribution of the gill net catch made in 1943, with poor representation of fish between 12 to 15 inches, seemed to suggest that there had been a failure in spawning and in survival of eggs. However, later samplings showed the same gap between an increasing proportion of small fish and a decreasing proportion of large fish. This supports the concept that spawning is successful, but the survival rate of young trout after they have reached an average length of 12 inches is very low. This critical stage in the life history of the lake trout at Lake Minnewanka coincides with the age of 4, 5, and 6 years.

The growth in length and in weight of the young lake trout in Lake Minnewanka is much slower than the growth of the same species of fish in the Waterton Lakes. Table 2 gives the average weights, for various ages, of the lake trout from these bodies of water.

Table 2

Age	Average Weights of Lake Trout		
Years	Lake Minnewanka	Lower Waterton Lake	Upper Waterton Lake
	lbs.	lbs	lbs
3	0·2	—	0·3
4	0·4	1·8	0·8
5	0·6	2·8	1·3
6	0·9	3·9	1·9
7	1·5	5·5	3·7
8	6·1	8·2	5·0
9	9·2	11·8	12·1
10	12·7	16·4	15·7
11	17·5	22·0	17·1

It should be noted that after the sixth year of life, the growth in weight increases at a high rate, even in Lake Minnewanka. It is among the small lake trout that the marked difference in rate of growth between Lake Minnewanka and the Waterton Lakes is significant and apparently of great importance. It seems that some limiting factors affect most of the young fish during their first five or six years of growth and that the heavy mortality occurs when the lake trout have reached five years of age. Sexual maturity has been found among 12 to 15-inch lake trout, which is normal as far as age is concerned, but seems abnormal when considering the length and weight of the fish.

The question is, then, if adult lake trout spawn, if a large proportion of eggs hatch, and if young lake trout are abundant, why is the growth so slow among young lake trout and why are there so few lake trout over 15 inches in length? The answer seems to be related to a change in the feeding habits of the young trout as a result of construction of the dam in 1941.

Food of Lake Trout

In his 1937 report, Dr. Rawson showed that amphipods, chironomid larvae, and forage fish occurred in 34 per cent, 26 per cent, and 19 per cent, respectively, of the stomachs of lake trout he examined. This food study was based, however, on only 21 specimens, without considering the size of the fish in the analysis.

The food of 116 lake trout taken in 1941 and analysed by Dr. Rawson, according to size groups, was as follows:

(1) Among lake trout ranging from 6 to 12 inches in length, chironomids and fish were reported from 22 per cent and 40 per cent of stomachs, respectively.

(2) Among lake trout with lengths greater than 12 inches, only 7 per cent contained chironomids, and 74 per cent contained fish in their stomachs.

In 1943, 380 lake trout, of which 169 had food in their stomachs, were examined by Dr. Rawson. This material permitted a more detailed break-down of the specimens into size groups. The results of this analysis were as follows:

Table 3

Food of lake trout—Lake Minnewanka—1943

Length Range	Number of Specimens	Percentage of Occurrence				
		Chironomids	Fish	Plankton	Amphipods	Others
		%	%	%	%	%
6-7	26	41	—	26	13	20
8-9	34	65	trace	—	17	18
10-14	26	32	53	—	—	15
15-20	65	14	78	—	—	8
Over 20	18	—	100	—	—	—

From this table it is noted that chironomid larvae constitute the main source of food of lake trout during their first years of life, that is, until they have reached lengths of about 10 inches. Beyond a length of 10 inches, the take of chironomids decreases and fish start to appear in the stomach contents. As the lake trout grow, the importance of forage fish in their diet increases until it constitutes 100 per cent of the lake trout diet.

The lake trout study carried out in 1951 at the Waterton Lakes gives approximately the same picture concerning lake trout feeding habits with regard to chironomid larvae and forage fish, mostly common whitefish. The results of that analysis are summarized in the following table:

Table 4

Food of Lake trout—Waterton Lakes—1951

Length Range (inches)	No. of Specimens	Percentage of Occurrence	
		Chironomids	Fish
		%	%
6-9	6	67	33
10-14	15	53	53
15-20	78	28	81
Over 20	99	36	81

This study indicated that the percentage of occurrence of chironomids in the stomachs of lake trout decreased as the size of the lake trout increased. On the other hand, the occurrence of fish as food increased as the size of the lake trout increased. The utilization of fish as food by young lake trout less than 15, even less than 10, inches in length is of importance.

During 1952, the stomach contents of 139 lake trout from Lake Minnewanka were analysed. This study, which includes specimens taken at various periods of the summer, reveals a drastic change in the feeding habits of the lake trout when the results are compared with previous data obtained from this lake, and when compared to data on lake trout from the Waterton Lakes. The data for 1952 are summarized as follows:

Table 5

Food of lake trout—Lake Minnewanka—1952

Length Range (inches)	Number of Specimens	Percentage of Occurrence				
		Chironomids	Fish	Amphipods	Molluscs	Others
		%	%	%	%	%
6-7	6	67	—	33	17	33
8-9	23	87	—	22	48	—
10-14	96	90	—	26	51	15
15-20	5	80	60	40	—	20
Over 20	9	11	89	—	—	11

The astonishing fact revealed by this study is the complete absence of fish in the diet of lake trout less than 15 inches in length. Those above that size, few in numbers, were feeding on forage fish, which behaviour seems to be related to their survival.

From the above reported data and from a survey made through published studies of lake trout from various waters, it seems obvious that the problem concerning lake trout at Lake Minnewanka is related to the feeding habits of this fish since the construction of the dam in 1941. Conditions are such that the lake trout, particularly at immature stages, are somewhat separated from their food requirements, even though cisco and Rocky Mountain whitefish are still present in the lake, apparently in fair numbers. Would conditions change with the years? Not likely, since the separation is probably related to a combination of factors, among which depth is considered the most important. To support this point the writer recalls the catch made by one gill net set in about 200 feet of water. The catch included 151 lake trout all ranging between 7 and 12 inches in length, and one small Dolly Varden. No cisco or Rocky Mountain whitefish were caught. The stomachs of these lake trout contained some plankton forms, but mostly chironomid larvae and sphaeriids. It seems, therefore, that small lake trout inhabiting the deep section of the lake do not find in this environment the forage fish to feed upon and that the cisco and Rocky Mountain whitefish

are not adapted to the new environment created by the rise in water level. To improve conditions for lake trout, it seems desirable to introduce a species of fish closely associated with lake trout, utilized elsewhere by lake trout for food, and not ecologically separated from the lake trout in the lake by depth or other environmental factors.

Proposed Management Plan

Among the species of fish which are native to waters of North America where lake trout are found are the following: the ling (or burbot), the sculpin, the northern sucker, and the common whitefish. An examination of a distribution map of these species and a review of their life history indicate that they have similar requirements, particularly with respect to water temperature and depth. Geologically, it seems that these species, under conditions created by the last glaciation, have invaded streams and lakes formed by the receding glaciers. Along the east slope of the Canadian Rockies, the association of the five species of fish listed above and the Rocky Mountain whitefish is found only in the Waterton Lakes. In the other waters where native lake trout are found, Lake Minnewanka and Glacier Lake in Banff Park and Moab and Pyramid lakes in Jasper Park, this association does not exist, probably because there were at one time obstacles to the migration of some of these species. These obstacles are unknown, but might have been falls, or even heavy silt in suspension in the water. This may explain the fact that the lake trout and the Rocky Mountain whitefish, but not the common whitefish, are found at the head of the watershed of the North Saskatchewan River in Glacier Lake, one of the most silty waters in the Rockies. The Bow Falls and the silty waters of the Bow River could have prevented the common whitefish, the sculpin, and the ling from reaching Lake Minnewanka.

Because the ling is considered a predacious fish with respect to lake trout and because the planting of sculpin, which in certain lakes is a favourite food item in the lake trout diet, is almost an impossibility considering the size of Lake Minnewanka, the alternative would appear to be the common whitefish. This bottom feeder was the dominant item in stomach contents of lake trout at the Waterton Lakes, and seems to be the species most closely related ecologically to lake trout. It would, therefore, seem logical to attempt its introduction into Lake Minnewanka, as a means of managing the lake trout population in this lake.

About one million and a half eyed eggs of the common whitefish, kindly supplied by the Provinces of Manitoba and Saskatchewan, were planted in Lake Minnewanka during the spring of 1953. It is planned to repeat such plantings, but it is too early to report on the results of the introduction.

Field Trials with "Fish-Tox" in Streams

by

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During the 1951 summer season, the Fisheries Research Group of the British Columbia Game Department carried out eleven field trials with the commercial toxicant "Fish-tox", produced by the Standard Supply Distributors, Wenatchee, Washington, U.S.A. The field trials were conducted with a view to obtaining information on the following points:

(1) Combinations of concentration, their period of application and their effectiveness.
(2) Stream factors contributing to success of poisoning.
(3) Distance downstream to which poisoning is effective.
(4) Relative cost and efficiency of stream poisoning vs. operation of coarse fish traps.

The programme of investigation was largely empirical and was designed to indicate the problems that might be encountered in wide use of Fish-tox in streams.

"Fish-tox" is a "rotenone" base mixture. (Rotenone is an organic substance derived from derris, cube, and timbo root. Its chemical formula is $C_{23}H_{22}O_6$). Combined with this base is a special dispensing agent which facilitates rapid and uniform dispersion of the poison.

According to Leonard (1938), rotenone affects the respiratory system of fishes by preventing consumption of oxygen. The initial effect of rotenone is to cause degeneration of epithelium of the gill filaments. Such a disintegration of surface cells prevents normal respiratory action of the gill filaments.

Methods Used For Dispersion

In the first two trials Fish-tox was mixed into a paste and placed in a cheesecloth bag. This bag was then moved through the water until the paste was entirely dissolved. By this method it was difficult to ensure a uniform and rapid application. In addition, the person releasing the poison suffered from keeping his hands submerged in cold water for long periods.

