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Minister of Fisheries

The Effects on Fisheries of Man-Made Changes in Fresh Water in the Maritime Provinces

by

A. L. Pritchard

Director, Conservation and Development Service, Department of Fisheries of Canada, Ottawa.

It seems inevitable that there will be a great deal of repetition in the presentations in this symposium. This is to be expected since we are all dealing with the same general subject—the influence of environment or changes therein on one type of animal —fish. There is no doubt, however, that there will be differences in emphasis as we consider different species, the variation in the patterns in industrial development, the different characteristics of each region and the differences in stress exerted in enlarging the economy in each district.

I should admit at the outset that I am glad to have such repetition since it will serve to stress again and again the problems facing the relatively recently developed Fish Culture Development Branch of the Conservation and Development Service of the Department of Fisheries of Canada. Our main responsibility is to overcome such problems to maintain and expand the runs of fish for use. We will be extremely happy if we can convince you of the challenge presented and perhaps persuade some of you to join us in our efforts.

The Maritimes area including New Brunswick, Nova Scotia, Prince Edward Island and Newfoundland, in its original state was adequately, although in the opinion of some, not over-supplied with natural resources. Early settlers could be selective from the abundant forests, fish and minerals. As the population grew and the demand for raw materials increased, it soon became evident that some resources would be seriously reduced or wiped out if improperly managed. Man-made changes were the basic reason.

As would be expected, particularly in New Brunswick, Nova Scotia and perhaps Newfoundland (although the latter is at a relatively early stage of development) the forest industry must be held responsible for the major environmental changes affecting fish. These have been either directly or indirectly responsible for reducing the productivity of some of the finest streams in salmon, alewives, smelt and other anadromous fish.

Direct action has been taken to erect dams to create head ponds to store water for log driving and mills. Dams and jams have resulted from log drives and logging slash. A few of these might only have been temporary obstructions, but I am afraid that the vast majority at one time or another provided complete blocks which prevented spawning runs from reaching their destination.

An added threat has been the destruction of spawning grounds and the eggs and fry therein through the physical action of log drives. This method was and still is the chief means of transportation of timber to the mills and pulp plants, although

fortunately for the fish, trucking is gaining ground. One would find it almost impossible to assess absolutely the damage from this source, but it has been heavy and the productive capacity of the rivers has suffered.

Logging has undoubtedly changed the environment through the removal of large blocks of timber. At the present this removal is proceeding to the very water's edge of some of our biggest and best streams. The adverse effects to fish must be rather obvious—the scouring of the redds from heavy freshets, the cutting of new channels, with the consequent dewatering of spawning nests and stranding of young fish, the heavy silting resulting from erosion and the rise in temperature in periods of low flow in the summer and early fall. I have always been convinced that the scientists have failed in not studying the effects of such changes more thoroughly. If we had, perhaps we could give firmer proof to support our generalizations. Pertinent studies are now taking place but the period of history is half finished.

Also associated with the forest industry but hardly its fault, is the necessity for control of forest insect pests. The outstanding example is the DDT spraying programme for spruce budworm. From 1952 to 1957, $11\frac{1}{2}$ million acres were covered at a cost of over ten million dollars. This is well over half the forested area of New Brunswick. The chemical had disastrous effects on the young fish and stream insects.

The mills and pulp plants must also accept some blame. Perhaps without too serious consideration solids such as sawdust and chips have been discharged into the streams. The results are obvious in such rivers as the St. Croix where good river bed is blanketed for miles. The introduction of liquid effluent and chemicals with a high oxygen demand has served to set up conditions almost intolerable for fish. Perhaps the fault lies to some extent with the fisheries scientist since it is only relatively recently that methods have been devised to control such waste and use it to advantage.

Hydroelectric installations have had their direct and indirect effects on fish in the Maritimes area. It is true that the topography of the district does not encourage the development of high head economical power in large blocks, but large numbers of low-head installations have been built to provide the necessary energy for industrial and domestic consumption. In many of these, fish facilities have been incorporated but in others they have been neglected, probably due to the lack of appreciation on all sides of the contribution of small rivers to the total fish production. In some such as the Mersey in Nova Scotia, construction has been allowed to proceed on one dam after another until the stream is just a series of reservoirs with little resemblance to the original salmon habitat. Such is the struggle for power!

Main stream dams, the usual type in the Maritimes, even when provided with fishways, inevitably seem to cause delay to ascending adults. Often in late summer or early fall, shortage of water precludes efficient operation of such fishways. The fish may become the victims of flow regulation on week-ends or other periods of low water utilization. They are then usually more vulnerable to the sportsman, the poacher and other predators.

Main stem installations also alter stream conditions above the dam, flooding out spawning grounds, and changing the productive capacity of the nursery areas. The composition of the fish in these reservoirs could quite easily swing from competitors to predators.

Downstream migrants are also affected. Loss of young passing through turbines may be small or large depending on the type of machine in use. Migrants stunned in this passage are obviously more vulnerable to predators.

Only a few diversion type power installations are found in the Maritimes, but the problems which they pose for fish are equally if not more complex. To obtain sufficient transportation water to pass adults is difficult in an area where economical storage is limited and summer droughts threaten power production.

A unique but clear demonstration of difficulty encountered is seen in the recent power development at Beechwood on the main Saint John River. Because of doubtful footings a standard pool and step fishway did not seem possible. A conventional fish collection gallery was constructed along the power-house face leading to a skip-hoist device designed to lift the migrants over the 60-foot dam. These facilities were completed and in operating order before the salmon run but minor difficulties in the construction schedule made their efficient utilization impossible. The remains of a coffer dam below the power-house created adverse current conditions and the release of the water from the spillway gates across the dam rather than from the draft tubes appeared to attract the migrants away from the gallery. This certainly proved the necessity of adhering to a previously approved schedule. It was a real challenge to experiment and adjust and a real accomplishment to pass over twelve hundred fish.

Agriculture, superficially an innocent industry which normally has similar objectives of water and soil conservation, as does fisheries, has created some complex problems in the Maritimes. In recent years there has been a trend toward the development of somewhat unique flood control structures known locally as aboideaux. These are in effect dams to prevent tidal waters from inundating low marshland areas near the river mouths and thus reclaim from the sea agricultural land.

The large aboideaux built in recent years are replacing the simple river bank dykes formerly used. Equipped with special gates to allow the outflow of the stream and yet prevent salt water inflow on flooding tides, these present many difficulties to migrating fish. The large difference in tide level in the area where aboideaux are most effective in recovering land, e.g. Bay of Fundy, practically eliminates the use of conventional fish passes. Because of the water control, the environment in the stream and estuary is altered. There is little possibility left for adjustment to salt water for downstream migrants and there is also a sudden change from salt to fresh for those moving upstream.

Agriculture has been indirectly responsible for introducing toxic chemicals into some streams. We have experienced on occasion the results of paris green which as a result of unusual rains drained from the potato growing areas into the streams. One or two streams have been seriously affected by effluents from potato starch plants.

It is well known that the mining industry may adversely affect freshwater streams by releasing sludge and toxic chemicals. Fortunately, however, the development is only now starting and there is opportunity to prescribe remedial measures at the outset.

It is rather peculiar that in Prince Edward Island in one or two streams a great problem has been created by gravel removal. This is probably due to the fact that on the "Island" gravel deposits are limited and large operations are carried out where it does exist. Silting as a result is widespread with the result that large stretches of the streams become non-productive.

In closing, it is perhaps pertinent to mention the development of recreation and transportation, man-devised, since this is responsible for opening areas previously inaccessible. Undoubtedly the result has been beneficial in equalizing the fishing pressure but road building has frequently been responsible for undesirable changes through filling, dredging and improperly designed culverts.

It would appear from this presentation that everything is against fish and that there is no hope in the Maritimes. This idea should be dispelled because in the overall there is an appreciation of the fisheries interest. We must be prepared to suggest and implement the remedies. For this we need more knowledge of fish behaviour and reaction and more people prepared to accept the challenge of overcoming the difficulties. I can assure you that it is a worthwhile reward to solve any one of the problems. We have a whole series of experiments on a grand scale thrust at us through the economic development—we should use them to gain more knowledge.

The Effects on Fisheries of Man-Made Changes in Fresh Water in the Province of Quebec

by

Vadim D. Vladykov

Department of Biology, University of Ottawa (formerly Department of Fisheries, Quebec, P.Q.)

Introduction

This very broad subject must be reduced to a few remarks dealing with conditions characteristic to Quebec. French speaking men, unfortunately, abuse the freshwater fisheries in the same way as English speaking do in other provinces. The fast developing industries—mines, paper-mills, and hydropower installations usually overlook such a small thing as freshwater fisheries! Within a few years, after new automobile roads, railways and dams had been built, the forests chopped down, and logs (or locally "pitounes") driven down salmon or trout rivers, Quebec lakes and rivers were no more a paradise for fish. During the present decade, the yearly cutting of wood in Quebec averages close to $2\frac{1}{2}$ million cords or 208 million cubic feet (Le Soleil, Nov. 30, 1957, p. 3). You can imagine easily that only a minimum quantity of this pulp is going to be used for scientific papers, the authors of which are trying to protect the natural resources.

In 1952, during the centenary of Laval University, a symposium on "The Conservation of Renewable Natural Resources" was presented. According to Desmarais (1953, p. 54), the Province of Quebec is not only the largest in Canada, with 600,000 square miles, but also its nap of fresh water is equal to 12 per cent of the total superficies. The annual precipitation varies according to the region, from 20 to 45 inches. There are 21 lakes with a superficies larger than 100 square miles and, in addition to the St. Lawrence, there are four rivers longer than 450 miles. The forests occupy 77 per cent of the whole province.

Unfortunately, the aquatic fauna of to-day's Quebec is not as rich as it was 400 years ago, when Jacques Cartier visited the St. Lawrence area in 1534. After spending the winter of 1536 at the estuary of the river, known today by his name, he wrote: "There are also to be found in June, July and August, plenty of large eels . . . . . and plenty of lampreys and salmon (Chambers, 1912, p. 20)".

Administration

The administration of Quebec fisheries, both fresh water and marine, by provincial authorities began only in 1883, that is 16 years after Confederation. However, long before that there existed in Canada a service of "Fisheries Protection". Dr. Pierre Fortin, a native of Verchères near Montreal and an M.D. from McGill University, was appointed in 1852 to direct this new service for Lower Canada, especially in the

Gulf of St. Lawrence from Pointe des Monts and Cap Chat to Baie des Chaleurs. Five years later another equally valuable man, of English birth, Richard Nettle, was appointed Superintendent of Fisheries with jurisdiction over the upper St. Lawrence, its tributaries, and interior lakes. Nettle can be called also "the father" of Canadian fish hatcheries. In effect, in 1857, in a house in Quebec City at the corner of St. Ursule and St. John Streets, he opened the first fish hatchery, which he called an "Ovarium". Both these men are well known also for their writings: "Reports" by Fortin and a small, but very interesting book, "The Salmon Fisheries of the St. Lawrence and its Tributaries" (1857) by Nettle.

The present administration of fisheries in the Province of Quebec is quite effective, especially for marine species. However, even here some more precision should be incorporated. For instance, according to the federal laws, applicable in Quebec as well, there are provisions regarding fishing for sturgeon, but the species is not mentioned. In the case of four eastern maritime provinces, there is no confusion, as there is found only one species sea sturgeon (*A. oxyrhynchus*); probably for Ontario and the Prairie provinces this law means the lake sturgeon (*A. fulvescens*). But how should it be interpreted for Quebec, as there are found two species *A. oxyrhynchus* and *A. fulvescens*. In British Columbia it is even worse as there live two very different species: white sturgeon (*A. transmontanus*) and green sturgeon (*A. medirostris*).

In the case of Quebec administration of freshwater fisheries, there are more complications. For instance, the Quebec Department of Game and Fisheries has jurisdiction only over fish and other animals, but not over the waters and woods wherein they live. If a company is planning to cut woods along a river, this company must secure, from the Commission of Running Waters and Department of Lands and Forests, permission to build dams to drive the logs. Then only this company obtains from the provincial Department clearing papers as to the necessity of erecting a dam with or without a fishway. The most important part of the law stipulates that upon completion of the period of exploitation of a given river, the company *must restore the original condition that existed in this river previous to exploitation.* I have always wondered and never found an answer as to how this can be done!

Man-Made Changes in Freshwater Environment

In the case of Quebec we shall mention only three types of human activities, which adversely affect the local fish and fisheries.

1.—*Paper Industry.* The principle abuses by this very important industry can be summarized as follows: fast thaw of snow, quick run-off of rain, and reduction in food supply especially for young fish (trout and salmon) due to excessive cutting of surrounding trees; building of roads for hauling logs; construction of dams to store water to drive pulp wood or operate hydro installations; and finally pollution of waters by bark, sawdust and industrial wastes ("black liquor").

To illustrate the influence of a papermill on freshwater fisheries a typical situation in the province where the plant is located near the mouth of a river will be described. This company produces its own power, has a large woods operation and manufactures a variety of paper products.

From an economic standpoint this establishment is very important, as it employs a large number of the local population, who work either in the mill, cutting and driving wood or at the hydro installations. Unfortunately, when a high dam was built across the river, provision was not made for a fishway. The results were that when the salmon returned to the river of their origin they found their ascent to the upper river spawning grounds had been blocked.

Water stored behind the dam throughout the summer is used during the winter to generate hydro-electric power required to run the mill. There is a 14-foot fluctuation in lake elevation between the late summer, when the reservoir is filled, and early spring when it is drawn down to its minimum elevation. The reduction in the lake level during the winter months results in the desiccation and freezing of aquatic plants and animals along the shoreline, which under natural conditions make a significant contribution to the food chain of resident fish populations. Storing surface water in the reservoir during the summer months prevents the temperature of the lower strata from rising above 40°F. The combination of the above factors in such an area are considered responsible for the slow growth of speckled trout in the lake.

Further damage to rivers is caused by removing the forest cover from large areas in these river systems. In recent years the amount of pulpwood cut in sections of the province has increased by two and one half times. Removal of trees accelerates spring thaws causing floods, reduces an area's ability to retain moisture causing floods and later drought. Stripping of trees from river banks reduces the natural stability of a stream.

Pulpwood in this part of the country is river driven, arriving at the mills about 60 per cent bark. Considering bark at approximately 600 pounds to the cord, bark deposition on some rivers amounts to several tons each year. Spawning areas may be reduced and rich food production areas may be completely smothered.

Several obnoxious substances known as "black liquor" are produced by mills during the production of paper products. "Black liquor" consists mainly of waste sulphuric acid, tannic acid and lignin. Serious losses to fish stocks may be caused by this pollutant if improperly treated before being released from a mill.

2.—*Mining Industry.* The mineral riches of Quebec are even higher than those of the forest. To-day we shall mention only the case of Black Lake, situated in the asbestos region, close to Thetford Mines.

This lake, of about 410 acres, is located 750 feet above sea-level. Its bottom consists of very rich deposits of asbestos. In 1956, work was started to drain this lake. Through an artificial canal of 6,000 feet, its water was directed to the Becancour River. So far about 57 feet of bottom deposit has been removed. This work required monthly removals of about 1,000,000 tons of bottom silt. Of course there are no more fish left in this lake. Apparently no obnoxious substances have been drained into the Becancour River, which is a popular fishing centre for small-mouth bass.

3.—*St. Lawrence Seaway.* Thanks to Mr. Cyrille Felteau, Information Officer of the St. Lawrence Seaway Authority, we were able to obtain the following data on the extent of work on this seaway.

The parts of this project that interest us most are the dredging of the channel and the building of locks and other installations. Altogether 112 new navigable miles, 27 feet deep, through the rapids, are being opened between Montreal and Prescott,

Ontario. To accomplish this job, 73,440,400 cubic yards of rock and mud are being removed.

The building of seven new Canadian locks, which are 768 feet long, 80 feet wide, and 30 feet deep, required 2,010,000 cubic yards of concrete. The construction of the Quebec lock, located at St. Lambert, opposite Montreal, required the removal of nearly 2,500,000 cubic yards of rock and mud and the pouring of 450,000 cubic yards of concrete. In addition a hydro-electric plant is located at Cornwall, Ontario, with an artificial lake of 40,000 acres.

The changes in the St. Lawrence River due to the different undertakings in connection with the seaway are unfavourably affecting the local fisheries. Unfortunately there are no precise data as to the extent of these influences. Nevertheless we can suppose that the dynamiting and dredging of the channel have killed the fish found nearby. In effect, during the summer of 1956 we saw several dead fishes, especially lake sturgeon and pike-perch (*Stizostedion vitreum*), over a large area, from Sorel to Ste-Anne-de-la-Pérade. However, the exact causes of this mortality were not established.