In the latter nine trials, immediately before the application the poison was mixed with water to make a smooth soupy paste. This "soup" could be easily, equally apportioned over the period of application.

In field trials sections of stream were cut off by seine nets or metal screens and effectiveness of kill was estimated for each section.

Tests in Eleven Field Areas

Norman Creek (Cluculz Lake, Prince George)

May 14, 1951, temperature 48° F., flow 2,169 cu. ft.-min. Swift flow over coarse gravel bottom. Bottom vegetation sparse. Species of fish in order of abundance: fine-scaled sucker, (*Catostomus catostomus*) (spawning run), coarse-scaled sucker (*C. macrocheilus*), peamouth chub (*Mylocheilus caurinus*), redside shiner (*Richardsonius balteatus*), ling (*Lota lota*), squawfish (*Ptychocheilus oregonensis*), Kamloops trout (*Salmo gairdneri kamloops*).

A poison concentration of 2 p.p.m. applied over a period of 15 minutes was ineffective in this fast-flowing, cold stream. A concentration of 5 p.p.m. applied over a period of twenty-five minutes was highly effective, and well over a ton of fish was killed by the use of 21·5 pounds of poison.

Sob Creek (Cluculz Lake, Prince George)

May 23, 1951, temperature 54° F., flow 396 cu. ft. min. Slow-moving, bottom covered with up to two feet of decaying organic matter. Banks heavily overgrown, in many areas stream margin a low marsh. Many channels at creek mouth. Species of fish: ling, redside shiner, peamouth chub, squawfish, fine-scaled sucker. Kill did not extend far downstream. A concentration of 4 p.p.m. for 20 minutes killed for a distance of one quarter of a mile; a concentration of 12 p.p.m. for 30 minutes killed for a distance of less than one mile. Where the stream was divided into many channels, application of poison in the main stream above the channels did not produce an effective kill.

Inlet Creek to Shumway Lake (Kamloops)

June 28, 1951, temperature 60° F., 480 cu. ft. min. Bottom largely coarse gravel. Some slow-moving stretches with mud bottom and small amounts of vegetation.

Poison was applied at three points on a 1·75 mile stretch of stream in concentrations of 5 p.p.m. for 13 minutes, 3 p.p.m. for 15 minutes and 6·5 p.p.m. for 20 minutes respectively. A complete kill was obtained over the entire stretch of stream. Some fish were killed within 7 minutes after application started. High water temperature may have been a contributing factor to the rapidity with which fish reacted to the poison.

St. George Creek (Nadsilnich Lake, Prince George)

June 18, 1951, temperature 48° F., flow 153·6 cu. ft. min. Slow flowing, largely gravel bottom, many short pools. Species of fish in order of abundance: coarse-scaled sucker, fine-scaled sucker, squawfish, peamouth chub, redside shiner, sculpin (*Cottus asper*), ling, Kamloops trout.

In this trial observations were made on the order in which various species were affected by poison. The following order was indicated:—

1. Trout, ling, redside shiner and peamouth chub together.
2. Squawfish (only slightly more resistant).
3. Fine-scaled sucker.
4. Coarse-scaled sucker.

Observations were made on 1,150 feet of this stream to which a dose of 7·4 p.p.m. was applied for 14 minutes. Trout, ling, shiners, peamouth chub, and squawfish were killed over the entire length of stream during the twenty-four hour period after application. Most of the suckers in the upper sections of the stream were killed but in the lower one hundred feet a substantial survival was indicated (roughly 50 per cent of coarse-scaled suckers and 25 per cent of fine-scaled suckers). Only one pound of "Fish-tox" was used and roughly 2,000 pounds of fish were killed.

Kalamalka Lake (Vernon)

June 12 and 27, 1951. Kalamalka lake and Woods lake lie in Kalamalka valley between Kelowna and Vernon, B.C. A channel roughly 200 yards long, five to ten feet deep and forty to fifty feet wide connects the two lakes. Flow in the channel is preponderantly to Kalamalka from Woods lake but reversal in flow is commonly observed. In general, water temperatures in the channel are high, ranging from 50 to 70° F. over most of the summer period.

On June 12 the channel and adjoining portions of the two lakes were poisoned. There was little flow in the channel and poison was dispersed over the entire trial area to give a concentration of 1 p.p.m.

At the end of the period of application flow had begun from Woods to Kalamalka lake at a rate of 0·5 foot per second. Accordingly, poison was applied at the Woods lake end of the channel at a rate sufficient to maintain a concentration of 2 p.p.m. in the inflow. This treatment was continued until kill of fish was observed. Five hours after the beginning of the application large suckers, squawfish and carp were apparently unaffected. Estimated kill was: 1,000 squawfish, four to eight inches in length; 500 peamouth chub, four to six inches in length; 2,000 shiners, one to three inches in length; 100 coarse-scaled suckers, two to six inches in length.

In a second trial, June 27, flow was from Woods lake to Kalamalka lake at 0·5 feet per second. A concentration of 5 p.p.m. of poison was maintained for 78 minutes. The total kills included eight carp and many thousands of peamouth chub, redside shiners and squawfish. Some of the large carp were the only fish apparently not affected by the poison.

Niskonlith Creek (Kamloops)

June 28, 1951, temperature 62° F., flow 180 cu. ft. min. Moderate rate of flow over a clean gravel bottom. Occasional deep pools, little marginal or aquatic vegetation.

A dose of 1·8 pounds of "Fish-tox" was released over a 30-minute period (5·2 p.p.m.) at a point three-quarters of a mile from the creek mouth. In one hour and forty minutes, apparently all fish from the point of application to the creek mouth had been killed. The various species were affected in the following order: sculpin and trout, redside shiner, squawfish and ling.

Monte Creek (Kamloops)

June 27, 1951, temperature 62° F., flow 800 cu .ft. min. Fast-flowing, gravel and sandy mud bottom, little marginal or aquatic vegetation.

Over a 30-minute period, 8·25 pounds of "Fish-tox" was added to the water (5·5 p.p.m.) and two hours after application started Kamloops trout and fine-scaled suckers were killed one mile downstream from the application point.

57 Mile Creek (Caribou Highway)

June 29, 1951, temperature 58° F., flow 80 cu. ft. min. Swift flowing, gravel bottom, little aquatic or marginal vegetation.

A concentration of 2 p.p.m. of "Fish-tox" was maintained over a period of 15 minutes. One-third of a mile downstream a small seine placed in the stream took roughly 200 Kamloops trout within 30 minutes after the end of the application. A rapid and complete kill for at least one-third of a mile from the application was indicated. The local game warden reported that the kill extended as far as two miles.

83 Mile Creek (Caribou Highway)

June 29, 1951, temperature 65° F., flow 156 cu. ft. min. Slow-moving, occasional shallows between long deep pools. Dense growths of submergent and emergent aquatic vegetation.

One and one quarter pounds of "Fish-tox" was applied in 15 minutes, (8·5 p.p.m.). Two hundred yards down-stream, in heavily weeded pools, poison dispersed very slowly. Roughly 800 yards downstream no toxic effects were observed one hour after the operation started. Many thousand peamouth chub and small coarse-scaled suckers were killed in the short stretch of stream in which the poison was effective.

Cluculz Creek (Outlet Cluclulz Lake) Prince George

June 30, 1951, temperature 65° F., flow 4,500 cu. ft. min. Part of Cluculz creek flows rapidly over gravel beds covered with heavy growths of algae. In other sections of the stream, flow is moderately rapid in the main channel but slow through large swampy areas at the margins. Species of fish: fine-scaled sucker, coarse-scaled sucker, squawfish, redside shiner, sculpin, ling, peamouth chub, Kamloops trout.

A concentration of 14·3 p.p.m. was maintained for a period of 15 minutes. Kill extended for over two miles. The relatively large water volume in relation to the area of stream bottom may have been a contributing factor to the great distance over which poison was effective.

Collett Irrigation Diversion (Merritt)

September 19, 1951, temperature 58° F., flow 66 cu. ft. min. Slow flow, bottom muddy with heavy plant growth. This trial was done in conjunction with the Federal Department of Fisheries to assess the extent to which young salmon had passed into the diversion.

Several hundred Kamloops trout fry, suckers and squawfish and a few spring salmon fry were killed. Dead fish were seen 400 yards below the application point.

Summary

In eleven trial poisonings, concentrations used ranged from 1 p.p.m. to 20 p.p.m. and times for application from 14 to 90 minutes. Concentrations of 1 and 2 p.p.m. did not effect complete kill even when maintained for over an hour. More extensive kill was obtained with higher concentrations applied over short periods of 15 to 20 minutes. Increasing the application time to 30 minutes gave slightly greater distance of kill. As might be anticipated, length of stream affected is related to concentration applied and rate of flow in the stream. In fast-flowing streams 5 p.p.m. doses killed for distances up to one mile. Increasing the dosages to 15 to 20 p.p.m. extended kill to at least two miles. In slow-moving streams, doses of 5 p.p.m. killed for distances of less than one quarter mile and increasing concentrations to 8 p.p.m. was not noticeably effective in extending kill farther down-stream.

Several factors may contribute to short distance of kill in slow-moving streams. Aquatic vegetation provides large surface area for adsorption of poison and is conducive to production of large numbers of invertebrates that would remove poison from solution. Bottom sediments of slow streams are largely composed of fine silt and organic detritus and adsorption of poison would be correspondingly high. Portions of Cluculz creek are slow-moving and swampy but a kill was obtained for a distance of two miles with a concentration of 14·3 p.p.m. The relatively large volume of flow in relation to the area of bottom would be a contributing factor in this situation.

Some species of fish are considerably more resistant than others to "Fish-tox" and concentrations of 5 p.p.m. were largely ineffective for large suckers and carp. In situations where these species are abundant further field trials using high concentrations might be planned.

It is suggested that the following general practices should be adopted in stream poisoning to ensure effective kill:

1. "Fish-tox" should be applied to provide a concentration of at least 4·5 p.p.m., and maintained for at least 15 minutes.
2. In small slow-moving streams repeated application at one-quarter mile intervals is preferable to increasing concentration.
3. In larger and faster streams application points could probably be one mile apart if concentrations of 5 p.p.m. are used. Higher concentrations do not give a proportionately greater distance of kill.
4. Poison can be conveniently applied in streams by preparing a poison and water paste which is dispensed uniformly over the application period.
5. Where large fine-scaled or coarse-scaled suckers, or carp are present, concentrations above 5 p.p.m. may be necessary to obtain a complete kill.

On the basis of the field trials the efficiency, cost and convenience of stream poisoning can readily be compared with the operation of coarse fish traps. First, poison kills resident stream fish in addition to spawning fish. This is a great advantage because a large fraction of the predation on sport fish may occur on or near the spawning grounds. Cottids, for instance, are predators of young fry, but coarse fish traps are

ineffective in removal of Cottids. The efficiency of the poison in killing spawning fish is undoubtedly higher than that of traps. A trap must be in operation before runs start and must operate until runs are over, and in almost all instances this ideal is not realized. With a small number of poisonings a far more effective coverage of a spawning run could be obtained.

Comparison of costs is strongly in favour of poisoning. "Fish-Tox" costs roughly 30 cents per pound and on most small spawning streams the dose necessary is usually not over 50 pounds. Labour costs could be negligible for application of poisoning, because it could be done in conjunction with routine patrols and surveys. Opposed to this is the large expense involved in construction of traps and the necessity for daily inspection. If disposal of dead fish is necessary then traps are much more convenient but probably more expensive than poisoning. Traps take fewer fish in smaller lots and mink ranchers and farmers can conveniently use them. There is no problem of collecting carcasses. Poisonings kill more fish, generally in large lots, and the majority of the dead fish are not put to good use. Collection of carcasses can be partially effected by screens and nets, but it would be expensive and probably impractical to attempt complete recovery. Obviously, in stream poisoning, only perfunctory collections of dead fish are advisable.

This aspect of poisoning is important also from the viewpoint of public relations. Dead fish soon produce offensive odors and no amount of assurance that it is in a good cause makes the odor any more tolerable. Many local residents fear that the carcasses will pollute the water for domestic use, and while this fear is not well grounded it is a widespread conviction. Some apprehension is voiced when poison kills large numbers of trout in addition to coarse fish. These problems imply the need for a public relations programme and emphasize the importance of discretion in the use of poison.

It might well be recommended that poisoning should not be an indiscriminate procedure but that it should be used under proper direction and only after careful consideration and adequate publicity. Similarly, it is emphasized that it should not be used merely for the sake of killing coarse fish but that like all coarse fish control practices it should be used only when and where there is satisfactory evidence that its use will contribute to production of desirable species.

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86291—3½

Ulcer Disease and Furunculosis in a Quebec Trout Hatchery[1]

by

L. Margolis

Pacific Biological Station, Fisheries Research Board of Canada, Nanaimo, B.C.

Ulcer disease (Snieszko, 1952) and furunculosis (McCraw, 1952) are two of the most destructive diseases of hatchery trout. The etiological agent in each disease is a specific bacterium. Infection with *Hemophilus piscium* Snieszko, Griffin and Friddle, 1950, causes ulcer disease of trout and *Bacterium salmonicida* (Emmerich and Weibel, 1894) is the causative agent of furunculosis.

Ulcer disease of brook trout (*Salvelinus fontinalis*) is known to have been endemic in hatcheries in the Northeastern United States for at least fifty years. The original source of infection is unknown. Reports of *H. piscium* infection in nature are as yet lacking. However, ulcerative diseases of fish, some of which might possibly be due to infection with *H. piscium*, are not uncommon in natural bodies of water.

Furunculosis was first described from brown trout (*Salmo fario*) in hatcheries in Germany and subsequently in natural trout rivers in Germany and other countries of central and western Europe. It was believed to have been transmitted from central Europe, via infected brown trout, to hatcheries in Great Britain, from where it was spread to natural rivers through stocking with infected trout. The disease was reported from United States hatchery trout in the early part of the twentieth century, presumably the source of infection again being European brown trout. Furunculosis is now endemic in trout hatcheries in many parts of the United States, where brown and brook trout are principally infected. It has also appeared in natural waters in the United States. In Canada, furunculosis has been reported from British Columbia in the Elk River, at a salmon rearing pond at Cultus Lake (Duff and Stewart, 1933) and in a trout and salmon hatchery at Lake Cowichan (Carl, 1939).

First Report in Canada

This communication constitutes the first report of ulcer disease of trout (known to be caused by *H. piscium*)[2] in Canada, and the first report of furunculosis in Eastern Canada. Fish of all ages in a trout hatchery in the Province of Quebec, were afflicted with ulcer disease at the time of examination in October, 1952. Furunculosis was not as evident as ulcer disease, although present in the same group of fish. All fish showing furunculosis were also afflicted with ulcer disease. Diagnosis was confirmed by bacteriological examinations.

[1] *Contribution from the Institute of Parasitology (McGill University), Macdonald College P. O., Quebec.*

[2] *Reed and Toner (Can. J. Res. D20, 161-166) reported* Pseudomonas hydrophila *as the probable cause of an ulcerative disease of brook trout in an Ontario hatchery.*

The hatchery, in operation for more than twenty years, has always been free from furunculosis and ulcer disease. Recently yearling brook trout, which previously had been mixed with brook trout received from a Northeastern United States hatchery, were introduced into the ponds at the Quebec hatchery. Furunculosis and ulcer disease are endemic in certain hatcheries of the Northeastern United States and it thus appears that the imported trout were the source of infection of the Quebec hatchery trout. As fish in the natural rivers and lakes in the vicinity of the hatchery show no evidence of either of these diseases, the water supply can be eliminated as the source of infection.

A second trout hatchery in the Province of Quebec was found to be free of ulcer disease and furunculosis. Foreign trout had not been introduced to this hatchery for at least two years.

This report is designed to emphasize the dangers involved when introducing alien stock to a trout hatchery.

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DUFF, C. B. and STEWART, B., 1933. *Studies on furunculosis of fish in British Columbia.* Contrib. Can. Biol. and Fish. 8, 103-122.

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SNIESZKO, S. F., 1952. *Ulcer disease in brook trout* (Salvelinus fontinalis): its economic importance, diagnosis, treatment and prevention. Prog. Fish-Cult. 14 (2), 43-49.

Aerator for Fish Hatchery Transport

by

A. H. Berst and J. W. Anderson[1]

During the past five years several papers dealing with various type of aerators for fish hatchery transports have been published. Most of the units at present in use employ one of the following methods of restoring dissolved oxygen to the water in the tanks:

(1) Forcing air through the water.

(2) Allowing pure oxygen to bubble up through the water.

(3) Re-circulation of the water and spraying it on the surface in fine droplets.

(4) Re-circulation of the water and pumping it through a "mixing chanber" where air and water are mixed by venturi action, then returning the water to the tanks.

Fish distribution units employing any one of the above methods are able to carry several times as many fish per load as transports which are not so equipped, and in addition to this advantage, prolonged stops for releasing fish, etc., can be made without worrying about "sick" fish due to depletion of dissolved oxygen in the tanks.

This paper, which describes an aerator built by the authors, is written as a result of several requests by persons concerned with the distribution of live fish. The unit was built in March and April of 1952 by the hatchery staff at a cost of less than $500.

The forced air system is employed to replenish the supply of dissolved oxygen to the water in the tanks. One of the chief reasons for selecting this type of system was that we were fortunate enough to be able to experiment with a commercial fish transport owned by the Krestel and Wrighton Fisheries of Port Rowan, Ontario, which used the same type. This transport was hired for several transfers of trout from the Lake Erie district to the Parry Sound area which involved trips of over 300 miles and proved to be quite satisfactory. We found that the aerator was relatively simple, practical, and inexpensive to build and operate.

The aerator which we built is an adaptation of the commercial unit. It was completed in time for the distribution of yearling trout from the Normandale Hatchery during May and June 1952. Approximately 125,000 speckled trout, 16,000 Kamloops

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[1] *Respectively, Department of Lands and Forests District Fisheries Biologist, Aylmer, Ontario, and Department of Lands and Forests Hatchery Manager, Normandale, Ontario.*

trout and 8,000 brown trout were released in excellent condition and with practically no mortality en route, even though the fish were held in the tanks for as long as 48 hours on some of the northern trips. The increased capacity of the load from 2,000 to 15,000 yearlings made possible significant reductions in distribution costs. The average annual mileage for fish distribution dropped from about 32,000 to 10,400 miles as soon as the aerator was put into operation. In addition, restocking was carried out in record time, which is a definite advantage because it is necessary to clear the rearing ponds of yearlings as early as possible each year in order to make room for the growing stock of fingerlings. This also results in savings in fish food costs, since the large fish are disposed of early in the summer.

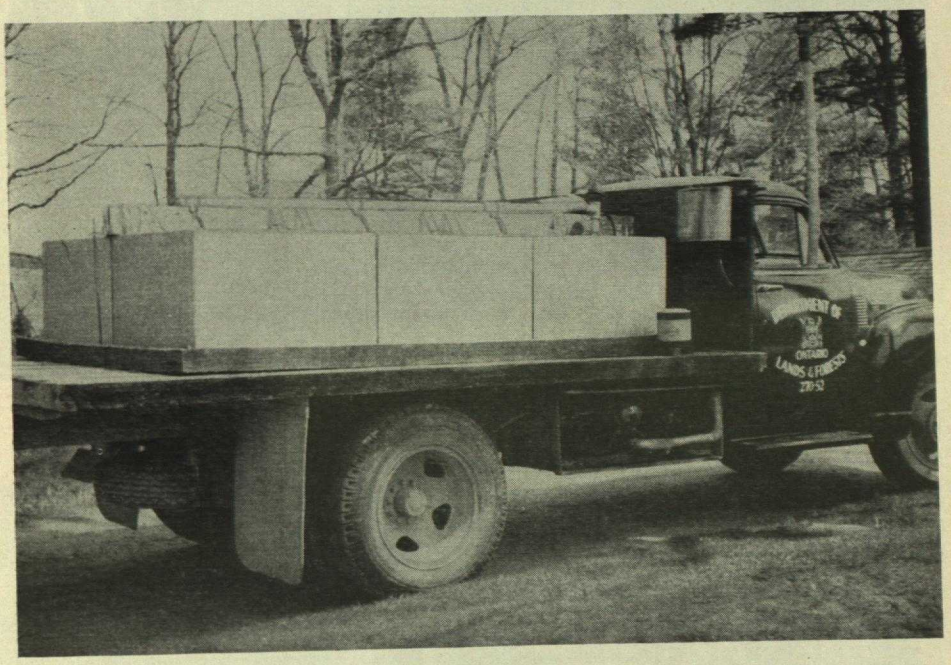

Figure 1—Fish distribution truck.