We suspect also that the tremendous quantities of cement used, could easily raise the alkalinity of the surrounding water to the danger point. In 1947, for instance, we poured cement over the bottom of a laboratory aquarium. After washing and repeated changes of water, some fish were put in from another aquarium without cement. In about two hours one young lake sturgeon and one small-mouth bass were dead, while a brown bullhead was dying. The difference between the two aquaria was in the pH values: 9.2 in the aquarium with the cement and 7.0 in the other.

During the summer of 1956, the year of the fish mortality, we took some surface-water samples from Montreal to Ste-Anne-de-la-Pocatière. The pH of the St. Lawrence below Montreal is no higher than 8.2. Around Montreal it is 8.6, while near the new St. Lambert lock the readings were 9.20 and 9.75.

Another very unusual observation is that in 1957, throughout the St. Lawrence River, adult striped bass, which spawn in the Lake St. Peter area, were apparently reduced to a very small number. The exact reason for the reduction of the bass is unknown. Fishermen observed in the spring of 1957 some large striped bass (4-8 pounds) dead among ice floes at Ste-Angèle-de-Laval, opposite Three Rivers, and about 150 miles farther east at Rivière Ouelle. The causes of this mortality remain unexplained.

It is probably an opportune moment to ask the question: what changes in fishery conditions will there be in the St. Lawrence River in a few years from now, with the seaway in operation? There is no doubt that excessive alkalinity of cement and other material used in the construction of locks and hydro plants will gradually be washed out. The direction of the current will follow a new definite pattern. Some new pollution, especially by discharge of oil and petroleum products, will increase due to the much greater volume of navigation. The exchange among freshwater and anadromous fish species from the lower St. Lawrence and Great Lakes region will be accelerated.

Since 1944 we have studied closely changes in fish composition in the upper St. Lawrence River. Two native Great Lakes species, the gizzard shad (*Dorosoma cepedianum*) and white bass (*Lepibema chrysops*), and, recently introduced in Lake Oswego,

the white perch (*Morone americana*) enter yearly in variable numbers in the Quebec section of the St. Lawrence River. The white perch is found in very small quantities; altogether from 1952 to 1957 only 43 specimens have been taken. The two other species are found in much larger quantities. The greatest number (3,098) of white bass was taken in 1954 and of gizzard shad (415) in 1955. The years 1956 and 1957 were very poorly represented, maybe due to the construction works on the St. Lawrence Seaway. We believe that Quebec will contribute "in exchange" a greater number of eels and sea lampreys.

4.—*Man Helps Nature.* In conclusion, we would like to bring to attention at least one case of man's activity which has helped increase the natural population of important animals. We would like to speak about the snow goose (*Chen hyperborea*) and Canada goose or outards (*Branta canadensis*). These two aquatic birds sojourn some months in Quebec in the spring and fall, during their migratory flights. The snow geese are found not very far from Quebec City, between Cape Tourmente to l'Islet, while the Canada geese extend through a much larger territory, from Kamouraska to Montreal.

Thanks to Mr. Louis Lemieux of the Canadian Wildlife Service, we can give the following information. There were, in 1957, about 20,000 Canada geese, weighing on the average nine pounds. They feed partially on aquatic vegetation and partially on grains from the farmers' fields. They are found quite often in the company of snow geese, and the duration of the sojourn for both species is about the same.

The second species, the snow goose, is far more interesting. It is the pride and joy of Quebec. Thanks to the protective steps taken by the authorities of the Quebec Department of Game and Fish and especially by the late Superintendent, Mr. Charles Frémont, the number of snow geese, from a skimpy flock of 3,000 in 1908, reached an estimated 100,000 in 1957. They sojourn in Quebec from the end of March to the end of May and from the middle of September to the end of November. Their average weight is about six pounds. They stay on the shores of the St. Lawrence River and feed on roots of the American bullrush (*Scirpus americanus*), locally known as "foin de gréve".

It will be important to find out the quantity of guano that the present Quebec flock of snow geese, amounting to 600,000 pounds of live birds, drops daily during its almost five months' sojourn on the St. Lawrence shores. Thus we consider both species of geese as very beneficial to local fish, due to the fertilizing effects of their guano in producing live fish food.

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The Effects of Power, Irrigation, and Stock Water Developments on the Fisheries of the South Saskatchewan River

by

Richard B. Miller—Professor of Zoology, University of Alberta

and

Martin J. Paetz—Fishery Biologist, Province of Alberta

I. Introduction

The South Saskatchewan River system rises on the eastern slopes of the Rocky Mountains in a large series of mountain streams. These flow together to form several major rivers which emerge from the mountains in a north-south series from central Alberta to the international boundary. On the prairies these rivers ultimately join to form the South Saskatchewan River which flows eastward into Saskatchewan and then north eastward to meet the North Saskatchewan River on the northern fringes of the prairies.

The portions of the system which lie within and close to the mountains at altitudes of 3,000 feet and higher are natural trout waters. They are cold, swift and subject to severe run-off floods; the native fishes are *Salvelinus alpinus malma*, *Salmo clarki* and *Prosopium williamsoni* in the highest parts, with the addition of *Cottus ricei*, *Catostomus commersoni* and *C. catostomus* at slightly lower altitudes. Stocking has established *Salvelinus fontinalis*, *Salmo trutta* and *Salmo gairdneri* in many of the streams. Some of the streams rise in headwater lakes in which the cutthroat and Dolly Varden were the native fish. Two large lakes contain *Salvelinus namaycush*.

On the prairies the trout and char disappear and the rivers support suckers, cyprinids, percopsids, goldeyes, whitefish, northern pike and yellow walleyes.

One of the major mountain rivers of this system is the Bow and its tributaries; all of the high altitude developments to be described in this paper are on the Bow River. Three of the large irrigation systems outside the mountains also use Bow water. Other irrigation and stock water developments involve the St. Mary River system and smaller tributaries of the Bow, Red Deer and the South Saskatchewan rivers.

II. Power Dams on Bow River Headwater Lakes

Five headwater lakes have been dammed to store water for power production. They are Lake Minnewanka, in Banff National Park, The Upper and Lower Spray Lakes and the Upper and Lower Kananaskis Lakes, the latter four in Alberta. Table I shows the original areas and depths of these lakes, the new areas and depths produced by the dams, and the maximum draw-downs.

TABLE I

Headwater lakes of the Bow River

	Years Dammed	Original Area (Acres)	Original Mean Depth	New Max. Area	New Mean Depth	Draw-down
Minnewanka	1912, 1941	3,464	125	5,454	170	35
Upper Kananaskis	1936, 1942	1,440	20	2,100	58	52
Lower Kananaskis	1954	720	45	1,620	47	43
Upper Spray	1949	113	6	4,800	120	35
Lower Spray	1949	313	70			

Lake Minnewanka: This is the largest of the headwater lakes. A dam in 1941 increased its area by a little over one-third and its average depth by 45 feet. Biological examinations of the lake were made before and after the dam was built by Rawson, Stenton, Solman and Cuerrier. A summary of the findings has been published by Cuerrier (1954).

The physical and chemical characteristics of Lake Minnewanka and the plankton have altered little, if any, since the dam was built. The bottom fauna has changed profoundly; the annual draw-down of 35 feet exposes most of the littoral zone and littoral bottom animals have not become established. Midge larvae have increased from $52\frac{1}{2}$ to $93\frac{1}{2}$ per cent of the total fauna and sphaeriids have decreased from 38.6 to 4.6 per cent of the total fauna.

TABLE II

Main stream reservoirs of the Bow System (Upper)

	Year Dammed	Area (Max.)	Mean Depth	Draw-down	Years Studied
Ghost	1930	2700	approx. 50	25	1938, 1943, 1947, 1954
Barrier	1947	760	approx. 50	25	1938, 1946-7
Glenmore	1932	960	approx. 25	5-10	1947-8

The major sport fish was the lake trout, *Salvelinus namaycush*, which fed on an introduced species of cisco and on the native Rocky Mountain whitefish. Since the dam was built this fishery has degenerated very seriously. The trout do not reach sizes beyond about one pound; at this weight there is normally a change from plankton and bottom feeding to fish feeding. This change is not now made, and growth is arrested. The fluctuations in water level apparently result in an ecological separation of the trout and the forage fish on which they feed. An attempt to remedy this situation has been made by introducing the lake whitefish, *Coregonus clupeaformis*.

An interesting sidelight of the Minnewanka story is the discovery that lake trout will spawn at great depths. It was thought that the eggs would be exposed by the draw-down and destroyed; some suffer this fate, but a substantial portion of the eggs is deposited well below the limits of the draw-down.

THE SPRAY LAKES: Originally there were two Spray lakes; the upper had an area of 113 acres and was very shallow. Few fish lived in it but it produced enormous numbers of freshwater shrimps and longnose dace and, during summer, cutthroat and Dolly Varden from the lower lake foraged there. The upper lake drained by a creek into the lower lake, which had an area of 313 acres and an average depth of 70 feet. It had a meagre bottom fauna, comparable to other high oligotrophic lakes, but a fairly rich zooplankton of large copepods. A large population of fast growing, red-fleshed cutthroat trout provided excellent angling. The other game species was the Dolly Varden.

In 1949 a dam was built across the Spray River below the lakes. This created a lake of 4,800 acres, completely obliterating the original two, and increasing the average depth to about 120 feet. An annual draw-down of 35 feet alternately exposes and floods about half of the lake bottom.

After six years, M. J. Paetz found that the plankton was fairly abundant, but that the larger species of copepod had disappeared, possibly due to increased turbidity. No bottom fauna had become established on the new lake bottom which is steep and rocky. The fauna of the original lake beds was reduced and sparse.

The Alberta government carried out a compulsory creel census during 1953, 1954 and 1955. The results were analysed by W. H. Macdonald and a summary published in 1956. The catch of cutthroat trout fell off markedly after the first year of the census. In 1953, 4,334 fish were caught of which two thirds were cutthroat trout; in 1955, 2,875 fish were caught of which one half were cutthroat trout. Anglers' reports indicate the cutthroat have declined further since 1955.

The explanation of the deterioration lies to some extent in the poorer food supply that followed on the flooding. However, the main cause appears to be the elimination of spawning areas. Before the dam the trout spawned in the creek between the lakes and in the gravel below the Spray Falls just upstream from the lakes. Both these areas were eliminated and the nearest spawning gravels are many miles up the Spray River. Here the distinctive lake population has merged with the river population and apparently is losing its identity.

Ciscoes and lake trout have been introduced in the hope of providing angling when the cutthroat trout have become too scarce to be of value.

LOWER KANANASKIS LAKE: This 720 acre lake had an average depth of 45 feet; when the dam was built in 1954, the area at FSL was increased to 1,620 acres but, owing to the gentle contours of the flooded area, the average depth increased only to 47 feet. The lake was studied, prior to impoundment, by Rawson in 1936 and 1947 and by Miller in 1954. Post-impoundment observations have been made by Thomas in 1957.

The 43 foot maximum annual fluctuation alternately floods and exposes 900 acres, or more than half the maximum area of the lake. This has eliminated the littoral fauna. The plankton and deeper bottom fauna appear little changed. Physical and chemical characteristics remain about the same except for increased turbidity

The native game fish were cutthroat trout and Dolly Varden. In the late 1930's rainbow trout came down from the upper lake where they had been introduced. The present *Salmo's* are mostly hybrids between the rainbow and the cutthroat.

The fate of the *Salmo's* seems fairly sure—they will vanish. While reduced food is of some importance, the main cause is the elimination of spawning areas. Originally, the trout spawned in three places; in the Kananaskis River between the upper and lower lakes—this has been dry since the dam was built on the upper lake; in the river below the lower lake—this has been flooded by the dam which impounds the lower lake; and Bolton Creek—a small tributary. This last still provides some spawning, but less than before, as its lower reaches are flooded; also it is subject to violent fluctuations in level during spawning time.

The suckers of Lower Kananaskis provide an instructive lesson in the results of changing spawning facilities. In 1936, three years after the Kananaskis River between the lakes had been cut off, Rawson took 202 sturgeon suckers in one gill-net setting. Eleven years later in a comparable setting he took only three. In 1954 the author caught 166 common and one sturgeon sucker. The sturgeon suckers spawned in the river between the lakes; when this vanished, they dwindled to virtual extinction and their place has been taken by the common sucker, which spawns in muddy bays in the lake.

UPPER KANANASKIS LAKE: This lake is formed by the headwaters of the Kananaskis River. Its original area was about 2½ square miles and its mean depth approximately 20 feet. It contained cutthroat trout and, after 1935, rainbow trout. The main trout food was evidently the shrimp *Gammarus* which formed an appreciable part of the bottom fauna. The water was very cold, slightly silty, and supported a moderate plankton, rich in crustacean species.

Control dams were built in 1936 and 1942. The area increased at FSL to 2,100 acres. The dams permit a draw-down of 52 feet. Dr. Rawson examined the lake in 1936 and again in 1947 after the dam was built. He found the *Gammarus* had virtually disappeared and midge larvae predominated in the bottom fauna; the trout grew slowly and naturally spawned year classes appeared to be absent. Fishing in the lake is poor and it is now little visited by anglers. The deterioration again seems largely due to interference with spawning facilities, with some influence due to change in the bottom fauna, induced, of course, by the fluctuating water level.

In summary of Section II it may be said:

Headwater power dams lead to deterioration of trout resources. The deterioration is produced by several factors:

(1) Interference with spawning grounds; in the Kananaskis lakes the trout are cut off from their spawning by the dams. In Spray the spawning areas are now remote from the lake.

(2) Reduction of the portion of the bottom fauna utilized by the trout.

This is caused by the seasonal changes in water level which do not interfere with midges but do cut down on amphipods, littoral may-flies and sphaeriids.

III. Power Dams on the Bow River, or on Large Tributaries

The major main stream reservoirs are the Ghost Reservoir on the Bow River, Barrier Reservoir on the Kananaskis River and the Glenmore Reservoir on the Elbow River. These have been examined at various times by Rawson and by Miller, Macdonald, Paetz and Thomas.

GHOST RIVER RESERVOIR: This reservoir was formed in 1930 by building a dam across the Bow River just below the mouth of the Ghost River, a large Bow tributary. It was examined in 1938 and 1947 by Rawson, in 1943 by Miller and in 1954 by Thomas.

At maximum level the reservoir has an area of 2,700 acres, a mean depth of approximately 50 feet, and it is subject to an average annual draw-down of 25 feet. The draw-down occurs in April; the reservoir fills again in June.

The plankton was sparse and the water silty in 1938; these conditions remained the same in 1943, 1947 and 1954 and presumably will not change.

The bottom fauna has also remained constant since 1948; it is a poor fauna consisting of oligochaetes, midge larvae and sphaeriids in that order of abundance.

In 1938 the fish fauna was predominantly of common and sturgeon suckers with some Rocky Mountain whitefish, burbot, *Lota lota maculosa*, and Dolly Varden and a sparse population of cutthroat and brown trout—too sparse to provide angling.

In 1947 lake trout turned up and thereafter lake trout were stocked several times. In the last few years anglers have caught small numbers of lake trout, but the fishery is confined to a small, silt-free area in the mouth of the Ghost River.

The combination of silt and fluctuating levels render this reservoir of extremely low productivity and no improvement is likely.

GLENMORE RESERVOIR: In 1932 the city of Calgary built a dam across the Elbow River upstream from its junction with the Bow and on the edge of the city. The dam created the Glenmore Reservoir which is used as a water supply for Calgary.

The reservoir has an area of 960 acres and a mean depth, when full, of about 25 feet. There is never a great fluctuation in level; the principal drop is in late fall and in winter, below the ice cover.

The reservoir was studied by Rawson in 1938 and by Miller in 1947. Both investigations found a poor plankton, reminiscent of the Ghost Reservoir and a moderate bottom fauna. No change was noted from 1938 to 1947.

In the summer and winter of 1947 an intensive study of the fish population was undertaken by gill-net settings. The reservoir was found to contain a large population of common and sturgeon suckers, a moderate population of pike and a sparse, and evidently seasonal, population of trout and burbot. At certain times trout fishing has been fairly good.

This reservoir, while more productive than the Ghost, is limited by the constant load of suspended silt.

BARRIER RESERVOIR: Barrier Reservoir was formed by a dam in the lower Kananaskis River built in 1947. When full, it has an area of 760 acres and a mean

depth of approximately 50 feet. The annual fluctuation, from April to June, is 25 feet as in the Ghost; the low water exposes an enormous area of mudflats.