Construction of the Aerator

Fish Tanks

Use was made of the six metal fish tanks which had previously been used on our fish transport. The tanks are 3′x3′ and 2′ in height. Metal splash deflectors are installed near the top of each tank. The tanks are held in place by oak 4″x4″ bolted to the floor of the truck. Each tank is equipped with a wooden top which is divided into two parts; a fixed portion and a hinged portion. The fixed portion, which is the smaller, holds the air outlet tube and valve and the hinged portion contains a metal "well" which holds a 50-pound cake of ice.

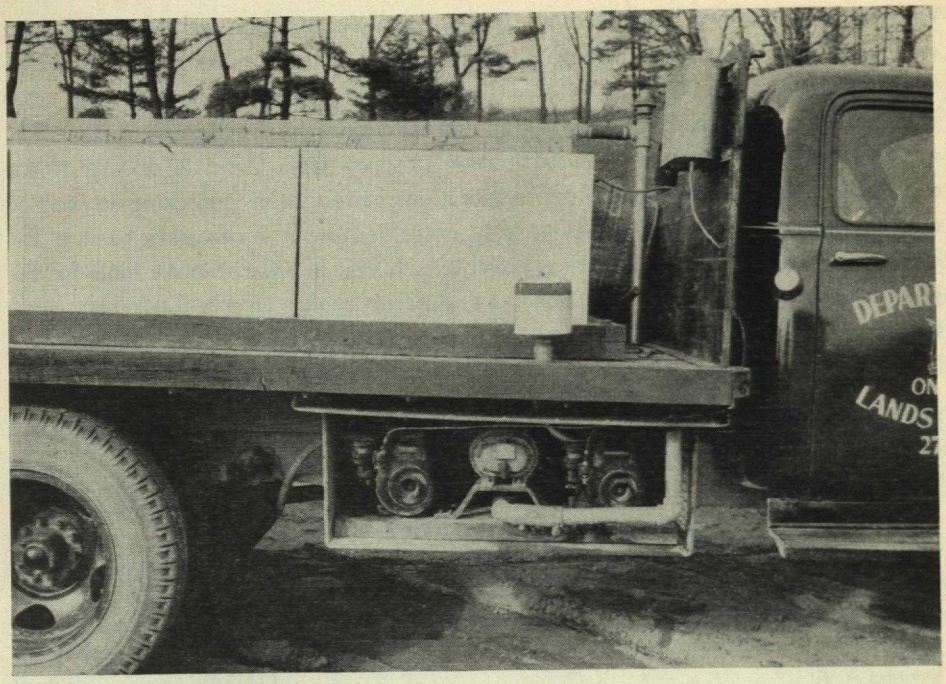

Figure 2—View of tanks and aerator.

Airblower and Motors

The main part of this unit is a rotary positive air blower which runs at approximately 1,200 r.p.m. and moves about 30 cubic feet of air per minute. It forces the air under a pressure of one pound into the water of each of the six 95 gallon tanks on the rack of the transport, through a system of tubing. The air blower is powered by a $1\frac{1}{2}$ to 2 H.P. Briggs and Stratton gasoline engine. A spare engine is mounted in such a position that it can be brought into operation in a matter of minutes if the first engine fails. Exhaust from the engines is carried away by flexible exhaust tubes. (Otherwise the hot exhaust fumes tend to heat the airblower).

The airblower and motors are bolted to a 2″ oak plank which in turn rests in a large steel support hanging from 2 bed pieces under the floor of the truck. In order to reduce the possibility of road dust and exhaust gases passing through the system, the air is drawn into the blower through a filter which is fastened to the end of an upright intake pipe extending above the rack of the truck. The outlet of the airblower is located in the bottom of the blower casing. For this reason, the airblower was raised about $4\frac{1}{2}$″ on a steel stand in order to let the outlet pipe (made of $1\frac{1}{2}$″ galvanized iron pipe) pass above the upper surface of the plank. This leaves the bottom of the frame free from any pipes or other parts which might be damaged when travelling through bush trails or over rough ground.

A 7″ V type pulley is used on the airblower and a 3″ pulley is installed on each of the motors. A Raybestos No. 64 fan belt connects the pulleys of the motor and the airblower.

Gasoline is supplied to the motors through $\frac{1}{4}$" copper tubing from a Coleman fuel tank which is located on the upper front section of the truck rack. A 3-way cock in the fuel line permits the operator to shut off the gasoline supply to either or both engines when they are not operating.

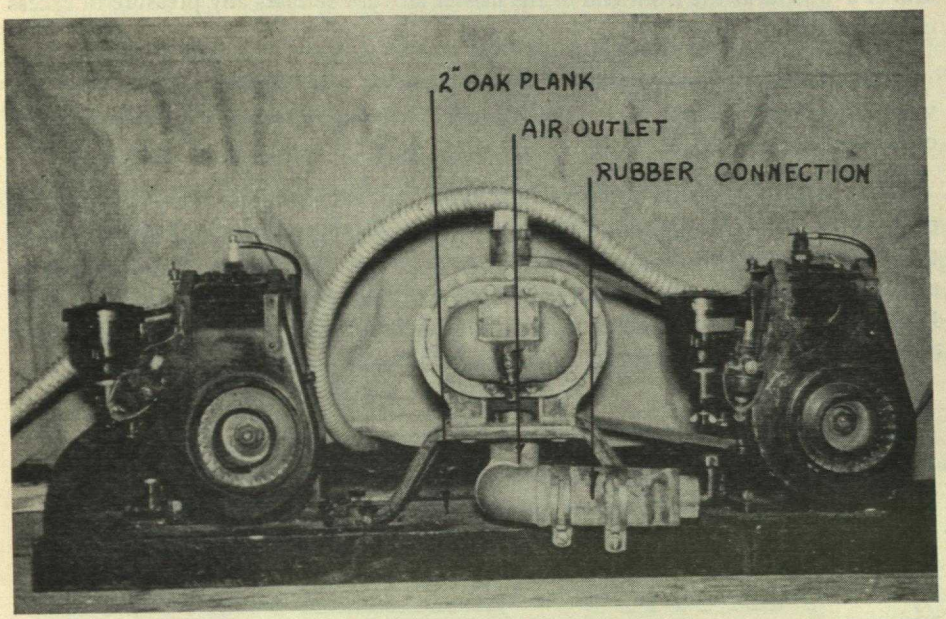

Figure 3—Front view of airblower and motors.

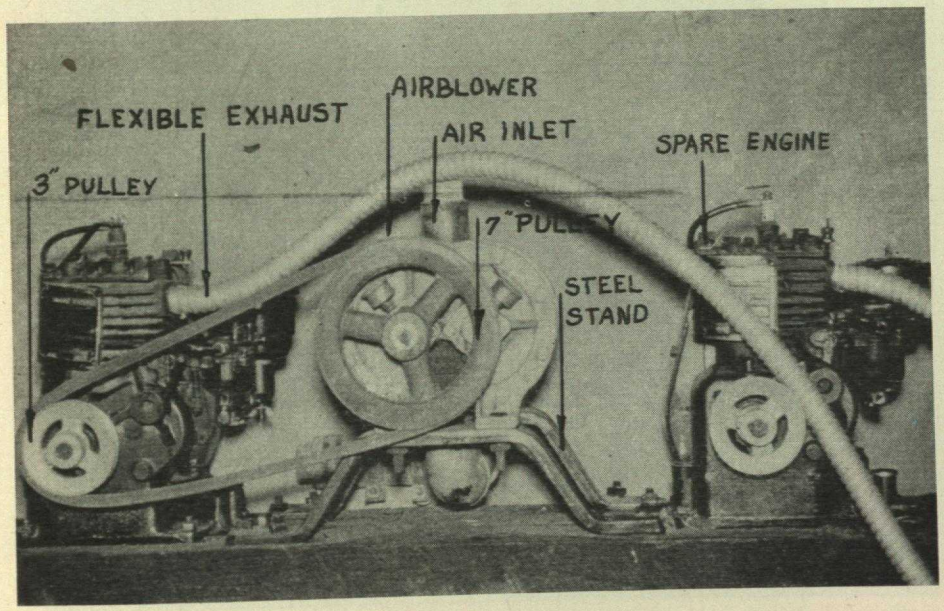

Figure 4—Rear view of airblower and motors.

Tubing System from Airblower to Tanks

After leaving the airblower, the outlet pipe passes laterally, under the floor of the truck, then up through a hole in the centre of the floor and then into the master air tube which lies along the centre of the tanks. A relief valve situated on the top arm of a T joint at the front end of the master air tube releases any pressure in excess of one pound.

There is a $\frac{1}{2}$" copper outlet from the master air tube for each tank on the truck which is connected to the corresponding tube in the top of the tank by a short piece of rubber hose.

A manually operated outlet valve is located in this tube, just below the wooden cover of the tank. It regulates the amount of air passing into the water of the individual tanks. Two rubber tubes lead from the outlet valve to a grid made of 6 pieces of copper tubing, which covers most of the bottom of the tank. Sixteen air holes, each 1/32" in diameter, were drilled in each arm of the grid, making a total of 96 small openings in the grid of each tank through which the air passes into the water.

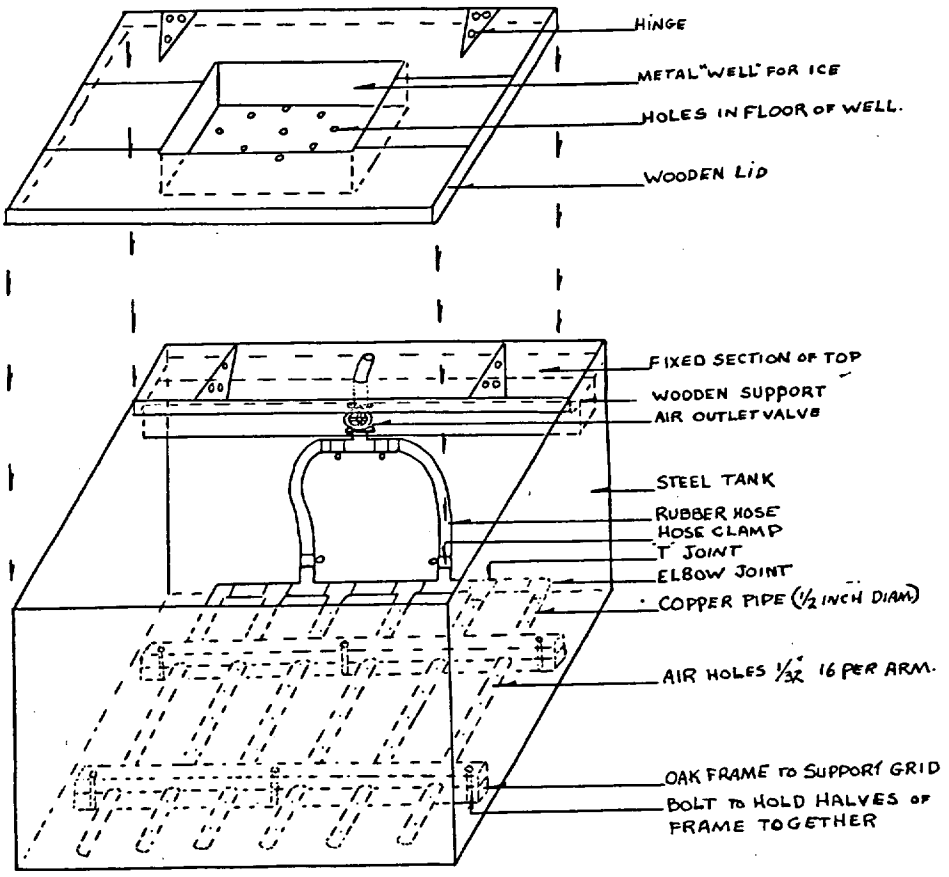

Figure 5—View of tank, grid and outlet valve.

Operation of the Aerator

Water Temperature Control

Cool temperatures are maintained by placing a 50 pound cake of ice in the metal "well" in the lid of each tank. As the ice melts the cold water drips through holes in the floor of the "wells" to the surface of the water in the compartments.

On long trips a tarpaulin is used to cover the tanks which acts as an insulator and serves two purposes; first, to reduce the rate of melting of the ice and, secondly, to help maintain cool and stable water temperatures.

A gauge in the cab of the truck shows the operator the air pressure in the system and the temperature of the water in the tanks without stopping the vehicle.

One of the disadvantages of this type of aerator is the fact that the water temperature is significantly affected by the temperature of the air which is pumped through the system. On extremely hot days this would be a problem. This is one reason why we try to distribute the bulk of our trout during April, May and the first part of June when temperatures in this latitude are not usually excessively high and so far we have had no difficulties in this regard.

Air Pressure Control

The relief valve at the front of the master air tube is always set at one pound pressure. Before loading the fish at the hatchery, the required amount of water is run into the tanks and the outlet valve in each tank is fully opened. The engine of the aerator is then started and the r.p.m. regulated by adjusting the throttle setting until the air output of the airblower is just sufficient to cause a small amount of air to continually escape from the relief valve.

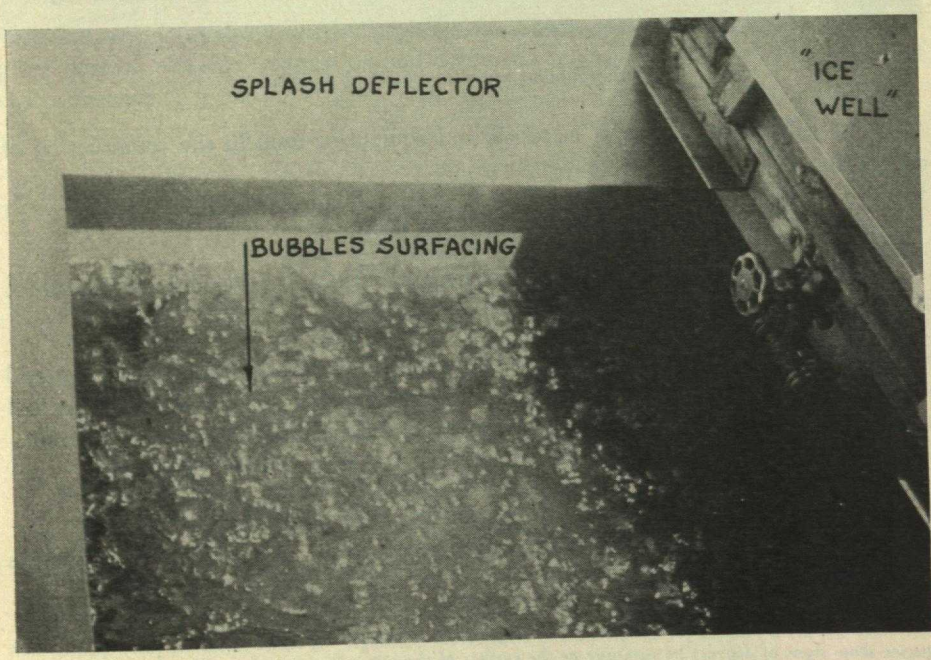

Figure 6—Fish tank with lid raised showing bubbles at surface of water.

The desired amount of air passing through the holes in the grid of each tank[1]. (which can be estimated by the amount of bubbles surfacing) is selected by adjusting the air outlet valve in the lid of the tank. When the truck reaches the stream or lake where the fish are to be released, the lid is lifted, the air outlet valve completely closed, and the grid lifted and hooked on the lid, as shown in photograph below. This allows the operator to dip the fish out of the tank without obstruction by the grid.

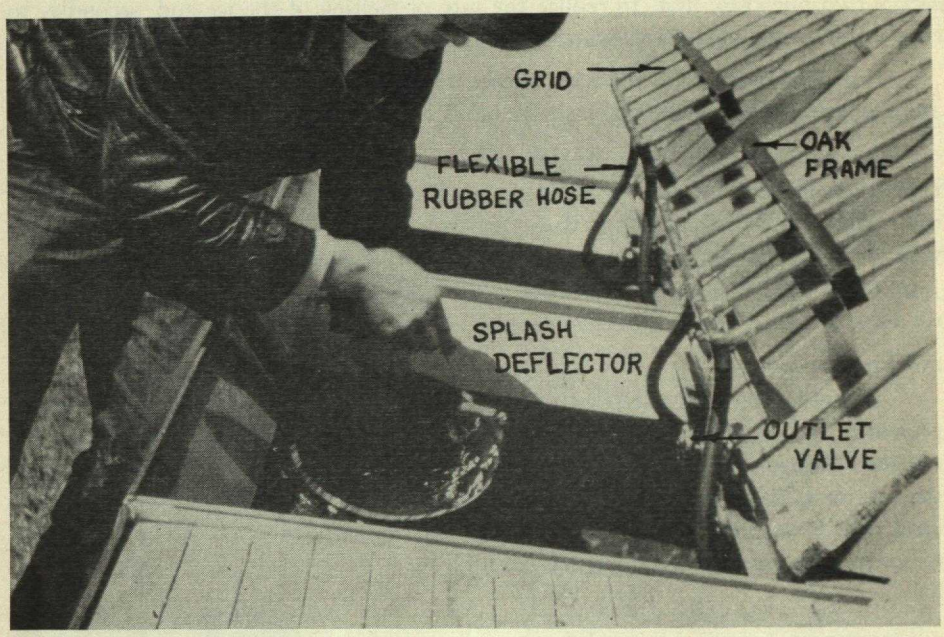

Figure 7—Dipping water from fish tank to fill tub.

The following is a list of materials and equipment used in the construction of the aerator:—

Truck—Two-ton stake truck with $7\frac{1}{2}'$x12′ floor.

Tanks—6 steel tanks 3′x3′ and 2′ in height, with hinged wooden tops in which are metal "wells" for ice. (Each well is 15″x15″x4″).

Airblower—1 Rotary Positive Airblower 24AF, with standard discharge and drive shaft, without base and pulley. 1 P.W. relief valve. 1 inlet muffler filter and two flexible connectors. (The airblower, plus attachments, approximately $100). One—7″ V type pulley (purchased locally). 1—Raybestos 64 Fan belt.

Motors—Two—1-1/2 to 2 H.P. air cooled gasoline motors (about $65 each). 2—flexible exhaust pipes (To carry heat away from blower). Two—3″ V type pulleys (purchased locally).

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[1] *Air supply is reduced for Kamloops and brown trout yearlings. If outlet valves are fully opened, both species show signs of distress by jumping at the surface of the water in the tanks. Yearling speckled trout will take full pressure at all times.*

Gas Tank and Fittings—One—gas tank, 3-gal. capacity. One—41x6 Weatherhead fitting. One— 3200x2 Weatherhead fitting. Four 68x4 Weatherhead fittings. One—6737 Weatherhead fitting. One—68x6A Weatherhead fitting. Two feet of 3/8 copper tubing. Eight feet of 1/4 copper tubing.