The reservoir was examined by Rawson during the year it filled and by Nursall in the following year. No studies have been made since. The reservoir has failed to produce angling of significant value.

Barrier Reservoir appears to be a smaller duplicate of Ghost Reservoir; it suffers from a similar silt load, sparse plankton, and fluctuating level. It is unlikely to provide a fishery of value.

In summary of Section III, it may be said:

The main stream reservoirs might be hoped to create a fishery where none, or only a very small one, existed before. Their construction could not lead to the deterioration of an established fishery, as is the case with the headwater lakes. However, they do not provide the angling that their surface dimensions might suggest. This is apparently due largely to two factors that diminish productivity, 1) a load of silt which leads to a sparse plankton, and 2) alternate flooding and exposure of the productive littoral zone which is proportionately large in reservoirs of this type, thus leading to a bottom fauna of small size and poor in trout-food organisms.

IV. Irrigation Reservoirs

Irrigation development in Alberta involving the South Saskatchewan river system has resulted in approximately 1,371,000 acre feet of water storage. This storage is divided among 37 reservoirs supplying water to nine irrigation systems. The primary sources of most of this impounded water are the Bow and St. Mary rivers. The remaining storage involves small projects on tributary streams in the Red Deer and Oldman river watersheds and tributaries of the South Saskatchewan River proper. Waters impounded for irrigation purposes may be divided into two categories, namely, irrigation dams on streams and reservoirs created by diversion schemes.

IRRIGATION DAMS ON STREAMS: For the purpose of discussing the effect on fisheries, stream impoundments may be further divided into: (a) large primary reservoirs on main streams and (b) reservoirs on tributary streams supplying relatively small irrigation projects.

a. Primary reservoirs on main streams

BASSANO RESERVOIR: Bassano dam was built on the Bow River in the early days of settlement on the Alberta prairies. It forms water headworks of the Eastern Irrigation District. The reservoir created by the dam extends up the Bow River valley approximately five and one half miles and has a surface area of slightly more than 1,300 acres. Rather than being designed for storage the dam serves to raise the water level of the river so that it can be diverted through a system of canals to irrigable lands.

The original reservoir had a maximum depth of 60 feet but extensive silting has reduced the maximum depth to 31 feet. Over four-fifths of the reservoir is now eight feet or less in depth. Since the main purpose is not one of storage, there is little annual fluctuation in level. Water temperatures in the reservoir during the summer are about

the same as those of the Bow River in this region (65° F in August). There is no thermal stratification and little oxygen depletion. Due to the heavy silt load, the water transparency is only five feet.

Plankton production in the reservoir is low and more typical of river plankton than lake plankton. The bottom fauna is rich but composed mainly of silt resistant forms such as Oligochaetes, Chironomids and a few Sphaeriids. Fresh water shrimps are absent or at best very rare.

Fish production during the early history of the reservoir is virtually unknown. The first recorded fish sampling was done by Miller in 1947. The tail waters below the dam were also sampled at that time. The reservoir was found to contain a population of common suckers and an occasional northern pike. The tail waters supported a rich fish fauna of goldeye, *Amphiodon alisoides*, yellow walleyes, *Stizostedion vitreum*, lake whitefish, Rocky Mountain whitefish, and suckers. Anglers fish these tail waters extensively but rarely fish in the reservoir. As well as goldeyes and yellow walleyes, the occasional cutthroat rainbow hybrid trout is taken in the tail waters. It would appear that Bassano reservoir produces less game fish than a comparable length of unaltered Bow River water.

ST. MARY RESERVOIR: St. Mary reservoir was formed by construction of a dam across the St. Mary River near Spring Coulee in 1951. It was examined by Miller and Paetz in 1952. The purpose of the reservoir is primarily water storage. At full supply level it has an area of 8,800 acres and a mean depth of 36 feet. The 80 foot vertical draw-down during the summer, reduces the surface area to 1,000 acres and the mean depth to 30 feet.

The water temperature, due to the influence of the incoming river, remains very uniform. It varies only six degrees (55° F to 61° F) from bottom to surface.

Plankton was abundant during the 1952 examination; Cladocerans were especially well represented. The bottom fauna was in early stages of establishment. Bottom animals are doubtless now restricted to only that portion which remains flooded at maximum draw-down.

The fish fauna in 1952 consisted chiefly of northern pike, sturgeon suckers, common suckers and cutthroat trout. These species were resident in the river prior to impoundment. Rainbow trout were stocked in 1953 and landlocked sockeye salmon were stocked in 1952, 1953 and 1955. Rainbow trout showed excellent growth in the reservoir but provided angling for only a brief period. At present, pike fishing yields considerably better returns than trout fishing. Gill net settings during the past year yielded no trout but fair numbers of pike and lake whitefish. There have been no indications that the sockeye salmon introductions were successful.

After a short period of fair trout production, St. Mary reservoir has undergone a shift in fish fauna to less desirable game species. There is little hope of a recovery of the trout fishery but there are indications that a small commercial whitefish fishery may be established.

TRAVERS RESERVOIR: Travers reservoir was formed by building a dam on the Little Bow river in 1953. An additional supply of water for the reservoir is obtained by canal from Lake McGregor which lies immediately to the north. At maximum

level, Travers reservoir has a surface area of 5,600 acres and a mean depth of 46 feet. The annual vertical draw-down of 16 feet reduces the surface area to 4,600 acres. The mean depth at low level is 39 feet. Although the reservoir exhibits definite thermal stratification, the hypolimnion retains an adequate supply of dissolved oxygen.

The bottom fauna is thus far sparse, except at the upper shallow end of the reservoir. Plankton is also scanty in deep areas but much richer in shallow portions.

Fish have access to the reservoir both from the Little Bow river and Lake McGregor. Sampling with gill nets and seines has shown that northern pike, common suckers, sturgeon suckers, chub, *Couesius plumbeus*, and lake whitefish have become established. A commercial fishery for whitefish was attempted early in 1956 but with little success. In 1957 the reservoir yielded 9,000 pounds of whitefish and 2,000 pounds of pike to commercial fishermen. The whitefish fishery is expected to develop further. Lake trout have been introduced but at this time it is not known whether or not the introduction was a success.

b. Irrigation reservoirs on small tributary streams

CAVAN RESERVOIR: Cavan reservoir was formed by a dam on Gros Ventre Creek to supply water to the Ross Creek Irrigation District. It was given only a brief examination by Miller and Paetz in 1952. At full supply level the reservoir has an area of 300 acres and a mean depth of 16 feet. The summer draw-down is variable, depending on the water demand of the small irrigation project which it supplies. Due to the contours of the coulee in which the reservoir lies, the draw-down does not significantly affect the area.

The plankton is rich, especially in plant forms, which cause extensive water blooms. The bottom fauna has not been studied.

The fish fauna originally consisted of suckers and fathead minnows, *Pimephales promelas*. Rainbow trout were introduced in 1952 and additional plantings were made in 1955 and 1956. The initial planting of trout was very successful and trout growth proved to be excellent. In four summers, these fish attained weights of 10 to 14 pounds. Yields to anglers for two years after the introduction, were good but thereafter a sharp deterioration in angling success was noted. Plantings of trout subsequent to the 1952 introduction have not restored the fishery appreciably.

CAROLSIDE RESERVOIR: Carolside reservoir was formed by damming Berry Creek, tributary to the Red Deer River. The stored water is used to supply a small scale irrigation project but future development will link this reservoir with a larger irrigation scheme.

At full supply level the reservoir has an area of 1,600 acres and a mean depth of 19 feet. Maximum draw-down is not expected to exceed one-half the total storage capacity. During seven years of operation the annual draw-down has not approached the expected maximum.

Carolside reservoir is typical of prairie lakes in that no thermal stratification occurs and water temperatures reach 65° to 68° F during the summer. The yield of both plankton and bottom fauna is moderate.

The fish fauna consists of common suckers, cyprinids, sticklebacks, *Eucalia inconstans* and northern pike. The latter species was introduced as a game fish in 1951.

This introduction was a decided success and the excellent pike fishing attracts fishermen from a radius of approximately 100 miles.

Carolside reservoir has provided angling in a part of the province where practically no angling opportunities existed previously. The future of the fishery is, however, dependent largely on water demand for irrigation purposes.

Reservoirs Created by Diversions

The greatest percentage of irrigation storage in the South Saskatchewan drainage is provided by diversion reservoirs. These projects vary in usable storage capacity from 1,000 to 240,000 acre feet. They are supplied by diversion canals from rivers or from mainstream reservoirs. A number of these reservoirs function as "balancing reservoirs" and do not fluctuate noticeably in level, whereas the water supply types fluctuate rather violently.

GRASSY LAKE RESERVOIR: This reservoir lies in the St. Mary-Milk River irrigation development. It is seventh in a series of reservoirs which obtain water from the main canal leading from St. Mary dam. The surface area, at full supply level, is approximately 1,100 acres. An expected seasonal draw-down of 14 feet will reduce the surface area to 700 acres.

Although no biological surveys have been carried out on Grassy Lake, there is considerable information available on the status of the fishery. The reservoir was filled in 1953 and 250,000 rainbow trout were introduced the following spring. A second planting of trout was made in 1955; no further stocking was considered worthwhile. Trout introduction proved very successful. Fish of 12 to 16 ounces in weight were being caught by September of 1954 and during the next two summers the lake provided excellent trout fishing. Deterioration of angling success similar to that experienced on Cavan reservoir, followed, although some large trout were known to be present. Recent sampling of the fish population indicates that whitefish, northern pike, suckers and burbot are now well established. Yellow walleyes were represented by two specimens.

DRIGG'S RESERVOIR: Drigg's reservoir was formed by building two dams on a basin in the Mami Creek Valley. The reservoir obtains its water from Mami Creek and a diversion canal from the Belly River. It supplies water to the Mountain View-Leavitt Irrigation District near Cardston.

At maximum level the reservoir has an area of 832 acres and a mean depth of eight and one-half feet. The original policy regarding draw-down, was to keep the reservoir at or near full supply level during the summer, then lower the level in late fall to a maximum depth of seven feet to avoid flooding in the spring. After trout planting was undertaken in the reservoir, irrigation authorities co-operated by keeping the fall water levels high to prevent winter kill. Under this policy of water manipulation there is actually little annual fluctuation in level.

Observations by Miller (1942) revealed a rich bottom fauna and plankton. The reservoir bottom was more productive at depths of 15 feet and over since these portions had not been exposed by fall draw-down.

During early years of operation, Drigg's reservoir supported a large population of common suckers, fewer sturgeon suckers, fathead minnows and a sparse population

of Dolly Varden trout. Cutthroat trout had access to the reservoir from Mami Creek but did not inhabit it in sufficient numbers to provide good angling. Rainbow trout stocking was carried out and this resulted in improved trout fishing. Trout growth averages eight to ten ounces per fish each summer. Drigg's reservoir offers opportunities for management of a trout fishery. Draining the reservoir periodically would achieve control of coarse fish populations as well as enabling removal of large trout when fishing begins to deteriorate.

McGREGOR RESERVOIR: McGregor reservoir was formed by construction of dams at the north and south ends of a large prairie coulee. Water is supplied to the reservoir by a diversion canal from the Bow River at Carseland. The maximum area of 10,700 surface acres is reduced to 6,380 acres by a 15 foot annual draw-down. The mean depths are 28 feet at full supply level and 22 feet at minimum level.

No plankton studies have been made on McGregor reservoir. Hartman (1957) took a series of bottom samples from north to south and found a low to moderate fauna present. Silting near the north-end inlet appears to restrict bottom food production in that portion of the reservoir.

McGregor reservoir supports a varied fish fauna of suckers, burbot, northern pike, lake whitefish and cyprinids. In addition to a substantial sport fishery for pike, a commercial fishery for whitefish is sustained. The average annual commercial whitefish yield over a 12-year period has been 151,800 pounds.

This impoundment has resulted in establishment of a commercial fishery comparable in importance to that of a number of small natural whitefish lakes in Alberta. No fishery existed prior to building of the reservoir.

CHIN LAKE RESERVOIR: Chin lakes originally were three natural lakes lying near the north end of a long prairie coulee. A dam was constructed between the two lower lakes in the early 1900's to provide approximately 7,700 acre feet of irrigation storage. Later, when the Chin project was included in the St. Mary-Milk River Development, a canal was built to convey water from the St. Mary reservoir to Chin lakes. This was the stage of development when the lakes were examined by Thomas in 1955.

The lower lake at this time was shallow and choked with emergent aquatic plants; it was not examined. Discussion here will be limited to the middle and upper lakes. The middle lake had a relatively constant area of 500 acres and a maximum depth of 22 feet. The upper lake comprised 1,600 surface acres with a maximum depth of 33 feet. In 1955 neither lake had been subject to draw-down during the preceding seven years.

No thermal stratification occurs; dissolved oxygen is present to near saturation at all depths during the summer.

Production of bottom fauna was low in both lakes but the plankton was moderately rich.

The fish fauna consists of cyprinids, common suckers, northern pike and lake whitefish. A commercial fishery was operated in 1947-48 with a production of 26,000 pounds of whitefish and 3,000 pounds of pike. Chin lakes were not fished commercially again until 1955. In 1955-56 the fishery yielded 3,000 pounds of whitefish; in 1956-57 the yield increased to 11,300 pounds.

The upper lake is now undergoing further development for irrigation. A dam recently completed between the upper and middle lakes will increase its area to 4,000 acres at full supply level. A rather severe annual draw-down of 54 feet will reduce the area to 2,300 acres. In view of this development and the existing low bottom food production, it is believed that fish production will show little, if any, improvement.

JENSEN RESERVOIR: Jensen reservoir was formed by damming Pothole Creek coulee, a tributary of the St. Mary River. Prior to completion of the St. Mary dam in 1950, Jensen reservoir was used as an irrigation water supply but since that time it has been used only as a "balancing reservoir" and is no longer subject to draw-down. It now receives water from St. Mary reservoir and delivers water to Ridge reservoir to the north east.

At full supply level the reservoir has an area of 525 acres and a mean depth of 34 feet. Thermal stratification occurs in August, resulting in depletion of oxygen below the 35 foot level.

Miller and Ward in 1950, found that the reservoir was poor in bottom fauna but rich in plankton with zooplankton predominating.

The fish fauna consisted of a large population of common suckers and small numbers of northern pike. Burbot have since been reported present in considerable numbers. Rainbow trout were stocked for three successive years beginning in 1950 and a fourth planting was made in 1955. Trout of the first two plantings grew rapidly and provided fair angling returns. Subsequent plantings have yielded poor returns. The establishment of pike and burbot in the reservoir and continued entry of these and other undesirable species through the irrigation system suggest that there is little hope of managing these waters for trout production.

In summary of Section IV it may be said that:

(1) Excessive fluctuation in level on St. Mary reservoir and pronounced silting of Bassano reservoir prevent development of worthwhile fisheries. Travers reservoir is a contrast in these respects and is expected to provide both sport and commercial fishing.

(2) Good sport fisheries have been provided by irrigation reservoirs on small tributary streams but continued production is dependent on extent of draw-down and is therefore uncertain.

(3) Diversion reservoirs in some instances offer opportunities for short term trout fisheries. The majority have provided sport fishing for northern pike while the larger reservoirs contribute substantially to the commercial pike and whitefish production of the province. The total annual commercial yield from irrigation reservoirs is approximately 580,000 pounds of whitefish and 40,000 pounds of pike. An increase in commercial production is expected as recently completed projects come into production.

V. Stock Watering Reservoirs

The water shortage which developed on the Alberta prairies as a result of the severe drought of the 1930's, demonstrated the need for a water conservation programme which would assure stockmen of a constant future water supply. Many small

reservoirs which store spring run off waters have since been built by the P.F.R.A. (Prairie Farm Rehabilitation Act) or by stock growers with assistance from this organization. These reservoirs are usually located on coulees, intermittent creeks or small permanent streams which drain into the larger water courses. A number of these stock watering impoundments have been found to offer suitable habitat for game fish; many, however, are too shallow to sustain fish life over winter; still others are located in such sheltered situations that shortage of dissolved oxygen renders them unsuitable for fish.

Limnological and biological data are lacking on many of these projects even though satisfactory fisheries may have become established in them. Several that have been examined and are providing angling may be used as examples.

ARMSTRONG RESERVOIR: Armstrong reservoir was formed by damming a small intermittent creek on the north slopes of the Cypress Hills. It was examined by Miller and Paetz in 1953 shortly after completion and while the level was approximately four feet below full supply.