Tubing and Fittings—Air System—20 feet—1-1/2″ galvanized pipe (Master air tube, air intake tube, air outlet from airblower). 1-1/2 feet—car radiator hose (For flexible connections in 1-1/2 piping). Six—1-1/2″ Galvanized Iron Elbows. (For right-angle bends in iron tubing between airblower and master air tube). 120 feet—1/2 inch copper tubing. (For grids). 42—copper 1/2″ T's. (For grids). 12—copper 1/2″ Elbows. (For grids). 6—Outlet Valves—Stop and Drain 1/2″ Bronze Valves (one for each tank). Six—1-1/2″ galvanized T's. (Master air tube to outlet for each tank). Six—1-1/2″ to 1/2″ Reducers. (Master air tube to outlet for each tank). Six—1/2″ copper to iron adapters. (Master air tube to outlet for each tank). 42 feet—car heater hose. (For flexible connection from outlet valves to grids). 36—Clamps to fasten hose to grids, etc.

Gauge—Air pressure and water temperature (both on same gauge with thermocouple). 12 feet—wiper hose for pressure gauge.

Acknowledgment

The authors wish to thank the staff of the Ontario Provincial Fish Hatchery at Normandale for their co-operation in the construction and operation of the unit.

Valuable suggestions on the design were made by Mr. D. N. Omand, who also helped in critical reading of the manuscript.

We are also grateful to Mr. John Krestel, Port Rowan, Ontario, who gave us a great deal of valuable information and advice on the construction and operation of the equipment.

A Device for the Controlled Drainage of Hatchery Troughs

by

H. H. MacKay

Ontario Department of Lands and Forests

After feeding trout fry or fingerlings in hatchery troughs, it is necessary to remove waste by sweeping down the debris to the outlet without injury to the fish. To do this effectively it is necessary to lower the water in the troughs.

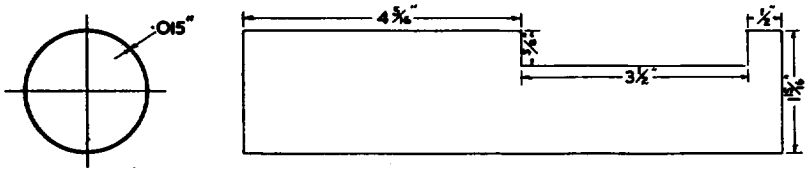
Several methods are in use, for example, by the partial removal of the plug at the outlet of the trough, by changing the level of the overflow pipe, or by slitting the bottom of a small tin can and inverting the can over the outlet. These methods are somewhat cumbersome and have been known to create considerable suction against the screen near the lower end of the trough causing small fry to be drawn against the screen. A controlled amount of suction speeds up the cleaning process without injury to the fish.

Mr. T. Marston, manager of the Pembroke Trout Rearing Station, Pembroke, Ontario, has devised a novel valve by which the flow of water against the screen may be regulated.

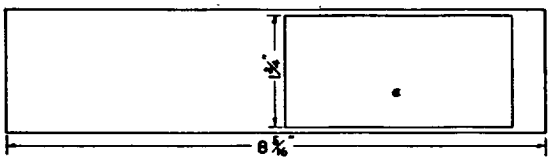
The valve can be made by a tinsmith to fit a drainage outlet of any practical size. It consists of two parts made of ·015 inch tin rolled and soldered. Tube A in the illustration is $8\frac{5}{16}$ inches long and $1\frac{5}{16}$ inches in diameter. From this tube an opening $3\frac{1}{2}$ inches long by $1\frac{3}{4}$ inches wide is cut. This opening is $\frac{1}{2}$ inch from one end of the tube.

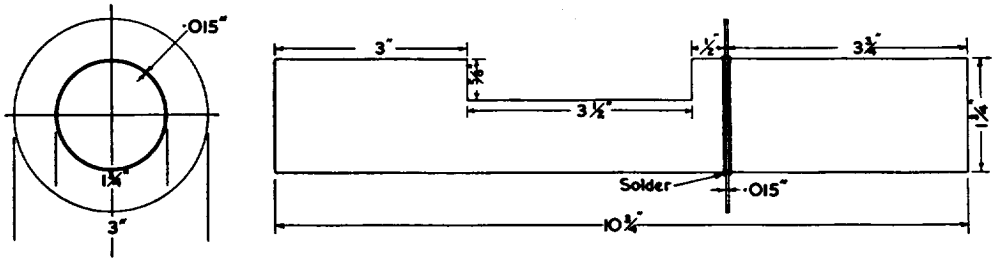
The inner Tube B is $10\frac{3}{4}$ inches long by $1\frac{3}{4}$ inches in diameter. The opening of this tube is the same size as the opening in the outer tube A. The inner tube B has a flange around its circumference and $\frac{1}{2}$ inch from the bottom of its open section.

Tube A may be turned until it closes the opening of Tube B. The drainage plug or overflow pipe at the end of the trough may be removed and the new valve inserted in the hole until the flange rests on the bottom of the trough. Tube A is then turned until an opening is provided between the two open sections. This opening may be adjusted in such a way that the amount of suction against the screen is increased or decreased at will, and in such a way that the fry or fingerlings are not drawn against the screen.



— DETAIL OF TUBE "A" —





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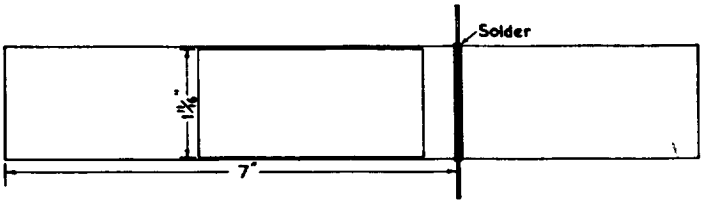
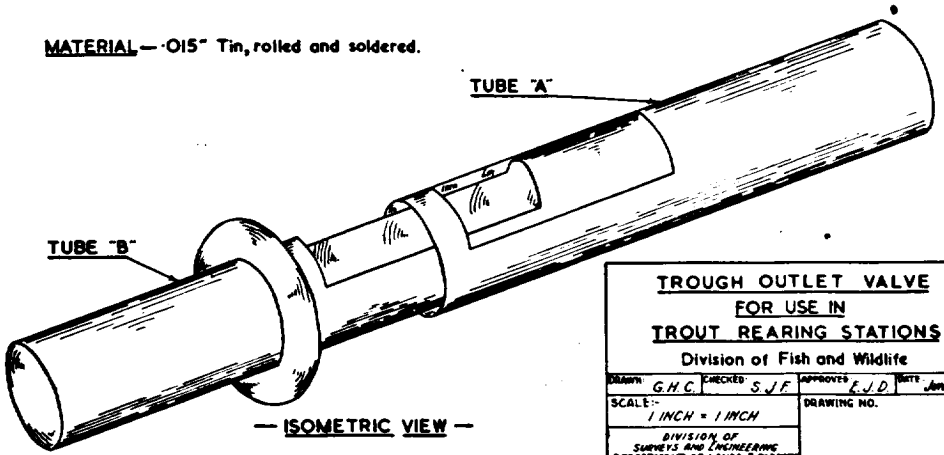


MATERIAL — ·015" Tin, rolled and soldered.



— ISOMETRIC VIEW —

TROUGH OUTLET VALVE FOR USE IN TROUT REARING STATIONS

Division of Fish and Wildlife

DRAWN G.H.C.	CHECKED S.J.F.	APPROVED E.J.D.	DATE June 1953
SCALE:- 1 INCH = 1 INCH		DRAWING NO.	

DIVISION OF SURVEYS AND ENGINEERING DEPARTMENT OF LANDS & FORESTS

The Education of Undergraduate and Graduate Students in Fish and Fisheries Biology*

by

W. A. Clemens

University of British Columbia

It seemed desirable in considering the above topic to indicate my conception of the meanings of some of the terms used. In a broad sense, education consists in imparting knowledge in such a way as to lead to an understanding of the universe. This may be done on the basis of what I may call the Pyramid of Knowledge (Fig. 1). The base consists of data or so-called facts. These, when systematized and analyzed, lead to the development of generalizations or principles which in turn, when synthesized and resynthesized, provide a concept of the universe.

Education, then, consists in imparting information or data (too often teaching stops here) and then leading the student through the logical process of analysis, generalization and synthesis. The end result should be an individual who has some appreciation of his place in the "scheme of things" and who will think and act accordingly.

Much the same idea is expressed by G. E. Hutchinson (Amer. Scientist, Vol. 38, No. 1, 1950): "The pleasure in analysis and intellectual resynthesis of experience is one of the mainsprings of our culture, and therefore one of the primary functions of the university is to encourage the appreciation of this pleasure." Again, "In a general sense, it is the basic function of the university to emphasize, as vigorously as possible, that intellectual activity is one of the great pleasures of life, for in so doing the university performs the fundamental duty of encouraging us to know enough to implement the will to set our house in order."

Research consists in visualizing a problem, instituting pertinent observations and experiments, analyzing the data and, when the solution is achieved, developing generalizations. The education objective is to lead a student to understand this logical process and to train him in a special field so that he may make a contribution to knowledge, that is, add a splinter to the Pyramid of Knowledge and perhaps become a leader in advanced thought and synthesis.

Fish biology has to do with the morphology, physiology, growth, reproduction, taxonomy and ecology of fishes, that is, with the general biology. On the other hand, fisheries biology involves fish populations and the relation of exploitation to the stocks. Research in this field requires a sound, broad background of biological knowledge including reproductive potential, natural mortality, distribution, movements, migrations, etc., and the use of statistical procedures. The results should make it possible to inform the fishermen and others concerned at any time of the distribution and composition of the stock and of the amount of the stock which may be taken, not only as to time and place but as to age.

* *A contribution to a conference held under the auspices of the Committee on Biological Investigations of the Fisheries Research Board of Canada.*

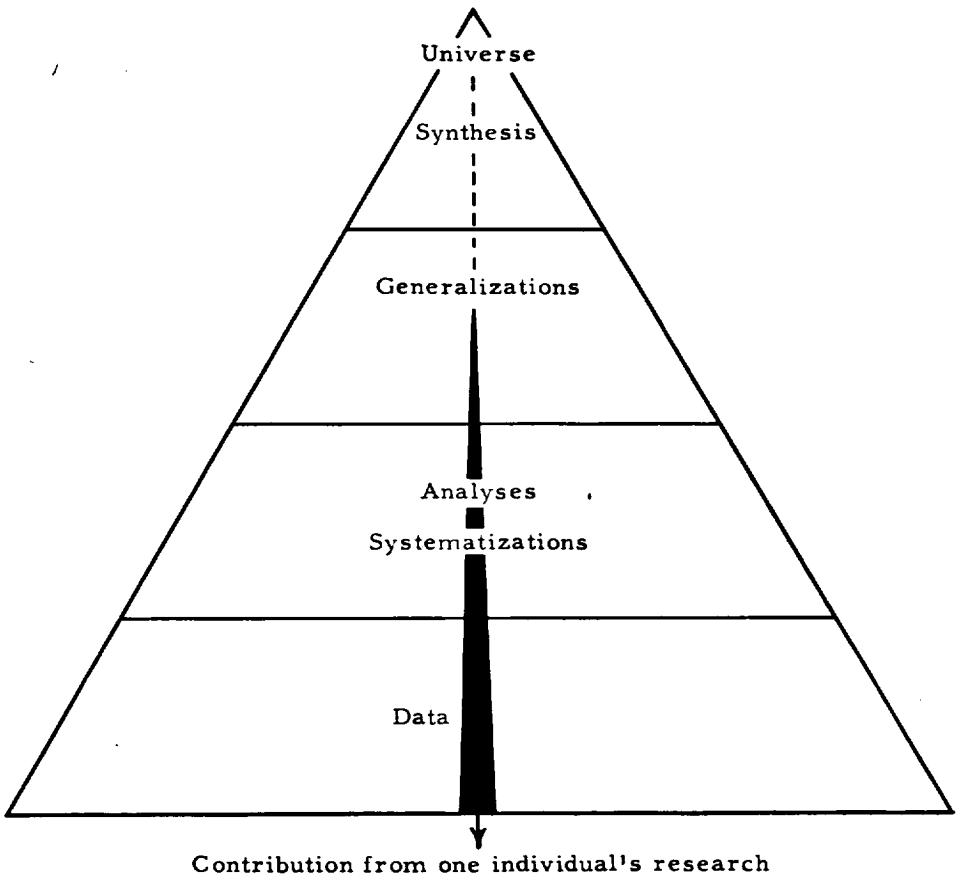


Figure 1—Pyramid of Knowledge.

Undergraduate Education

On the basis of what I have outlined, I believe that the undergraduate years should be a time for the acquisition of a broad, sound education. For the biologist I would suggest five divisions from which the student should make a judicious selection of courses:

a) Humanities:— English, Modern Language, Philosophy, Logic, Economics, Sociology, Political Science, etc.

b) Physics:— General, Physical Optics, Electricity and Magnetism, Biophysics.

c) Chemistry:— General, Analytical, Organic.

d) Mathematics:—General, Calculus, Statistics.

e) Biology:— Botany, including Morphology, Systematics. Zoology, including Morphology, Embryology, Physiology, Genetics, Systematics, Ecology. General Biology in the fourth year. An introduction to the student's speciality ex. Biology of Fishes.

The end product should be a student who thinks logically and biologically.

In the biological field I think there is some need for a revision in the "set-up" of instruction based upon:

a) a broader vision of the objective in biological education.

b) more attention to the animal kingdom as a whole,

c) some shift of emphasis from the static to the dynamic aspects.

Figure 2 illustrates the content of biology and the focus of its various divisions which, of course, are all interrelated.

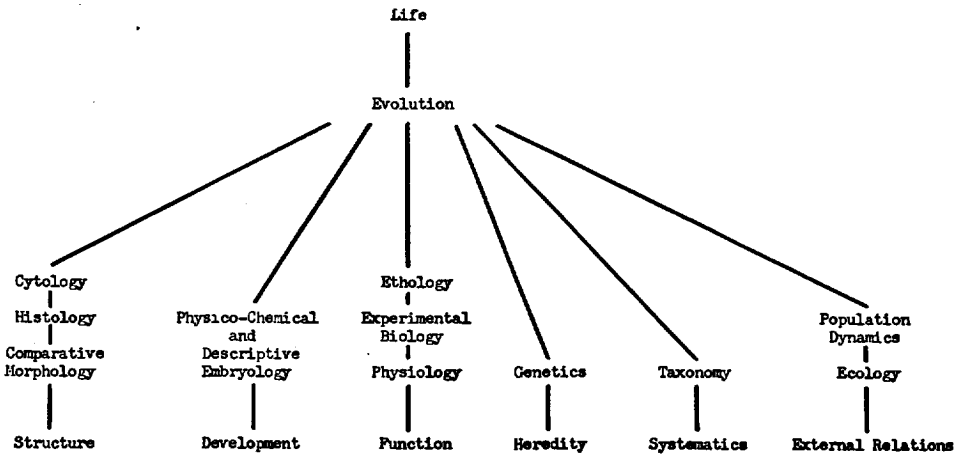


Figure 2—Content of Biology.

Graduate Education

The fifth and sixth years should be a period of specialization and of training in research, culminating in the award of the Master's degree. With reference to fish and fisheries biology, courses such as the following might be available:

> Ichthyology, Fisheries Biology and Management, Population Dynamics, Oceanography, Limnology.

In addition, courses which might appear desirable to "round out" the student's field of knowledge might be selected from among the following:

> Entomology, Marine Zoology, Meteorology, Law, Geology, Parasitology, etc.

Some of the instruction should be tutorial. Considerable attention should be given to directing the student in research and in the preparation of a thesis.

Very many courses have been mentioned in connection with the undergraduate and graduate years to the Master's level. It is not suggested that all of these should

be covered in formal course work. The student should select with advice and he should be encouraged to develop the reading habit by which he may obtain knowledge in fields outside those of formal instruction.

The Doctorate period should follow the Master's and in it there should be:

a) Emphasis and concentration on independent research,

b) a minimum of instruction, most or all of which should be tutorial,

c) some time given to the development of a cultural field.

The objective should be the development of the student in the realm of productive scholarship.

It is not expected that any set programme of instruction will produce an educated and trained fishery or fish biologist. But if the teacher has, and the student gains, a vision of the objectives, the end result should be most satisfactory. In the final analysis very, very much depends upon the qualities of both teacher and student.

The Toxicity of Heavy Metals to Fish, With Special Reference to Lead, Zinc and Copper[1]

by

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Salts of heavy metals such as lead, zinc, copper, iron, manganese, cobalt, nickel, and cadmium may be discharged into natural waters as waste effluents from mines, chemical plants, steel plants, pigment works or other industrial processes. Because salts of heavy metals are very toxic to aquatic organisms, this paper was written as an outline of information for fisheries biologists, indicating the effects of heavy metals on fish, some toxicity levels, some relations with water chemistry and a partial introduction to literature on the subject.

Action of Heavy Metals on Fish

Salts of heavy metals combine chemically with proteins in the mucus secreted by the fish's skin, mouth parts and gills, forming insoluble compounds which prevent aeration of blood and lead to acute respiratory distress and death.

If the pollutant be sufficiently dilute, or if the supply of pollutant be intermittent, the secretion of additional mucus may wash away the precipitated compound as it is formed, or may carry away the larger masses of the precipitate before serious damage to the fish results. If, however, the concentration is large enough and the exposure time long enough the precipitated insoluble compound covers the body, lining of the mouth and the gills. Ellis (1937) states that the precipitate caused death by a combination of three conditions which individually or collectively disturbed the proper functioning of the respiratory and circulatory mechanisms.

(*a*) In the weaker concentrations, the precipitate coated the gill filaments and filled the filament interspaces so that water pumped through the mouth and onto the gills for aeration of the blood could not reach cells of the gill filaments. Aeration of the blood was prevented and death followed from anoxemia and carbon dioxide retention.

(*b*) In stronger concentrations, larger masses of flocculent precipitate formed on the gills, clogging the interlamellar spaces and preventing movements of the gill filaments. This condition affected circulation of blood in the gills, in that stasis of blood in the gill capillaries usually followed cessation of movements of gill filaments.

[1] *Derived from a Literature Review.*

(c) Gills of fresh water fishes are extremely important excretory structures, removing from six to ten times as much nitrogenous wastes as the kidneys. Special chloride-secreting cells are also present in gills of fresh water fishes. Therefore even weak solutions of heavy metals which do not damage the gills rapidly enough to cause speedy respiratory or circulatory failure can result in impairment of other functions, particularly those of salt-balance and excretion.

Apparently the outer epithelial tissues of fishes effectively block the penetration of heavy metals to the internal tissues. Chemical analyses and tests with isotopes have failed to detect traces of heavy metals in the internal organs of fish killed by these metals.

Some Effects of Natural Waters on Effective Concentrations of Metallic Salts

Variation in physical, chemical and biological conditions in natural waters has a very great effect on the concentration of metallic salts in solution. These salts must be in solution or in colloidal suspension to be effective as toxic agents.

Fluctuations in stream flow may radically change the concentrations, if an effluent is discharged at a uniform rate. In some cases (Jones, 1940) where pollutants are reaching waters from old mining refuse dumps, these pollutants may be washed into a stream in much greater amounts during periods of heavy rainfall. Periods of maximum concentration should be determined. These periods, even if of short duration, may be limiting factors in the survival of fish.