At maximum level the reservoir is about 60 acres in area and has a maximum depth of 20 feet. There is a possibility of draw-down in dry years to supply water to the ranches below the dam. Thus far a draw-down has not been required.

No thermal stratification occurs. Water temperatures reach 65° to 70° F during the summer.

Plankton was rich in variety of forms but only moderate in quantity when compared with that of typical prairie lakes. Although quantitative estimates of bottom fauna were not made it was noted that fresh water shrimps, Chironomids, snails and leeches were becoming established.

The only species of fish occurring naturally in the reservoir was the red belly dace, *Chrosomus eos*. Rainbow trout were stocked in 1953, 1954 and 1955. The growth rate of trout was comparable to that in Cavan reservoir and a successful trout fishery has resulted. Deterioration of angling success is now taking place, suggesting a need for a trout rehabilitation programme.

NEUFELDT RESERVOIR: This reservoir was formed by a dam on Tennessee Creek, a small stream draining from the Porcupine Hills to the Oldman River. It is a very small reservoir, approximately one and one-half acres in area with a maximum depth of 14 feet. Tennessee Creek flows throughout the year at a rate of less than one cubic foot per second except during spring run-off when the flow increases considerably.

Water temperatures in the reservoir do not exceed 60° F.

A moderate plankton is produced with zooplankton being greater in quantity than phytoplankton. No bottom fauna studies have been made.

No fish were resident in the reservoir prior to introduction of 3,000 rainbow trout in 1956. Throughout the 1957 season, angling success was excellent. The trout averaged less than one pound in weight by the end of the second summer. Growth rate was therefore noticeably less rapid than in Armstrong and Cavan reservoirs.

In summary of Section V it may be said that:

Stock watering dams have added significantly to the sport fishery potential of the South Saskatchewan watershed. The small size of most of these impoundments and the absence of undesirable coarse fish species provide opportunities to establish successful trout fisheries.

VI. Discussion and Conclusions

We have been considerably hampered in our attempt to evaluate the fishery situation in these reservoirs by a shortage of factual material on physical, chemical and biological conditions before and after the developments were made. However, some firm conclusions may be drawn:

(1) Power projects on high altitude lakes and rivers have proven to be, in Alberta, uniformly deleterious to the sport fishery. Trout and char fisheries which existed in the lakes prior to the power developments have deteriorated very markedly. On the whole, physical and chemical conditions and the plankton have been little affected; the bottom fauna has usually suffered profound changes, particularly littoral forms which are eliminated by fluctuating water levels. The trout have become scarce partly because of this change in bottom food, but mainly because of the elimination of suitable spawning gravels. At present there is no promising management scheme in sight for these power lakes.

(2) Power projects on rivers and streams have not increased the productivity of sport fishes beyond the level that existed in the rivers before damming. The reservoirs are characterized by high silt loads, low plankton and bottom fauna and sparse fish faunas. The fluctuating water levels rule out any useful management scheme.

(3) Irrigation dams and diversions and stock-watering projects, all at lower altitudes than power projects, lie, therefore, in more fertile soil and are considerably warmer. This gives them an inherently greater productive potential. In addition, the majority is subject to much less draw-down than mountain developments. These advantages are reflected in the fish production. The large reservoirs have developed valuable commercial fisheries for whitefish and pike and sport fisheries for pike. Little or no success has been achieved in attempts to establish trout fisheries in them. The small reservoirs which acquired a coarse fish fauna at the time of their construction have provided good pike angling; those where coarse fish could be excluded have been stocked with rainbow trout. The trout grow extremely well and have provided some excellent angling. However, the angling degenerates as a residual population of large trout accumulates. Some of these may be managed by lowering fall water levels to create winter kills, but most of them constitute, at present, an unsolved management problem.

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The Effects on Fresh Water Fisheries of Man-Made Activities in British Columbia

by

P. A. Larkin and Graduate Students

Department of Zoology and Institute of Fisheries, University of British Columbia

Introduction

The development of British Columbia has been confined to such a recent period of history that it is relatively easy to describe with some confidence the effects of man's activities on the abundance and distribution of freshwater species of fish. It is only since the turn of the century that there has been any major exploitation of the province's resources and industrial development has taken place most noticeably only in the last decade. Fisheries agencies were thus largely cognizant of the potential effects of development on fisheries and were organized to cope with them almost from the time that the problem was posed.

British Columbia has a diversified group of natural resources and thus a great variety of effects on fisheries can be observed. Logging is the province's major industry. Mining for gold, base metals, coal and other valuable minerals is another major provincial industry. In fairly restricted areas agriculture is very intensive. There are abundant sites for development of hydro-electric power, and access to the sea and the subsequent cheap transportation cost encourage secondary industry. Hence the recent and diversified resource development occurring at a time when fisheries agencies were both informed and conservation-minded has provided an excellent opportunity for study, both of the effects of man's activities on freshwater fisheries, as well as the methods of alleviating the effects when they are harmful.

Most of the material in this paper was assembled by six graduate students at the Institute of Fisheries at the University of British Columbia. These students were Messrs. G. Dibblee, J. C. MacLeod, J. D. McPhail, V. R. Pantulu, J. T. Pennell, and C. E. Stenton. Their information was gained both from reviews of the literature and extensive discussions with Messrs. C. H. Clay and W. R. Hourston of the Department of Fisheries of Canada and Mr. R. G. McMynn and Mr. F. P. Maher of the British Columbia Game Department.

It is to these latter authorities that most of the credit is due for the factual material which was assembled, most of which was available only in government files and accessible only to those who were initiated into the intricacies of finding things in government filing systems.

Effects on Fresh Water Fisheries of Forestry Practices: (J. T. Pennell)

The effects of forestry practices on freshwater fisheries can conveniently be divided into general effects, such as the effect of logging on run-off characteristics of watersheds; and particular local effects that depend on the mechanics of the logging operation and the particular local situation.

General effects

It has long been known that the characteristic pattern of flow in streams can be greatly influenced by modifying the character of the plant cover. Extensive logging of an area undoubtedly changes the pattern of run-off from that area. Although there has been no work in B.C., directly correlating these changes in run-off with change in fish productivity, Neave (1949) in a study of the game fish population of Cowichan River, cautiously ascribed a change in the abundance of fish and/or their availability to anglers to changes in run-off consequent upon extensive deforestation in the area.

Logging results in removal of the forest cover, a compaction of the soil, and an overall decrease of ground litter. Removal of the trees decreases the area of surface available for the evaporation and interception of precipitation. Compaction of the soil and reduction of litter is followed by a decreased permeability and storage capacity of the soil for water. A greater fraction of the water runs off the soil surface.

These changes are reflected in the consequent run-off pattern after deforestation. After deforestation there is:

1. An increase in the absolute amount of water flow from that area. It has been estimated that for every pound of dry wood produced by a tree, 1,000 pounds of water are transpired.
2. An increase in the flood peak discharge and a decrease in the low water flow. This is attributable to the changed storage capacity of the soil and the increased amount of direct run-off.
3. Increased run-off and flood peak flows usually mean increased erosion of the watershed area and increased turbidity and sedimentation in streams flowing from the area.
4. An increase in the temperature of streams flowing from the area. This increase in stream temperature follows the removal of streamside shade trees and possibly the increase in the proportion of direct run-off as compared to water percolating slowly down through the soil.

The importance of stream temperature in the distribution and migration of trout has often been noted. A study in the Smoky Mountains of Tennessee showed that migration upstream of brook trout followed logging of the watershed. In a comparison of stream temperatures from two watersheds—one containing a farm, the other a forest, Green (1950) records that over a period of a year the farm stream with little or no shade averaged 11.5°F higher (ranging from 9·20°) than the forest stream with its abundant shade.

The increased turbidity and sedimentation in streams after logging usually has a detrimental effect on the fish population, smothering eggs and altering the aquatic organisms, particularly the aquatic insect fauna, upon which many fish feed.

The increased flood peak flows gouge out fresh stream channels, disturb existing spawning gravel, and pile up debris impeding the water flow. The decrease in low water flow reduces the area available for spawning and feeding of fish. Eggs may be left high and dry in the gravel.

Sustained yield and patch logging with greater care in the construction and placement of logging roads mitigates deforestation effects on run-off pattern.

Concerning B.C., A. J. Whitmore of the federal Department of Fisheries, in the brief to the Sloan Commission on Forestry, 1956, has this to say, "Our department would welcome recognition in the forestry permits of the fisheries needs as associated with streams and lakes, in the terrain to be logged. The recommendation in our previous brief (to the Royal Commission of 1945) that a one-half mile wide belt of timber be left along all salmon streams was ruled to be uneconomical".

These recommendations have now in part been implemented. In the Prince Rupert area an arrangement has been made between forestry and fisheries departments whereby as soon as an application for logging is received at the district forester's office the files are consulted to see if a salmon stream is within the area to be logged—the salmon streams within forestry areas having been indicated on forestry maps by the fisheries inspectors of each sub-district. If a salmon stream or portion of a stream is involved, the district supervisor is advised and he notifies the fisheries inspector in charge of the district involved requesting that he recommend the most suitable clause of the Forest Act, Forest Management, that would provide adequate protection to the salmon stream involved. The clause is then inserted in the logging contract and once the licence is granted the fisheries inspector can carry out periodic checks to ensure that the conditions of the contract are not being violated. The forest management clauses most applicable are—

L30: "The licensee shall at all times keep all streams and stream beds free from logging debris, sawdust and slabwood, and shall cause no interference with, or obstruction to, stream flow at anytime. All trees felled within.....feet of the..... stream shall be felled away from the creek."

L30A: "It is understood and agreed that it is a condition of this contract that no slash or other logging debris is to be placed in any stream channel, neither are earthfilled stream crossings to be used, nor are logs to be skidded within any stream channel whether containing water at the time or not".

L30B: "All streamside trees within.....chains of any stream or stream bed on the sale area, which are required to be cut under the contract shall be felled away from the stream even though this may require special measures".

L30C: "All logging and road building debris shall be kept out of streams at all times and out of reach of high water. Such logging and road building debris as does get into the streams shall be removed by methods as directed by the forestry officer in charge".

L30D: "All tractors and logging equipment shall be kept out of stream channels and away from the banks except for the minimum number of necessary crossings which shall be carefully situated and protected as required, to ensure that they do not become sore spots in the channel."

Local Effects

In the above-mentioned brief to the Sloan Commission it is stated: "*Log driving* in shallow rivers caused considerable damage in the past and remains a constant threat. Besides the devastation from the gouging of spawning gravel bars and resultant channel erosion, the construction of so called 'river improvements' creates further hazards by disrupting the normal regime of the river." Stranded logs may divert water flow from gravel bars, resulting in drying out of deposited spawn, or diversion of normal water

flows from potential spawning areas. Although log driving is now rare in B.C., the operations that do occur can do tremendous harm to the fishery. The remains of many of the old "splash dams" still exist on many rivers in B.C. Some have been removed and programmes are underway to rehabilitate the salmon runs. The Adams River is an outstanding example of what log driving can do to a stream and its fish. The Kalum and Zymoetz (Copper) tributaries of the Skeena River, and the Nass River from the North end of the Columbia Cellulose Licence area to Grease Harbour—a distance of about 75 miles—are understood to be currently under view for log driving.

Log driving and booming on larger rivers such as the Fraser appear to leave the fish unharmed.

Log jams and logging debris often cause obstructions and where they hinder up and downstream migration of fish, are undesirable. Where log jams are directly attributed to the operations of a logging company, the operators are obliged to clear the obstruction. Fisheries officers and stream clearance personnel of the Fish Culture and Development Branch of the Department of Fisheries, clear jams other than those mentioned. Unless jams are impassable or at least a decided hindrance to fish passage, they may be a stream asset; the deep holes usually asscciated with jams afford places of refuge for salmon prior to spawning. In addition a jam often prevents severe scouring during freshets.

Pulp mills are large water consumers; their waste products must be disposed of economically. Water intakes for pulp mills have been screened and storage facilities provided where pulp mill demand would have reduced stream flow.

Sawdust disposal from small sawmills requires constant checking by fisheries officers in order to prevent pollution. Mill Lake (personal communication from Dr. P. A. Larkin) at Abbotsford has been adversely affected by sawdust pollution and smothering the bottom fauna. The disposal of water, containing a heavy concentration of bark sediment, from the hydraulic barking process now being installed in many mills could cause increased pollution problems. No serious pollution has been reported from this specific cause as yet in B.C. Adequate screening is usually practised.

Spraying against forest insects has recently created some local problems. In 1957 there were extensive efforts on the part of federal and provincial governments and the companies whose timber was affected, to save large stands of hemlock in the Nimpkish-Port Hardy area on Vancouver Island from defoliation by the black headed budworm. Aerial spraying of D.D.T. over some 158,000 acres at a cost of over $300,000 was carried out in 1957. Timber values were estimated at $25 million.

From test pens and general observation, damage to young salmon was extensive. Every effort was made by those in the spraying operation to avoid contamination of streams and lakes but seemingly without success.

Summary

There can be no question that historically, extensive clear cut logging has had deleterious effects on populations of freshwater and anadromous fish, particularly in coastal areas. However, the recent trend to sustained yield management of forest resources together with the inclusion of practices in logging which are designed to protect fisheries resources, will no doubt greatly mitigate these effects in the future.

At the same time, other trends in modern forestry practices are causing substantial concern to fisheries agencies. The indiscriminate spraying of large areas of forest for insect control is known to have disastrous effects on fish in streams. If forest spraying is to be carried on in the future on a large scale—and there are indications that it may be—fisheries agencies will require a greatly increased knowledge in this field upon which to base sound conservation measures.

Effects on Fresh Water Fisheries of Agricultural Development in British Columbia (J. D. McPhail)

At the present time the effects of agriculture on fisheries in B.C. are relatively unimportant. Nevertheless these effects are real, and it seems likely that they will become increasingly important in future years.

The major agriculture practices affecting fisheries in B.C. are:

1. Irrigation
2. Removal of cover from a watershed
3. Crop spraying

Since many of the flood control devices which have been installed in British Columbia have been designed for protection of agricultural areas they will also be discussed here.

Irrigation

It is estimated that 150,000 acres are under irrigation and that in British Columbia another 500,000 could be brought under irrigation at a somewhat higher cost (Purcell 1955). Most of the irrigation takes place in the dry interior region of B.C. although there is considerable land under irrigation in the lower Fraser Valley. Irrigation is especially important in the Okanagan Valley and the Kamloops-Merritt district.

Irrigation can affect fish in the following ways:

1. Fish are diverted into irrigation channels
2. Water is removed from the stream
3. Water is stored for irrigation
4. Silting arising from irrigation caused erosion

The diversion of fish into irrigation channels can be a major problem. For example the Nicola River and its tributaries are important salmon producers, but there is also extensive irrigation and large numbers of young salmon are diverted each year into the irrigation channels. In many small diversions water is pumped from the stream. Unless the pumps are properly screened young fish can be sucked into the pumps and killed.

It is not expected that losses of this type will become a serious problem. Present regulations specify that all types of irrigation diversions must be properly screened. The Department of Fisheries has developed self-cleaning screens for larger diversions. These are being installed by the Government on all old diversions and by the builders on any new diversions.

The minimum flow of a stream is held to be one of the most important factors limiting productivity. The removal of water for irrigation purposes comes at a time

when stream flow is naturally low. Irrigation therefore aggravates the minimum flow condition. Low water reduces nursery areas, exposes spawning beds and causes an increase in maximum temperatures. In many cases so much water is taken that the stream dries up. Clemens et al. (1939) estimated that perhaps 60 per cent of the tributary streams entering Okanagan Lake were being more or less completely utilized for irrigation purposes. Undoubtedly the percentage is much higher at the present time. The Salmon River which flows into Shuswap Lake once supported a run of sockeye salmon. So much water is being utilized for irrigation purposes that the stream goes dry over much of its length during the summer months.

Applications for water licences are now referred to the Department of Fisheries, the B.C. Game Commission and the International Pacific Salmon Fisheries Commission for comments and suggestions. These organizations attempt to reserve minimum flows in fish producing streams.

The storage of water for irrigation purposes has some important effects. Dams are built at the outlets of lakes whose outlet streams are used for irrigation. The flow through the dam can be controlled and in this way a good supply of water is assured during the irrigation season. Beaver Lake and many other mountain lakes in the Okanagan are dammed in this manner. The water level fluctuations of these lakes are increased by the storage dams, but in some instances productivity is improved by changes in lake morphometry. In many of these lakes adult trout go over the dams to spawn but neither the adults nor the fry can get back into the lake. Where possible the storage regime is modified for fish conservation purposes. The construction of fishways at storage dams and stocking programmes where indicated have greatly offset any harmful effects.

Silting caused by erosion has been minimized in recent years by increasing use of soil conservation techniques. Sprinkler irrigation (rather than furrow irrigation), the planting of cover crops, and contour plowing have all been encouraged with mutual advantage both to the agricultural and fisheries resources.

Removal of Watershed Cover

When the large trees and other cover are removed from a watershed the result is usually a very rapid run-off and often a lowering of the water table.

The physical characteristics of a stream determine to a great degree what the level of abundance of fish will be. Some of the more significant physical characteristics which can limit productivity are:

1. Minimum flow—low flows restrict the food supply, strand fish inside pools, render fish more susceptible to predation and can increase temperatures to intolerable levels.
2. Stability of bottom deposits—highly variable run-off, freshet conditions, stream silting, bottom scouring etc., destroy food organisms, prevent successful incubation of eggs and in other ways adversely affect fish populations.
3. Stability of stream banks—largely associated with natural cover. Bank erosion causes silting, absence of shade warms the water and reduces natural cover.

These three characteristics are inter-related and often occur together. All three can be caused by man's utilization of the stream's drainage area. In most parts of B.C. agriculture does not affect a very large portion of a stream's drainage area. However, the lower mainland is a notable exception. The entire drainage areas of many of the small, but heavily fished lower mainland streams are almost entirely utilized for agricultural purposes.

A good example of such a stream is the Salmon River in the Langley area. The forest cover of the Salmon River drainage area has been greatly reduced and replaced by cultivated crops and grass land. This has resulted in increased stream discharge during periods of heavy precipitation and in lower reserves of ground water during the more arid periods. Farmers with wells in this area have reported a drop in the summer water table of from 15 to 20 feet since first entering the area (McMynn and Vernon 1954).

It has been demonstrated (Neave 1949) that a simple general relationship existed between stream run-off and the commercial catch of coho salmon two years later. It is also known that minimum flow of any stream is an important limiting factor in the number of fish produced by that stream. Utilization of the Salmon River drainage basin for agricultural purposes has resulted in greater variability in stream flow, restriction of cover and erosion of stream banks. The low flow condition is further aggravated by irrigation. There are 30 licensed water users in the area. They utilize nearly 400 acre feet of river water annually. The greater portion of the water used for irrigation is used during the minimum flow period. It seems very likely that in the case of the Salmon River minimum flow is a main limiting factor in fish production. There can be little doubt that the low minimum flow is largely a result of the utilization of the drainage basin for agricultural purposes.

Flood Control

Because flood control is intimately connected with the problem of run-off it is included here. It is not, however, strictly an agricultural problem.

Two of the major flood control projects in B.C. have affected fisheries. These are the Okanagan River flood control project and the flood control programme on the lower Fraser River.

With the construction of the Grand Coulee Dam the upper Columbia River salmon populations were relocated. Large numbers of sockeye were planted in Osoyoos Lake. As a result the Okanagan River above Osoyoos Lake is now one of the major salmon producers of the Columbia system. In 1950 a flood control project was proposed on the Okanagan River. The project plans included the construction of a new stream channel between Osoyoos Lake and the Southern Okanagan Lands Project Dam. Part of the new stream bed was to be paved with heavy boulders. This would eliminate a major portion of the sockeye spawning beds. Because the new river bed would be much shorter than the original, the channel gradient would be much increased. In order to compensate for this it was proposed that thirteen vertical drop structures be built between Osoyoos Lake and $1\frac{1}{2}$ miles north of the town of Oliver. These drop structures would constitute a series of obstructions which would cause the delay of the migrating salmon. Because the salmon ascending the river from Osoyoos Lake are fast approaching maturity this delay would be of serious consequence.

A report on these fisheries problems associated with the project was prepared in 1954 by the U.S. Fish and Wildlife Service, the Washington State Department of Fisheries, and the Department of Fisheries of Canada. In this report modifications of the proposed project were suggested in order to preserve the salmon runs. The following pertinent modifications were suggested:

1. Instead of paving, parts of the channel should use dyking or some other means of channel protection.
2. That the vertical drop structures be built in such a manner as to assure unobstructed movement of the salmon, i.e., the installation of weirs in the drop structure stilling basin.
3. That provision be made for a minimum flow in the summer months.

These recommendations were followed to a large extent by the flood control authorities and salmon still spawn successfully in this portion of the Okanagan River.

Following the flood of 1948 the Fraser Valley Dyking Board was set up to carry out a flood control programme. This programme consisted primarily in the construction of dykes on the low-lying regions contiguous to the Fraser River. Flood gates were constructed on several lower mainland tributary streams entering the Fraser. These flood gates are automatic and close when the Fraser starts to back up into the tributary streams. When the gates are closed water is pumped out of the stream, over the dyke and into the Fraser.

The 15-year average duration of freshet on the Fraser extends from May 1st to July 31st (Hourston 1950). The months of April and May are the period during which the greater part of the seaward migration of young salmon takes place. This means that during a large portion of the migration period the only route to the Fraser is through the pumps. It was observed that some degree of mortality was resulting from this passage through the pumps. Experiments were carried out and it was established that the mortality varied directly with the length of the fish. The rivers involved are utilized by coho, chum and pinks. Chums and pinks migrate seaward very soon after hatching and as a result they are very small, and so is the mortality through the pumps. Coho, however, usually spend up to a year in fresh water and are of such a length when they migrate that a high mortality could occur when they go through the pumps. For this reason it has been recommended that bladeless pumps be used.

Crop Spraying

It is well established that many of the insecticides used agriculturally are toxic to fish in the concentrations used. It has been reported (G. Dibblee, personal communication) that there have been several cases of minor fish kills in the lower Fraser Valley due to crop spraying. However none of these instances have been investigated.

In Alabama, Young and Nicholson (1951) report that a combination of heavy rainfall and repeated applications of insecticide resulted in the washing of sufficient toxic material into streams to cause major fish kills. These conditions are often duplicated on the lower mainland and it seems likely that there is some fish mortality from crop spraying.

Summary

In general, the effects of agriculture on fisheries in British Columbia can be regarded as relatively unimportant at the present time. Losses of fish in irrigation diversions have been reduced by screening. Reduction of flow in streams and storage dams on small lakes have had harmful effects but every effort has been made to minimize losses. Soil conservation practices have lessened the harmful effects of silt in streams. Flood control programmes have been studied from the fisheries viewpoint and have incorporated fish protection measures.

With complete inspection of all water licence applications an established routine there is every reason to believe that the present situation can be maintained.

Effects of the Mining Industry on Fresh Water Fisheries of British Columbia (G. Dibblee)

Generally speaking, the mining industry of British Columbia poses a potential threat chiefly to the sport fishery of the province. Damage to the sport fishery can arise mainly from two phases of mining activity which may be described as mining and processing. In placer gold mining it is the actual mining operation that adversely affects the sport fishery while in the case of other minerals it is the waste products of the processing operation which can cause harm. Since the extraction of minerals from their ores and the disposal of the resulting waste products requires a large amount of water it is not surprising to find that processing plants are almost invariably located near a lake or stream. If any lake or stream on which a plant is located is used to carry away the waste product of the processing operation, serious harm to any sport fish present will result.

The most intensive mining area is the southeastern portion of the province. In terms of the number of mining centres and value of minerals produced, it represents well over 50 per cent of the provincial total. This area also presents more mining pollution problems than all the other areas combined.

Placer mining is particularly detrimental to the sport fishery. Because the mining operation itself takes place in the stream and utilizes the gravel of the stream, there is little that can be done to avoid the harmful effects of this operation. Placer mining by dredging involves scooping up the gravel of the stream bed, screening out the larger stones, and running the rest through sluice boxes where the gold particles settle out and are reclaimed. Hydraulicing is also used in placer operations. This consists of directing water through high pressure hoses at the banks of the stream bed and at other gravel areas that cannot be reached by dredging. Mr. F. P. Maher (personal communication) summarizes the effects of placer mining on a river as follows:

1. The removal, screening, and final replacing of the gravel in the stream bed greatly increases its porosity since only clean stones are replaced. This may result in the stream disappearing and flowing underground.
2. Stacker belts of the dredges replace the gravel in the stream in an unnatural way with the fine gravel on the bottom and the coarse gravel on top. This reduces the bottom fauna and prevents or reduces spawning.

3. The gravel might be replaced by piling which creates pools and back-waters which become dry at lower water levels.
4. The operation of sluice boxes and hydraulicing produce large volumes of silty water which affect the stream as mentioned below in the case of tailings.
5. Large scale placer mining operations often remove plant cover and top soil from large areas along the stream banks. This causes higher stream temperatures due to lack of cover, reduction of surface insects available as food, and erosion—which can cause excessive siltiness.

The majority of *mining pollutions* in southeastern British Columbia are caused by the wastes or tailings of the processing operation which extracts the minerals from their ores. Most commonly the minerals are lead, zinc and tungsten. The ore from the mines is conveyed to the mill, ground up, mixed with water and various re-agents, put through a flotation process and the metal extracted. Since the mineral recovered forms a small part of the ore, the waste product amounts to a sizeable output. Small mills put out up to 150 tons of tailings a day, while larger mills produce up to 2,000 tons a day. Tailings appear as a sludge made up of water, chemicals and ground-up rock of various sizes. If the tailings are allowed to enter a stream the effects are highly deleterious to the sport fishery:

(*a*) The turbidity caused by the tailings inhibits angling, reduces photosynthesis which in turn reduces productivity. Algal growth disappears.

(*b*) The coarser sand particles of the tailings are usually quite clean and apparently have a scrubbing effect on the rocks and gravel of the stream. This tends to remove algal growth as well as bottom organisms.

(*c*) Coarser rock particles plug up the interspaces in the gravel and hence reduce the habitat of bottom fauna.

(*d*) Spawning of trout is affected since observations by Maher on the Lardeau River indicate that trout avoid highly turbid water and will crowd into clear areas to spawn. If the clear area of the stream suitable for spawning is insufficient a reduction in the number of offspring would result.

(*e*) If eggs are already in the gravel when pollution occurs, the compacting of the gravel with tailings will reduce circulation of water through the redd and cause the eggs to suffocate.

Maher found that no aquatic life is present in the area of a stream affected by a tailings pollution.

Although small concentrations of metallic salts are known to be lethal to fish, Maher reports that they are not present in the tailings in sufficient concentrations to cause harm.

Although mining pollutions by chemical wastes are rare, in certain instances potassium cyanide used in processing gold ore has caused serious harm to sport fish. This reagent is used to reclaim gold in either the leeching or flotation process. In the former case, any potassium cyanide which enters the stream is purely accidental since it may contain gold. On occasion this has been known to occur in the Kootenay region, resulting in high mortality to fish. Maher reports that concentrations as low as 0.27 p.p.m. of potassium cyanide have killed trout in ten minutes. When potassium cyanide

is used in the flotation process it is included in the effluent from the mill and therefore presents a serious pollution if it is allowed to enter water containing fish. A pollution of this type exists in Jack of Clubs Lake near Wells, where the outlet stream is used to carry away plant wastes. In this instance the part of the lake adjacent to the outlet and the outlet itself are toxic to fish, while the remainder of the lake is unpolluted. Test cages containing one hundred rainbow trout fingerlings were put in the outlet and inlet streams. After twenty-four hours all of the fish in the outlet cage were dead while complete survival of the inlet fish resulted.

As already mentioned, the area with the greatest mining pollution problem is the southeastern part of the province, commonly referred to as the Kootenay region. An examination of the pollution files of the B.C. Game Commission showed that in 1952 there were at least 16 mining pollutions in this area. Four of these were caused by gold processing operations, two by placer mining, and the remainder by tailings mostly from base metal concentrators. At the present time two known pollutions exist and they are in the process of being remedied. This excellent "clean-up campaign" is due to the co-operative efforts of personnel of the B.C. Game Commission, particularly Mr. F. P. Maher and the various mining concerns. In the remainder of the province only a few isolated mining pollutions still exist but it is expected that these will be overcome in the near future. On a province-wide basis, more than 85 per cent of the mining pollutions existing in 1950 have been corrected.

Three methods of preventing tailings from entering lakes and streams are employed in British Columbia. Most commonly an impoundment of tailings is accomplished by erecting a barrier around the area into which tailings are dumped. The impoundment may be made of wood, stone or concrete, etc., or may utilize the local terrain, i.e., damming a ravine. Since the quantity of tailings produced is large, impoundments often reach a considerable size. For example, the impoundment area for the H. B. concentrator (Pb, Zn) is three-quarters of a mile long and one-half mile wide. The lead, zinc concentrator of the Reeves-MacDonald Mines Ltd. on the Pend d'Oreille River discharges 1,200 tons of tailings a day; 200,000 tons a year; and 900 cubic feet of tailings an hour. Another method of dealing with the tailings problem is by back-fill. In this case the waste material is pumped into the worked-out sections of the mine. The Bluebell Mine (Pb, Zn, Ag) on Kootenay Lake uses this method in conjunction with an impoundment. A centrifuge pump separates the solid waste from the water, whereupon the solid waste material is conveyed into the worked-out chambers of the mine. In one instance at least, the spring high water period is used to convey excess waste from an impoundment. The waste, calcium sulphate, is retained in an impoundment until the spring freshet occurs, whereupon it is pumped into the river. Release of the effluent at this time does not interfere with the sport fishery since the river is unfishable due to natural turbidity.

The correction of a tailings pollution in most cases is costly and drawn out. This is often due to difficulties involved in enlarging existing disposal facilities and securing land for additional impoundment areas. In precipitous terrain particularly, this presents a real problem. In pollution, as with illness, an ounce of prevention is worth a pound of cure. This is especially true in mining pollutions where a programme of abatement is simplified by the inclusion of adequate disposal facilities with initial construction plans.

Effects of Hydroelectric Development on the Fresh Water Fisheries of British Columbia (V. R. Pantulu)

By the end of 1956 there was an installed hydroelectric turbine capacity of slightly over 2½ million horse power in British Columbia. Estimates by competent authorities suggest that a total of about 9½ million horse power may be required by 1975, to meet the growing demands of various agencies. Past experience elsewhere, has shown that the effect of power dams on salmon producing streams and rivers could prove disastrous to the existing and potential salmon fisheries. While on this score alone "it would be unrealistic to adopt an attitude that fish production and power development are completely incompatible resource uses" (Larkin 1956), it certainly highlights the necessity of closely examining every project with a view to analyzing its probable effects on fisheries and planning in advance, fish protection facilities, to ensure judicious exploitation of resources.

There have been many recent accounts of the various effects of hydroelectric developments on fisheries (Hoar 1956, Larkin 1956, Brett 1957, Hourston 1958). Table I briefly sketches the nature of many of the problems and indicates both the types of solution at present and the lines on which current research is progressing. (From Larkin 1956). Figure 1 is from Hourston (1958) and indicates the types of problems which occur in diversion projects.