Salts of heavy metals are largely precipitated by carbonates so that, in general, "hard" waters with a high pH tend to greatly reduce effective concentration of metallic ions. With reference to copper, Smith (1935) finds that in hard waters a basic copper carbonate is formed:

$$2\,CuSO_4 + 2CaH_2(CO_3)_2 \rightarrow CuCO_3 \cdot CuO_2H_2 + 2\,CaSO_4 + 3\,CO_2 + H_2O$$

which hydrolyses to copper hydrate and precipitates:

$$CuCO_3 \cdot CuO_2H_2 + H_2O \rightarrow 2\,CuO_2H_2 \downarrow + CO_2$$

In hard waters no trace of copper salt remains in solution after 24 hours, but in acid waters hydrolysis does not occur and much copper remains in solution.

Moore and Kellerman (1904) also working with copper, suggest that the minimum lethal concentration of copper sulphate is increased 0·5% for each 10 p.p.m. of temporary hardness.

Ellis (1937) warns that even though precipitated out, compounds carrying heavy metals, as long as they remain in the stream, are subject to ingestion by fish and other animals, and, if water conditions change, are subject to re-solution.

The toxicity of metals increases with temperature and Moore and Kellerman (1904), using copper sulphate for the control of algae, suggest the following procedure to adjust a minimum lethal concentration to various temperatures. Fifteen degrees

centigrade is taken as standard and 2·5% copper sulphate is added for each degree below standard temperature. Conversely 2·5% copper sulphate is subtracted for each degree above 15°C.

Heavy metals are removed from solution by combination with organic matter. All plants and animals contain proteins which combine with, and precipitate metallic ions. Smith (1935) cites the case of an *Anabaena* scum which was found to contain 11·25% metallic copper two hours after copper sulphate was applied to a lake. Only traces of copper could be found in the water at this time. In lake waters particularly, dissolved proteins and amino acids also remove metallic ions by precipitation. Moore and Kellerman (1905), using copper sulphate for algae control, suggest a 2% increase in $CuSO_4$ for each 10 p.p.m. organic matter.

These considerations indicate some of the difficulties of making accurate predictions of resultant metallic ion concentrations when measured quantities of metallic salts are added to known volumes of natural waters.

Some Toxicity Levels for Fish

Many records of toxicity to fish of heavy metals exist in the literature but most are of no practical value because conditions have not been accurately defined or natural situations have not been considered in designing laboratory experiments. Application of results to particular situations is rendered impossible. However, the following records are considered by the writer to be among those of practical value and will serve to indicate some toxicity levels for copper, lead and zinc. Jones (1938), using very soft water with calcium at about one p.p.m., found the following minimum lethal concentrations for the three-spined stickleback, *Gasterosteus aculeatus*:

0·3 p.p.m. of $Pb(NO_3)_2$ fatal in $4\frac{3}{4}$ days.
0·4 p.p.m. of $ZnSO_4$ fatal in 6 days.
0·04 p.p.m. of $Cu(NO_3)_2$ fatal in $5\frac{1}{2}$ days.
All concentrations are of metal—not salt.
Temperatures varied from 14° to 17°C.
pH was 6·4 to 6·6. Survival times are the means of four fish.
Volume of each solution was 2000 c.c. and was renewed daily.

Goodman (1951) found the following concentrations of zinc to be critical and cause some mortality in rainbow trout of various sizes:

10 to 14 day-old	— 3 p.p.m.
4 weeks	— 2 p.p.m.
8 weeks	— 4 p.p.m.
3 inch fingerlings	— 6 p.p.m.
5 inch fingerlings	— 6 p.p.m.
10 weeks old	— 6 p.p.m.

All concentrations are of zinc. Temperature was 11°C. and pH 7·4 to 7·8. Tap water was used. These experiments were terminated after 48 hours and it is mentioned that some survivors died subsequently. It is very likely that much lower critical concentrations would have been found if fish had been exposed to the zinc for longer periods of time.

Compounds of various metals may have a cumulative toxic effect. Ellis (1937) found that goldfish kept in glass containers, with very insoluble lead sulphide ore on the bottom, suffered some mortalities after 61 days exposure. Jones (1938) found that three-spined sticklebacks were killed after 14 days exposure to 0·1 p.p.m. of lead. He concluded that for sticklebacks, critical lethal concentrations were: Pb— ·01 p.p.m., Zn— 0·3 p.p.m., Cu— 0·01 p.p.m.

Ellis (1937) lists the experimental results of many workers, a few of which follow:

Copper

0·143 p.p.m. $CuSO_4$—maximum concentration tolerated by brook trout in hatchery water. (Moore and Kellerman, 1905)

1 p.p.m. $CuSO_4 \cdot 5\ H_2O$ killed perch, catfish, suckers and trout in 10 hours. (Smith, 1935).

Lead

0·33 p.p.m. Pb. lethal to fresh water fish (Carpenter, 1936).
10 p.p.m. $Pb(C_2H_3O_2)_2$ killed yearling trout in stream water.
10 p.p.m. $Pb(NO_3)_2$ killed trout in stream water in $2\frac{1}{2}$ hrs.

Zinc

100 p.p.m. $ZnSO_4$ killed goldfish in 5 days.

Jones (1938) has shown that apart from the precipitation reaction of $Ca(HCO_3)$ on metallic ions, there is also a direct antagonistic effect of calcium on the protein precipitation reaction. Even when no apparent precipitation occurs in a solution of metallic salt, calcium prevents the precipitation of mucus on the gills and reduces toxicity. This was checked (*in vitro*) on mucus of an eel, which precipitated with metal salts only in the absence of calcium. Jones (1938) also experimented with a running supply of "hard" water containing approximately 50 p.p.m. calcium as $Ca(HCO_3)_2$ and containing the maximum amount of lead it could hold in solution (0·7 p.p.m.). This solution proved harmless to the minnow *Phoxinus phoxinus* and to the stickleback *Gasterosteus aculeatus*, although a similar concentration of lead in "soft" water was fatal to sticklebacks. Ellis (1937) presents similar data which show that sodium also has an antagonistic effect on the precipitation of proteins by heavy metals.

Some Toxicity Levels for Other Aquatic Organisms

Toxic action of heavy metals has been utilized for many years in control of undesirable aquatic plants such as algae and pond weeds. An extensive literature on the subject exists including: Moore and Kellerman, 1904; Speirs, 1948; Hasler, 1949. Copper sulphate has been the metallic salt most generally used, and concentrations of approximately one p.p.m. are highly toxic to plants.

Newton (1944) describes the toxic action of zinc and lead on aquatic plants in a river. Because of the greater solubility of zinc she found that it had a greater toxicity and that this increased sharply with concentrations from 1 to 10 p.p.m. *Ranunculus aquatilus* was found to be most sensitive to lead and zinc and disappeared first, after pollution occurred.

Newton (1944) also found the highest concentration of zinc which the following aquatic animals could withstand:

Pond snail (*Limnaea pereger*)—0·2 p.p.m.
Fresh water limpet (*Acylastrum fluviatile*)—0·2 p.p.m.
Shrimp (*Gammarus pulex*)—0·3 p.p.m.
Mayfly nymph (*Chloeon simile*)—0·2 to 0·5 p.p.m.
Planarian (*Polycelis nigra*)—30 p.p.m.
Water boatmen (Corixidae), stonefly nymphs (Plecoptera), Dragonfly nymph (Anisoptera), Caddis larvae (Trichoptera)—500 p.p.m.

Suggestions for Control and Standardization of Procedures

The chemistry of natural waters is complex and extremely variable. To define the relationship of heavy metal toxicity with all the chemical variables, and to formulate general rules for application to any specific situation, would require extensive and fundamental research. The fisheries biologist will be forced to make decisions for many years without benefit of this research, but perhaps much may be accomplished without it if intelligent use is made of what is already known.

When considering an already polluted stream, the complexities of water chemistry are largely excluded. The usual procedure of chemical analyses of filtered water from the stream gives the effective concentration of metallic ions in solution. While some very small colloidal particles may be included in such analyses these probably contribute to the effective concentration. These colloidal particles may well go back into solution in the higher carbon dioxide concentrations adjacent to gill membranes of fishes.

While a good approximation of effective concentration of toxic metals in a polluted water may be made, the interpretation of results by comparison with experimental toxicity assays is, in many cases, impossible. In most toxicity tests, concentrations have been estimated by adding known amounts of metallic salt to a measured amount of water of unknown chemistry. The effective concentration is unknown and the results can have no application except to that particular water. If effective concentration of test solutions is measured by periodic chemical analyses the results can have far more general application.

As the antagonistic effects of calcium and sodium reduces toxicity of heavy metals, the concentration of these ions in test solutions should be known. If this proves impossible, some measure of their concentration such as pH or total alkalinity may be a useful approximation.

Temperature has an effect on toxicity of heavy metals and therefore should be controlled.

In attempting to predict the effects of a polluted water on aquatic organisms the fisheries biologist must know the maximum concentration which a particular species can tolerate, usually for considerable periods of time. Many experiments have not attempted to define these limits but have merely resulted in records of animals dying a short time after immersion in a single test solution. To find the minimum lethal

concentration a series of solutions of increasing concentration should be tested over a period of at least 96 hours. To test for possible cumulative effects, experiments may have to extend over several weeks.

To establish the toxicity of a polluted water by reference to experimental results of other workers may be difficult, and such a procedure may merely indicate the nature of the problem. The concentrations found in a polluted stream may be of such magnitude that an immediate decision is possible. However, if concentrations are close to critical values found by other workers, bio-assays using the water in question may be necessary to establish whether toxic pollution is occurring.

Since this paper was written a valuable additional paper on the subject of metal toxicity has come to the writer's attention: Doudoroff, P. and Max Katz. 1953. Critical review of literature on the toxicity of industrial wastes and their components to fish. II. The metals as salts. Sewage and Industrial Wastes. 25 No. 7: 802-839.

Appended is a partial list of pertinent papers on the subject of heavy metal toxicity. The literature cited in the present paper is included in this list.

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