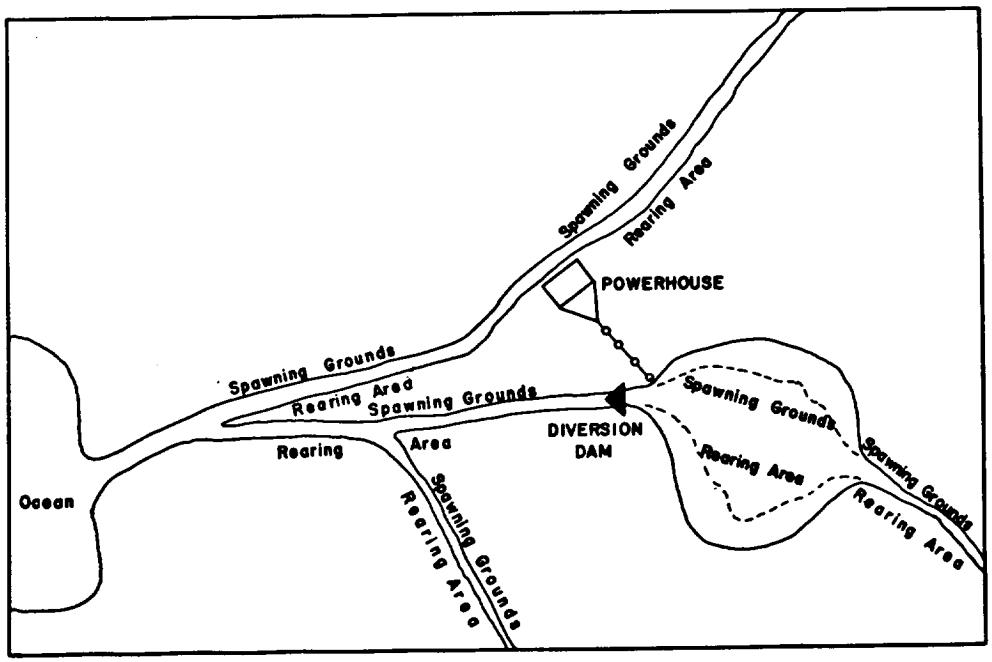

FIGURE 1. *Plan of a typical diversion type hydroelectric project. Areas utilized by anadromous fish are shown. (From Hourston 1958).*

TABLE I

Types of effects on fisheries of hydroelectric developments in British Columbia

Structure or Phenomenon	Example	Effects	Possible solution	Type of Research or investigation needed or in progress
Diversion of stream to new drainage system.	Babine from Skeena to Fraser.	Portion of young Babine fish diverted to Stuart would probably return as adults to Babine via Fraser; thus portion of Babine run lost.	Prevent migrants from going down diversion.	Screening or guiding.
Diversion of most of stream through pipe or tunnel to power house.	Seton lake power project; any typical diversion type project.	Adult fish congregate at power house; do not take simple passage through lesser flows.	Shut off power house for short period when necessary; guide fish to lesser flow.	Could be a guiding or attracting problem.
Change in temperature regime of streams.	Depth of water release from impoundments can alter temperature characteristics.	Alters rate of dissipation of energy reserves of fish, ability to swim and negotiate obstacles and fatigue; may alter behavior; end results can be failure of fish to reach destination, or reduced reproduction. Under some circumstances this factor could alleviate harmful effect of mechanical obstructions.	Manipulation of level of water release to obtain desired temperature. Basic research on physiology much needed to gauge effects and suggest solutions.	1. Basic research on physiology. 2. Prediction of temperature structure of reservoir. 3. Investigation of mechanical methods of drawing water for turbines or spills from various depths.
Change in volume of flow and chemical characteristics.	Diversion or impoundment of water.	Possible physiological effects largely unknown.	Manipulation of water release levels. Research needed to gauge effects and suggest solutions.	Basic research on physiology.

TABLE I (*Continued*)

Types of effects on fisheries of hydroelectric developments in British Columbia—*Continued*

Structure or Phenomenon	Example	Effects	Possible solution	Type of Research or investigation needed or in progress
Obstruction by dam.	Any large dam in which only small proportion of flow can be economically spared for fishpasses.	1. Fish die or are at least delayed because they do not locate fishpass entrance. 2. Fish are delayed or injured because fishpasses will not accommodate sufficiently large number of fish. 3. Fish are exhausted or injured in fishpass because of faulty design.	1. Proper design of fishpasses and attraction devices based on— 2. Knowledge of behavior and performance of fish.	1. Hydraulics research on fishpass design. 2. Basic research on physiology and behavior.
		4. Fish swept back over dam after negotiating bypass.	1. Guiding or steering fish away from spillway. 2. Transport of fish above forebay of dam.	1. Guiding of fish. 2. Physiology in transport of fish.
Transport by tank truck.	Capilano; any high dam where elevator structures uneconomical.	Fish injured or die from effects of handling and trucking.	1. Fish swim into truck. 2. Drugs used to quiet fish. 3. Application of research on physiology of transport.	1. Research on improved trucking techniques. 2. Research on physiology in transport.
Delay in reservoir.	Any large impoundment on a migration route.	Fish not adapted to going through still water, delay from temperature stratification in lakes? Seriousness of problem needs evaluation.	1. Transport of fish past reservoir. 2. Attract or guide adults through reservoir.	1. Research on possibility of this being a problem needs study

Accumulation of small delays at many dams and reservoirs.	Any series of dams and/or reservoirs.	Fish attain maturity before reaching spawning grounds; or reach spawning grounds but reproductive ability impaired.	1. Transport of fish past series of dams. 2. Improve fish passes and speed up passage in reservoir.	See above.
Flooding of spawning grounds.	Lake storage flooding out spawning streams; river dams flooding out pink, spring salmon or steelhead spawning.	Prevents successful spawning or crowds too many fish on remainder of grounds or forces spawning on inferior grounds.	1. Build artificial spawning channels. 2. Create storage by lowering rather than raising lake levels (in some cases).	1. Research on making artificial spawning grounds. 2. Engineering surveys.
Rate of flow from storage area to spawning grounds.	Storage dam located on lake above outlet spawning grounds.	Can reduce spawning area, in some cases can improve on natural conditions.	1. Build artificial spawning channels. 2. Regulate flow to be high and uniform from spawning to fry emergence.	1. Research on artificial spawning grounds. 2. Engineering surveys.
Temperature of water from storage area higher than natural.	Storage dams upstream of spawning grounds.	Can influence growth and survival of eggs and young.	Modify storage regime, siphons for outlet works.	1. Survey local site to gauge effects.
Obstruction of young fish by storage dam.	Storage dams upstream of spawning grounds.	Young salmon cannot *ascend* from spawning grounds to lake.	Fishpass through storage dam for young salmon.	1. Research on ability of young fish to perform. 2. Hydraulics research on fishways.
Productivity of lake changed by storage use.	Any alteration in lake levels.	May reduce capacity of lake to produce fish, may be compensatory effects.	Modify storage regime; artificial culture of fish.	Survey lake before and after project to assess effects.
Productivity of lake changed by diversion of water into it.	Many diversion type projects.	May affect productivity by changing transparency, temperature and mineral content.	Modify storage regime; artificial culture of fish.	Survey lake before and after project to assess effects.
Flooding out stream habitat areas.	Capilano. Coho and steelhead rearing areas.	Substitute lake environment for stream fish, may affect production of young fish.	Artificial culture of fish.	Survey lake before and after project to assess effects.

TABLE I (*Concluded*)

Types of effects on fisheries of hydroelectric developments in British Columbia—*Concluded*

Structure or Phenomenon	Example	Effects	Possible solution	Type of Research or investigation needed or in progress
One or more reservoirs on stream.	Any large integrated basin development scheme.	Pink and coho salmon and steelhead not adapted to migrating through lakes. Spring and sockeye naturally migrate through one or at most two lakes. Passage through several reservoirs probably would cause high percentage of death or "residualism".	Devising methods of flushing young salmon through reservoir areas; guiding migrants, diverting migrants, catching migrants above reservoirs and trucking them downstream.	1. Research on steering or guiding migrants. 2. Research on catching and trucking migrants.
Spillway of dam.	Any dam.	Young fish killed in spillway by abrasion, concussion, and various other kinds of mechanical factors.	1. Design spillways so fish not killed. 2. Guide migrants away from spillway and into bypass.	1. Research on spillway design. 2. Guiding migrants.
Turbines.	Any dam where power turbines water intake within 100 ft. (?) of surface.	Fish killed in passage through turbines by turbine blades or pressure change.	1. Screen turbine intake. 2. Change design of turbine. 3. Guide migrants away from intake and into bypass.	1. Research on turbine design. 2. Guiding migrants.
Changed ecological conditions in stream.	Below reservoirs.	Accumulation of predators causes high loss of migrants.	Seasonal eradication of predators?	Survey to assess after dam built.

TABLE II

Developed hydroelectric projects in British Columbia

Name of Project	Location	Species of fish involved	Problems	Solutions
1. Alouette River Project.	Alouette Lake.	Sockeye, spring, coho and chum salmon, steelhead and cutthroat trout.	Barrier of migration. Flooding of spawning grounds above dam. Reduction in flow of residual river reduced runs and destroyed spawning grounds.	No fish protection or passage facilities exist. Facilities at this stage not likely to be helpful unless other provisions, indicated below, made. Arrangements needed for release of minimum flow and construction of artificial spawning channels. If these provisions cannot be made at this stage main Alouette may be fenced off to divert the migrants to Pitt River spawning grounds.
2. Ruskin dam.	Ruskin.	Coho salmon Steelhead.	Reduction of flow in the river below the dam—results, spawning areas destroyed, no attraction flow for adults.	No fish protection facilities exist. Arrangements needed for releasing adequate quantities of water from the reservoir.
3. Alcan project.	Nechako River.	Sockeye, pink, spring salmon.	Reduced water flow in residual river. Increase in water temperature. Unsuitable to migrants. Creation of points of difficult passage. No clearing of reservoir.	Facilities exist: Dam constructed on Cheslatta tributary to provide sufficient water during periods of migration. Suggested release of cold water at a depth of 200 ft. from reservoir. Channel improvements where necessary. (Int'l. Salmon Comm. 1953).
4. Seton Creek Project.	Seton Lake.	Sockeye and pink salmon, steelhead trout.	Obstruction to migration. Reduction of water level in Seton Creek spawning areas. Turbine-mortality of downstream migrants.	Vertical-slot fishway constructed. Provision for releasing water from reservoir. (Andrew and Geen 1958).

TABLE II (*Concluded*)

Developed hydroelectric projects in British Columbia—*Concluded*

Name of Project	Location	Species of fish involved	Problems	Solutions
5. Puntledge River Project.	Comox Lake.	Pink, chum, coho and spring salmon, steelhead trout.	Obstruction to migration. Reduction of water level in spawning areas. Turbine mortality of downstream migrants.	Fishway constructed. Provision for releasing water from reservoir. Experimental screens and louvres installed for keeping migrants out of penstocks (Brett and Alderdice, 1958).
6. Wahleach River Project.	Wahleach Lake and Jones Creek.	Pink and chum salmon.	Reduced water flow in residual river.	Artificial spawning ground provided. (Hourston and MacKinnon 1957).
7. Cheakamus River.	Cheakamus.	Chum, pink, sockeye and coho salmon, steelhead trout.	Reduction of flow below diversion dam will impede migrations of adults. Creation of points of difficult passage. Attraction of migrants to power house on Squamish River. Loss of spawning areas.	Provision for minimum flow of 200-350 c.f.s. through a low level outlet. Channelization work. Collection and trucking of adults so attracted. Provision of artificial spawning areas. (Dept. of Fisheries 1957).
8. Bridge River.	Bridge River.	Spring salmon.	Blockage of migration.	Relocate spawning grounds.
9. Campbell River Project. (i) Dam at Irene pool. (ii) Lower Campbell. (iii) Upper Campbell. (iv) Buttle Lake.	Campbell River.	Rainbow trout..... Cutthroat trout..... Dolly Varden.....	No appreciable effects on commercial fishes. Flooding shoreline destroys sport fishing. Sport fish spawning areas reduced.	Clearing of lake margins done. Artificial propagation (McMynn and Larkin 1953).

10. Waneta				
11. Buntzen				
12. Southslocan				
13. Cora Linn				
14. Lois River				
15. Jordan River		No appreciable effects on commercial fishes.		Clearing of lake margins done.
16. Whatshan				
17. Powell River				Artificial propagation.
18. Ocean Falls		Minor effects on sport fisheries.		
19. Britannia				
20. Big Falls River				
21. Spillimacheen				
22. Clowhom River				
23. Wood Fibre				
24. Victoria Lake				

TABLE III

Proposed hydroelectric projects in British Columbia

Name of Project	Location	Fish affected	Problems	Solutions
1. Atlin-Yukon-Taku	Taku Valley.			
(a) Atlin Lake dam (b) Tagish Lake dam	.....	Lake trout.....	Complete loss of spawning areas following flooding.	Construction of artificial spawning grounds.
(c) Yukon River (d) Mary River (e) Taku Valley	.....	All species of salmon.	Barriers to migration. Reduction of water flows in residual river. Inundation of spawning grounds.	Provision of adequate fish passes. Release of required quantities of water at appropriate period. Construction of artificial spawning channels if necessary (Withler 1956).
2. Fraser-Thompson development.				
(a) Emory Creek	Fraser 60'		Barriers to upstream migration.	Construction of suitable fishways.
(b) Spuzzum Creek	" 100'			
(c) Anderson River	" 100'		Interference to local fry migrations, in Babine and South Thompson rivers. Alteration of ecological and limnological conditions in all storage reservoirs. Changes in temperature regime and flow conditions in all river systems. Cumulative delays to migration period might exceed the critical limit. Provision of facilities to reduce mortality of downstream migrants.	
(d) Cisco	" 100'			
(e) Gladwin	Thompson 95'	All		No solution, research required.
(f) Seddel	" 50'			
(g) Basque	" 35'	species		Release of adequate quantities of water from the reservoirs at proper periods.
(h) Ashcroft	" 35'	of		
(i) McAbbee	" 35'			No solution, research required.
(j) Kamloops Lake	" 35'	trout		
(k) Shuswap	Shuswap River			No definite solution though various types of screens and collection devices could be tried.
(l) Adams	Adams Lake			
(m) Mabel	Mabel Lake			
(n) Quesnel	Quesnel Lake			
(o) Stuart	Stuart Lake			
(p) Babine Lake	Skeena River (to be diverted to Fraser)			

3. Moran development.	Fraser River at Moran above confluence with Thompson.		Dam too high for fishways. Delay of adult migrants. Reducing mortalities of downstream migrants.	No solution—research required on quick gathering and transport facilities for adults. Research required on collecting and transporting downstream migrants.
4. Peace River Diversion.	Peace River.	Salmon and trout.	Invasion of Fraser system by northern pike which might affect adversely salmon and trout.	
5. Somass River Project.	Somass River.	Sockeye, spring, coho and chum salmon, steelhead trout.	Spawning areas either completely eliminated or greatly reduced. Reduced rearing capacity of Ash and Stamp rivers. Diversion of spawners bound for Ash and Stamp rivers to tail races in Sproat system.	Artificial propagation. Provision for adequate water releases from dams. Collection of spawners and releasing them in home streams.
6. Taseko-Chilko-Homathko.		Sockeye.	Lake productivity affected by storage. Outlet spawned fry could not ascend into lake. Reduction of water flows in residual river.	No diversion of Chilko Lake or into Chilko Lake.
7. Stikine River		Salmon involved.	Facilities have to be provided.	
8. Iskat River		"	"	
9. Chilliwack River		"	"	
10. Elaho River		"	"	
11. Dean River		"	"	
12. Moss River		"	"	
13. Bulkley River		"	"	
14. Nass River		"	"	
15. Quesnel River		"	"	
16. Nahatlatch River		"	"	
17. Nimpkish River		"	"	
18. Harrison River		"	"	
19. Upper Adams River		"	"	
20. Columbia River at Murphy Creek		Salmon not involved.	No appreciable effects.	Facilities need not be provided.
21. Murtle Lake diversion				
22. Bull River		"	"	
23. Columbia River-Mica Cr.		"	"	
24. Pend d'Oreille River				

Table II summarizes developed hydroelectric projects in British Columbia and their effects on fisheries. Details on all of the projects are available from the various government agencies responsible.

Two points might be mentioned in connection with this tabulation.

(1) It must be concluded that to date the effects on fisheries of power development in British Columbia have been relatively slight. None of the major salmon producing rivers has yet been involved. For all recent projects facilities have been provided that should ensure partial or complete protection for fish populations. Of necessity, many of the installations have been experimental, and careful study of their effectiveness will prove extremely valuable (Hourston et al, 1955).

(2) Sport fish protection poses special problems that are not brought out in the tabulation. In most instances the monetary value of the stocks affected is difficult to gauge. In addition, the effects of a project are more often concerned with "fishability" and aesthetic values than with the production and maintenance of fish stocks. Finally, there are available a large number of alternative sport fishing and recreational areas so that for the present at least the loss of a few areas does not meet with general public concern. Nevertheless, for all recent developments a substantial measure of consideration has been given to sport fish values. Clearing of lake margins prior to flooding is now an accepted practice. In some instances monies have been provided by the project builders for artificial propagation of trout.

Table III summarizes some of the major proposed hydroelectric installations in British Columbia. Many of these are such major developments that they pose problems of fish conservation that have no parallel in the past. For instance, it has been estimated that a dam in the canyon of the Fraser River would require facilities for accommodating as many as 700,000 fish per day if runs were to be passed without delay. Similarly, any scheme of artificial culture of fish would require the production of several hundreds of millions of smolts, far in excess of the largest existing hatchery installations. For many of the problems posed there are no existing solutions, and recent investigations give indications that in developments involving a series of dams many serious effects on fish may occur which to date have not been suspected. For example, Brett (1958) reports on the possibilities of mortality to young migrants caused by the accumulation of indiscriminate stress. At each dam, a fraction of the fish which survive are sufficiently affected that they more easily succumb to stress conditions downstream. Recent work of Black (summarized in 1958) and others, suggest limitations to the degree and duration of exercise of which salmon are capable, implying the need for modification of fish pass designs particularly where delay may be critical.

These and many similar findings have prompted even more intensified research both on all aspects of salmon biology, and all phases of applied biological and engineering research as they pertain to hydroelectric developments.

At present a major integrated development of the Fraser watershed for hydropower would pose problems of fish conservation for which there are at present no adequate solutions. The joint report of the various fisheries agencies (1955) estimated that fish protection facilities for a multiple dam and storage development on the Fraser and Thompson rivers would cost $306,000,000 and that they "would not be successful in maintaining the salmon and steelhead runs." The situation is undoubtedly essentially

the same today, and will remain so until much more progress has been made in the technical investigations. It is certainly to be hoped that alternative sources of power will be available until adequate solutions to the fisheries problems have been indicated.

The Effects of Industrial Pollution on Fresh Water Fisheries in British Columbia (J. C. MacLeod)

Introduction

In some cases of pollution the decline of a commercial fishery may indicate the results of pollution. In other instances, for example in streams which have a fish population but no fishery, the adverse effects may be noted by evidence of dead fish in the water. However in the vast majority of cases it is not possible to measure directly the effect on the fish populations. Thus the main part of this discussion will deal with the degree of pollution in B.C. waters, keeping in mind that this affects the fish in the water.

Several factors have combined to give the present comparatively "rosy" pollution situation in B.C. These are:

(1) The concentration of industry and population on the coast and on the large waterways leading into the ocean.

(2) The comparatively small population of B.C.

(3) The present early stage of development of B.C.

Domestic Sewage

There have been no records of serious pollutions or major fish kills caused by domestic sewage in the province. This is rather startling when we consider that in 1953 only five municipalities had secondary sewage treatment and only six others had any primary treatment. In 1953 Vancouver and Victoria, with a sewered population of almost 400,000 people, had no treatment whatsoever. (Bowering 1953). This condition exists because of the situation of cities and towns close to the ocean or on large rivers such as the Fraser, Thompson, and Columbia. Most inland towns used septic tanks in the early days, and today as the towns grow in population, sewage treatment plants are set up. In the Okanagan Valley the towns of Penticton, Vernon and Kelowna all have secondary treatment facilities for sewage. At Kelowna a sewage reclamation plant has been set up.

In Vancouver harbour, Victoria harbour, Nanaimo harbour and parts of Ladysmith harbour the Department of Health has made it illegal to take oysters and other shellfish from the areas because of threatened sewage contamination. Disposal of sewage is a common use of water and in some cases organic matter may increase productivity of aquatic environments.

Pollution of the North Arm of the Fraser River

Vancouver is situated on the delta of the Fraser River. Having as yet no sewage treatment plants, the city has directed most of its main trunk sewers into the North Arm which is also a concentrated industrial area. It is estimated that five per cent of the sockeye salmon going up the Fraser pass through the North Arm.

The North Arm is one of the two main branches of the mouth of the river. It is 18.46 miles long and from 400 to 1200 feet wide. It discharges five to 10 per cent of the flow of the Fraser and is tidal, with a considerable inflow of salt water at high tide. At seasons of low water and spring tide the effect is to halt or reverse the outward flow of the river during part of each day, which periodically corresponds to the highest rate of sewage discharge into the river. (Rawn 1953). Both sides of the river have been zoned for heavy industry. In 1953 there were 30 lumber mills and ten other more specialized wood processing plants, six food processing plants, three chemical and fertilizer plants, five building material plants, one metal fabricating plant and two shipyards. (Farry et al. 1953).

In 1952 the B.C. Research Council published the results of a water quality survey from the mouth of the river to Prince George, 400 miles upstream. The data indicated that the chemical composition does not show large seasonal or chemical variations and that pollution is probably not significant except in the North Arm below New Westminster. (B.C. Research Council 1952).

Tests of the five-day, 20°C Biological Oxygen Demand in the North Arm showed an average B.O.D. of 2.1 ppm with a maximum of 3.5 ppm at Lulu Island bridge. The dissolved oxygen averaged 11.5 ppm with a minimum of 8.8 ppm at Sea Island bridge. It is generally accepted that in fresh water, at least five ppm of oxygen is necessary to support a healthy population of fresh water fishes and their necessary food organisms (Vernon 1956). Thus it can be seen that the oxygen present was, at the time of the survey, above the required level for fish survival.

Bacterial *coli-aerogenes* counts made by the B.C. Department of Health and Welfare, showed that the river was in a moderately polluted stage as far as health standards were concerned. A check on the 1951-52 survey was made by the B.C. Research Council in 1955 and it was found that the dissolved oxygen had not decreased markedly but that the *coli-aerogenes* count had increased. (B.C. Research Council 1955). At present the pollution should not affect the 50,000 sockeye salmon using the channel.

The B.C. Research Council made comparisons with the Willamette River in Oregon which "supports" a salmon run and received organic wastes equivalent to wastes from a population of 4,000,000 people—a situation similar to that which might develop in the lower Fraser in the future. The oxygen content of the river gradually decreased until in Portland harbour, the oxygen content was zero and the water had a dangerously high bacterial count. This oxygen block prevented the anadromous fishes from passing on to the headwater of the Willamette River and created a barrier to the young fish trying to reach the ocean. Quoting from the report: "With large industrial developments in prospect in British Columbia it is not impossible that similar septic ones could develop in the Fraser". Many of the food processing plants and other manufacturing companies at present utilize the city sewers, releasing wastes which first must meet a certain standard.

A Greater Vancouver District Joint Sewage Board plan for sewage disposal has been drawn up. In one plan, Vancouver sewage would be diverted to a treatment plant on Iona Island at the mouth of the South Arm. The municipality of New Westminster would release its sewage into the South Arm rather than the North Arm. (Rawn 1953).

Industrial Waste

The main consideration of the B.C. Fisheries is the preservation of the salmon runs. The major industries, excluding mining, which might produce harmful wastes are: the wood industries, the lower Fraser valley food processing plants, and the petroleum industry refineries and pipe lines. Their wastes seem to have had comparatively little effect on B.C.'s salmon fishery to date. There are however numerous individual cases of pollution which have posed problems.

Pulp and Paper

The pulp and paper industry is one of the largest of the wood product industries in B.C. The pulp and paper can be processed in the same mill or as is usually the case, the pulp can be processed in a pulp mill, and then shipped to a paper mill. Paper mills produce very little waste. However a *sulfite* pulp mill can produce an amount of waste equivalent to that of a town of 450,000 people. Pulp mill wastes can be divided into (McMynn 1953):

(1) bark and wood fibre wastes
(2) inorganic wastes from
    (*a*) liquor used to boil the woods chips
    (*b*) wash water

In the liquor sulfides, mercaptans and alkali are the most critical constituents. Experiments indicate that roughly 1/20th dilution of test solutions are "safe" for fish but that an accumulative effect may occur. Alderdice and Brett (1957) using sockeye salmon underyearlings and samples from the *sulphate* pulp mill effluent on the Somass River found that a 4.8 per cent concentration of the effluent by volume in seawater of 20 parts per thousand salinity at 17.8°C was a limiting concentration for toxicity, below which survival was complete and independent of length of exposure. An effluent concentration of 2.5 per cent for the liquor was recommended.

Alberni Inlet on Vancouver Island supports well-established runs of sockeye, coho, chum, and spring salmon and steelhead trout. (Tully 1949). A site on the Somass River was chosen for a pulp mill after consultation with the Fisheries department. The pollution effects of the pulp mill effluent would be attributed to high oxygen demand, high acidity, direct toxic effects or the presence of wood fibres. The fibre contained in the liquor consists of pure cellulose which settles to the bottom and oxidizes very slowly. The resulting matte is deleterious in the neighbourhood of spawning grounds of anadromous fish because it interferes with the adults spawning and the fry feeding. The pulp mill wastes would have been lethal only at low flow periods of the Somass River. Thus a water storage reservoir was constructed and during low flows of the river the water is released to increase the flow.

At Crofton, B.C. the Pacific Biological Station studied the problem created when a proposed pulp mill threatened to wipe out the oyster fishery. As a result of the survey, the completed mill disposed of its wastes by running a long effluent pipe far into the bay where a diffusing system released the waste so that at no point was it concentrated enough to be harmful to the oyster beds. (Waldichuck 1955).

In 1956 Dr. M. Waldichuck carried out an investigation at the Port Alice pulp mill regarding its proposed expansion. In as much as the salmon runs in the inlet were small, the expansion would have little effect on the fishery.

Pulp mills first set up in the province utilized the *sulfite* process for cooking pulp. This method wasted 100 per cent of the cooking liquor. Modern mills are usually of the *sulfate* type in which the cooking wastes are burned to recover the liquor constituents resulting in only a 10 per cent total loss of digestor liquor. This improved method has meant that the pulp industry saves on the boiling process and at the same time releases a smaller amount of waste to pollute surrounding waters.

Sulfite mills which are still in operation such as at Port Alice and Prince Rupert are close to the disposal facilities of the ocean. There, the highly concentrated wastes are easily accommodated without harm to the fishery.

Oil Wastes

Oil which escapes to surface waters floats, and the volatile fractions evaporate rapidly, leaving only heavy oils. Oils which may be trapped along the shoreline will either be worked into the shore through wave action or will become attached to vegetation and eventually sink to the bottom. There, bacteria gradually destroy the hydrocarbons through biochemical oxidation. (Department of Fisheries 1953). Thus shoreline and emergent vegetation becomes coated and dies. Aquatic organisms feeding or living at the surface become coated with oil and die. Fish may get oil on their gills from feeding at the surface and die from asphyxiation. Fish eggs and bottom larvae die when coated with bottom sludge. Oil itself can taint the flesh of the fish. Oil emulsions in the water usually break down forming free oil.

Only a few occurrences of ships dumping oil into Vancouver harbour have been recorded and no apparent fish losses were observed. An oil line break on the coast caused the pollution of several miles of beaches but no large fish mortalities were observed.

A possible break in the transmountain oil pipeline would be extremely important in the case of one or more salmon producing streams. Thus special valves have been installed at all stream crossings under Federal Department of Fisheries supervision. The oil companies also have special devices to immediately warn of any leaks and periodic inspections of stream and river crossings are made by helicopter and otherwise.

At Kamloops on the Thompson River, an oil refinery was recently built. Very large numbers of sockeye, pink, and coho salmon annually enter the Thompson River to reproduce in various parts of the watershed. The sockeye run to the Adams River has a value of as much as $12,000,000 in a year. The refinery empties none of its oil wastes directly into the river. A large settling basin has been constructed which settles out the sludges and removes the oils which might remain when the extensive recovery process is completed. (Department of Fisheries 1953). Brine separated from the crude oil is sufficiently diluted and treated to make it non-toxic. Caustic soda used to treat gasoline for removal of sulfides, mercaptans and phenols is used many times over and is finally discharged to sewers, usually in batches. The caustic soda has a high pH. and a high B.O.D. Thus it is greatly diluted and neutralized with acid. It has been the rule to keep the pH. of the river between 6.7 and 8.6 and the fish runs should not be affected to any extent. A pH. of 9 is considered lethal to fully developed fish.

Localized Industrial Pollutions

Each year the B.C. Game Commission and the federal Department of Fisheries investigate numerous pollution cases either through water license applications or public complaints.

A harbour containing approximately 700-900 tons of schooling herring was found polluted by a large quantity of alkaline waste. Dead herring were in great numbers all around the area and it was estimated that the lethal concentrations for fish could easily be reached in the harbour with the amount of alkaline waste disposed of. The actual tonnage of herring killed is not known except that it was a considerable portion.

A chemical plant has prevented pollution from its chlorine wastes by using a diffusing system along the inlet bottom which provides sufficient dilution at all areas.

A stream entering Burrard Inlet was periodically polluted by large amounts of acid wastes which were found harmful to the salmon populations; pH's below 4 are considered harmful. In Burnaby a plant using an alkaline cleaning compound, each week emptied its tanks into a small stream where it was found that the small cutthroat trout were being killed by a pH of 10.0.

Gypsum is a large byproduct of certain base ore processing plants and fertilizer plants. One company produces 4.4 tons of calcium sulfate per hour and releases the waste into a river. It was found to be almost completely soluble and there was no oxygen depletion. The river flow was large and the effluent did not seem to affect the fish. A fertilizer plant was advised to retain its $CaSO_4$ wastes in an impoundment to avoid silting of salmon spawning beds during periods of low water in the river. The calcium sulfate also caused a cloudiness in the water. During spring freshets when the river flow was at a maximum, the $CaSO_4$ was released, the cloudiness not being detected in the muddy water.

Food plants and Breweries

Along the coast there are numerous salmon canneries. On the lower mainland are many food processing plants and breweries. The salmon canneries usually dispose of their offal right into the ocean or into fast flowing rivers which carry the waste into the sea. In recent years the salmon canneries have begun to use the offal in the production of profitable byproducts such as mink food, thereby reducing the waste material in the water.

One cannery on the lower mainland was releasing vegetable wastes into a stream containing salmon fry. Fifteen hundred feet downstream the oxygen concentration was 4.4 ppm, 41 per cent of the full saturation. There was a slight increase in bottom fauna (oligochaetes and chironomids) at the effluent but a thick fungal matte covered the bottom. Salmonid fry were abundant upstream but none were found below the polluted area. This situation has been rectified.

In Vancouver, breweries are allowed to empty their wastes into the city sewers as long as they do not contain harmful substances such as acid which would damage the sewage system. One brewery situated beside a lower mainland river uses a spray pond to aerate its wastes before turning them into the river.

Milk wastes are a most serious stream pollutent demanding a large amount of oxygen from the stream. One milk plant repeatedly polluted a stream making it unfit

for fish for the entire distance from the plant to a larger river. The problem was temporarily solved by running a pipe 1½ miles to the larger river.

Bakeries too have polluted lower mainland streams. Two bakeries discharged flour into a small stream. The stream became undesirable for fish and the waste contributed to oxygen deficiency.

One meat plant found that the removal of all trade waste from its effluent was beyond its financial capacity and yet seriously polluted the nearby river.

In some cases the pollutions of small industries pose difficult problems. Only when streams and rivers reach a certain level of pollution is it necessary to ask a company to treat its wastes and when they have been operating in an area for a long period of time they are reluctant to finance an elaborate treatment system. It is essentially the increasing number of industries, each contributing perhaps only a small portion of waste to a river or stream, that poses one of the more difficult pollution problems for the future. It is economically impossible for some companies to treat their wastes completely. At present each plant that requires the use of water for disposal purposes must apply for a water licence. If it is decided that the company will remain within certain standards so that it will not cause pollution to the stream, then the licence is granted. However when the load put on a river is increased by new industries the original plant may have an inadequate sewage treatment.

Discussion

The solution to these problems may not be easily forthcoming. Various courses of action have been proposed:

(1) to make new plants improve the quality of their wastes

(2) to establish zoning regulations for certain industries and to allow them to release their wastes into rivers which would be "sacrificed" for sewage disposal.

(3) the zoning of industries and a central treatment by government subsidized treatment plants.

At present, pollution effects on fisheries are relatively minor and under control in B.C. but with increasing industry and population, problems will undoubtedly multiply.

Aware of these developments, in 1956 the B.C. legislature passed a bill providing for establishment of a Pollution Control Board. The board is now constituted and co-ordinates all the provincial government agencies concerned with pollution. It has jurisdiction in the lower Fraser river basin and at present has no direct representation from the fisheries agencies.

The most satisfactory step towards eventual pollution control will undoubtedly be a long term resource zoning and planning programme carried out with the close co-operation of all concerned groups—provincial, federal, industrial and private.

The Effects on Fresh Water Fisheries of Development Construction in British Columbia (C. E. Stenton)

No description of the effects of man made activities on fisheries of British Columbia would be complete without brief mention of catastrophes occasioned by construction projects concerned with the province's development. In most instances of road or

railway construction care is taken to avoid creation of obstacles to fish migration or excessive silting of streams. The classic example of an inadvertent effect on fisheries is provided by the Hell's Gate story.

The Fraser River sockeye salmon catches up to 1913 were a large industry—estimated 2,400,000 cases in 1913. After 1913 the catches dropped rapidly and in 1917 approximated 500,000 cases. From then until 1937 it rarely exceeded 200,000 cases. (Talbot, 1950). The drop in the catches following 1913 was attributed to a blockage of the Fraser River at Hell's Gate Canyon by debris from railroad construction (Talbot 1950).

Hell's Gate is a narrow gap through which the Fraser River flows with considerable speed and turbulence. Prior to 1913 the river in Hell's Gate was fast and turbulent but salmon were able to pass it. In 1913 the Canadian Northern Railway (later to be known as the Canadian National) was constructed through this area. The rock from the road-bed construction was dumped into the river, thus causing a narrowing of the channel. This added material caused an increase in the flow and turbulence, which in turn produced a barrier to fish at certain water levels. (Jackson 1950). This barrier resulted in a delay in the migration followed by a heavy mortality (Talbot 1950). In 1914 there was a rockslide resulting from the construction of a tunnel on the railroad. In late 1914 and early 1915 an excavation of the debris was done in hopes of returning the river to its former state. These excavations did not prove to be of much success. These were the last changes made at Hell's Gate for twenty-six years. Due to this barrier the sockeye runs above Hell's Gate were seriously reduced and some were completely wiped out.

In 1938 the International Pacific Salmon Fisheries Commission made a study of Hell's Gate. From the study it was concluded that fishways must be built to restore the sockeye runs. In 1942 a temporary fishway was constructed to provide information for designing a permanent fishway and to pass some salmon past the obstruction (Talbot 1950).

In 1944 work had begun on the permanent fishways and by early 1946, fishways on both sides of Hell's Gate were completed. The fishways are of the vertical slot type and are designed to operate from water levels between 23 and 54 feet (Talbot 1950). From a tagging programme initiated by the International Pacific Salmon Fisheries Commission it was found that the sockeye could negotiate Hell's Gate (Talbot 1950).

As a result of the fishway construction there has been an improvement in the number of sockeye reaching the spawning grounds, and it has been concluded that the fishways have been a success. (Royal 1953).

Similar types of problems have been posed by natural obstructions and while they were not caused by man's activities their solution has been instructive in demonstrating the types of effects which can result from man-made obstructions.

In 1951 numerous dead and injured fish were found in the Skeena and lower Babine Rivers. Reports from a counting weir just down stream from Babine Lake, showed that the fish were having difficulty getting up the river. A survey was made and it was found that a large rockslide had blocked the river (Godfrey et al. 1954). The slide was 420 feet long and consisted mainly of large rocks. From a study conducted

by engineers and biologists, it was concluded that high water velocities and excessive turbulence were the main block to the salmon and that a removal of the material would be the best remedial measure (Godfrey et al. 1954).

Since the slide occurred late in 1951 no remedial measures were taken that year, but the following spring some removal of the material was done. By the spring of 1953 the channel was back to its original state.

During the period of blockage, some salmon were able to surmount the barrier but heavy losses occurred. In 1951 it was calculated that 319,000 fish out of an estimated run of 461,000 were lost and in 1952, 700,000 out of a run of 1,051,000 were lost. Of the fish that did arrive on the spawning grounds only 60-70 percent spawned, the rest died from injuries received coming over the barrier (Godfrey et al. 1954).

The effect on the future fisheries is not considered a serious problem as the slide only stopped the runs of two years. This effect will probably not be evident after two or three generations of fish (Godfrey et al. 1956).

In the management of the Pacific salmon, much concern has been given to the removal of obstacles which block or delay the spawning migration. The rivers of the mountainous coast of British Columbia have many waterfalls, which, through tagging programmes, have proven to be a factor in the delay of the migrating salmon. During such delays, there is an appreciable amount of mortality, either from injury or from Indian fisheries which are usually located at such places (Milne 1950).

The federal Department of Fisheries and the International Pacific Salmon Fisheries Commission have constructed a number of fishways which allow the salmon to pass such barriers. Fishways have been constructed on the Fraser, Chilcotin, Stamp, Stoat, Skutz, Naden, Indian, Bulkley, Nimkish, and Kajusdis rivers. Each of these fishways bypasses either a waterfall or a place of very fast and turbulent water.

The fishways on all except the Nimkish and Kajusdis rivers are of the vertical slot type. This type of fishway has been found to work best with varying water levels. There are five of these fishways in Farwell Canyon on the Chilcotin River. The fishway which bypasses Karmutsen falls on the Nimkish River is of the Denil type. The fishway on the Kajusdis River is a pool and weir type.

The efficiency of most of these fishways has not been thoroughly checked but local reports indicate much improvement over previous conditions. A tagging programme on the Moricetown fishways on the Bulkley River showed that several days were cut off the period of delay (Hourston and Stokes, 1952).

Discussion

In reviewing the effects of man-made activities on freshwater fisheries of British Columbia four generalizations are suggested:

(1) In recent years, most major effects on fisheries have been foreseen or have been quickly acted on when evident. In consequence there are few instances in which the effects on fisheries have not been avoided or largely alleviated.

(2) The present fortunate state is largely attributable to efforts of the substantial trained staffs of the various government agencies which have investigated each of the man-made projects for effects on fisheries.

(3) Future problems will require an even broader base of research in biology and engineering if effects of some of the potential projects are to be minimized.

(4) Most problems are presently being handled on an *ad hoc* basis. However, if as planned, multiple resource use becomes more and more a part of administration of resources, it will be necessary to provide better representation of fisheries interests to ensure that fisheries are not harmfully affected.

The first three statements concern quite self evident trends in events, but the fourth perhaps needs enlargment.

At the present time the Government of Canada carries most of the load for protection and regulation of stocks of fishes, both marine and anadromous. The Provincial Department of Recreation and Conservation, Fish and Game Branch, shoulders responsibility for sport fish administration but regulation of catch is still the formal responsibility of the federal Government. The provincial Department of Recreation and Conservation, Fisheries Branch, handles licensing of processing plants and freshwater domestic fishing licences. This division of federal and provincial responsibility conforms to the provisions of the British North America Act and subsequent legislation and to date has resulted in effective, harmonious action by the various agencies.

Within the last decade however resource development has proceeded at an accelerating pace in British Columbia and in all resource fields there has been growing concern about the best procedures for resolving resource conflicts. The general objective of wise use of natural resources must be to develop each resource as far as possible without harm to other resources. When conflict arises between two resource uses in a common area then the greatest public interest must be served. Great public expense can be saved if conflicts of this type are anticipated and if a plan for multiple resource use is developed for each region—usually a stream drainage area. These problems were recognized as serious and were the stimulating factor in the formation of the B.C. Natural Resources Conference. This group comprises a majority of the technical personnel employed in government, university and industry in the province. The conference has produced 11 volumes of transactions concerned with resource use problems in British Columbia as well as a splendid Atlas of Resources which summarizes current technical information on the province. It has brought together the people concerned with resource use and established a cordial spirit of understanding between various agencies. Finally it has indicated the need for planning agencies that would suggest schemes for co-ordinating resource uses and adjudicating resource conflicts.

The recent formation of a Pollution Control Board and the recent organization of a Department of Recreation and Conservation were both in large part initiated by conference discussions. Further steps to provide planning agencies will no doubt be forthcoming.

In such an atmosphere it is anomolous that the fisheries resource (excluding the sport fisheries) can only be adequately represented by a federal agency which has a limited authority in directing provincial resource use planning. Accordingly our conclusion must be that a strong provincial fisheries department would be most desirable if effects on fisheries are to be minimized by the proverbial ounce of prevention rather than by the usual pound of cure. Effects on fisheries of man-made activities in British

Columbia have fortunately been a minor factor in fisheries conservation to date, thanks to the excellent services provided by the Canadian Department of Fisheries. This happy situation can continue provided the federal agency is adequately assisted by strong representations of a provincial fisheries department.

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Homing Behaviour in Spawning Lake Trout

by

N. V. Martin

Ontario Department of Lands and Forests, Maple, Ontario

In 1954 three artificial lake trout spawning beds were established in an Algonquin Park, Ontario, lake (Martin, 1955). These were constructed at depths below the limits of late fall low water levels caused by drawdowns for hydro-electric power stations.

One of these areas, situated near a natural spawning ground which was not entirely exposed by low lake levels, was used by the lake trout while the other two were not.

It has been thought a homing tendency on the part of spawning lake trout might explain their deterrence to the use of these new areas. On the basis of tag recoveries in Lake Superior, Eschmeyer (1955) suggests lake trout in this lake may return to the same beds each year. Similarly tagging of Lake Superior lake trout spawning in the Dog and Montreal Rivers has shown their repeated return to the same river each year. (Loftus, 1957).

In order to acquire more definite information on this homing behaviour a study was made of lake trout movements at spawning time in Lake Louisa, a 1,480 acre lake in Algonquin Park, Ontario. This lake was chosen for the investigation as a good deal was already known about the reproduction of the lake trout in this lake from previous studies (Martin, 1957).

In 1951, 1956 and 1957 lake trout were captured on different spawning beds in Lake Louisa by small-mesh (2 and $2\frac{1}{2}$ inch) gillnets. These fish were tagged and the beds were subsequently kept under observation to determine the movements of these trout. Coloured (yellow, green, red, silver) plastic streamer tags and two points of insertion of these tags (anterior to dorsal fin and on caudal peduncle) were used to distinguish the trout of particular areas.

The tagged fish were identified by night observation on the spawning grounds, and occasionally by the use of gillnets when wind hampered visual observations. Tags were readily seen in the clear water of Lake Louisa in the two to five foot depths where most of the trout spawn.

Figure 1 shows the location of the major spawning areas where tagging was carried out (A, B, C, D, E) and other known spawning areas of lesser importance (G, H, I). The approximate distances in yards between major areas are as follows:

	A	B	C	D
B	180	–	–	–
C	1100	940	–	–
D	1400	1600	360	–
E	1700	1480	660	330

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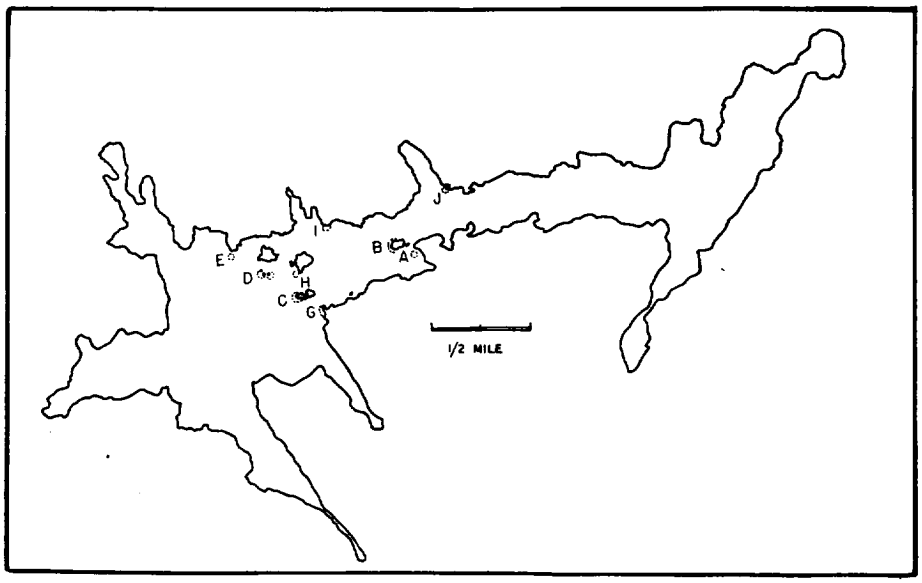

FIGURE 1.—*Location of known lake trout spawning beds, Lake Louisa, Ontario.*

A preliminary investigation of lake trout movements during spawning was made in 1951. On October 16 a total of 60 lake trout was tagged on four different beds (A, B, C, D). The following night 10 tagged fish were seen, all but two of which were on the same area in which they were tagged (see Table I).

In October of 1956 a total of 212 lake trout was tagged on five beds (A, B, C, D, E) on dates and in numbers as shown in Table 1. Of these, 173 were males, 31 females and eight were of undetermined sex.

On subsequent nights over a 19 day span (October 12-30), 44 tagged fish were seen, of which 16 were on the areas where they had been tagged. Of these 16 trout, 14 were on areas A and B, which are less than 200 yards apart, and there is considerable inter-mingling of trout between them. If these two are considered as one spawning ground there were then only three exceptions out of 54 tagged fish seen in 1951 and 1956 where trout were not observed on the same area as they were tagged. It is quite likely, of course, that the same fish may have been seen several times but this applies equally to fish returning to the same area and those that went to other areas, and therefore does not alter the general pattern of behaviour.

In 1957 checks were made on the fish tagged in 1956 to see if this apparent homing behaviour within a year held true between years. The results are shown in Table 1.

A total of 35 tagged fish were seen or caught in gill nets in the five nights of observations in 1957, all but one on the areas where they had been tagged (again considering areas A and B as one bed).

In 1958 and 1959 a further 11 tagged trout were observed, these fish again appearing on the same beds.

Therefore in the five years 1951, 1956, 1957, 1958 and 1959 all but five of 100 observed tagged fish have returned to the spawning area where they had been originally tagged.

TABLE I

Movement of lake trout between spawning beds on basis of observations of coloured tags, Lake Louisa 1951, 1956, 1957, 1958, 1959

Spawning Area	Date Tagged	Number Tagged	Dates of Observation	Number of Tags seen	Initial point of Tagging
	1951				
A	October 16.....	22	October 17.....	2	A
B	October 16.....	14	October 17.....	3	B
				1	A
C	October 16.....	18	October 17.....	3	C
				1	A
D	October 16.....	5	October 17.....	0	
	1956				
A	October 10, 11.....	55	October 12, 15, 19, 30....	5	A
				1	B
B	October 11.....	37	October 12, 15, 19, 30....	14	B
				13	A
C	October 5, 10, 24....	61	October 15, 19, 30.....	7	C
				1	B
				1	E
D	October 24.....	32	October 24.....	0	
E	October 12.....	27	October 15, 19, 30.....	2	E
	1957				
A	—	—	October 14, 21, 22, 25, 28..	11	A
B	—	—	October 14, 21, 22, 25, 28..	8	B
				5	A
C	—	—	October 21, 22, 25, 28....	7	C
D	—	—	October 22, 25, 28.....	2	D
E	—	—	October 22, 25, 28.....	1	E
F	—	—	October 25, 28.....	1	A
G	—	—	October 25.....	0	
	1958				
A	—	—	October 16. 20.....	2	B
B	—	—	October 16, 20.....	5	B
				1	A
C	—	—	October 16 20.....	0	
D	—	—	October 16. 20.....	0	
E	—	—	October 16, 20.....	1	E
	1959				
A	—	—	October 22.....	1	A
B	—	—	October 22.....	0	
C	—	—	October 22.....	1	C

On the basis of the above observations a homing behaviour is indicated in spawning lake trout. In order to initiate spawning on the second of the three artificial spawning beds in Shirley Lake, various measures were undertaken in 1956 and 1957 to attract the trout to this area. These included the penning of ripe fish over the beds, the transfer of rocks from used spawning areas, the blocking off of grounds that were being utilized, and the seeding of eyed eggs. This second spawning ground was used by the lake trout in the fall of 1958.

The third bed, which was kept as a control and where no attempts were made to attract the trout, was not used until 1959.

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In conclusion it would appear that in spite of a marked homing behaviour lake trout will spawn on new artificial beds. The utilization of these areas may be expedited by various attraction methods.

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Further Observations on the Survival of Yearling Lake Trout Planted in South Bay, Lake Huron

by

J. C. Budd and F. E. J. Fry

Division of Research, Ontario Department of Lands and Forests and Department of Zoology, University of Toronto.

The lake trout *Salvelinus namaycush* (Walbaum) has been studied since 1947 in South Bay in northern Lake Huron. Fry (1953) established that the South Bay lake trout formed essentially a closed population and described the passage of a strong 1944 year class through the fishery. He suggested that the sea lamprey was the factor responsible for the rapid and complete disappearance of what may well have been one of the last native lake trout populations in the main body of Lake Huron.

Since the disappearance of the last of the native trout in 1952, a population has been maintained in South Bay through the planting of fin-clipped yearling fish. The plantings were begun in 1949 and discontinued in 1955. The results of these plantings through 1956 were described by Fry and Budd (1958). Because larger numbers of trout were taken during the 1957 season, it seems advisable to summarize the data accumulated since the last mentioned paper. Any information concerning the survival of planted yearling lake trout is of immediate interest to the people and agencies concerned with the lake trout rehabilitation programme on the Great Lakes.

Catch and Population

The catch of lake trout taken from South Bay during the 1957 season was the largest since 1950, when native fish made up the entire catch. A total of 1,372 fish was taken in the net fishery and 12 were taken by anglers. Only 12 fish were not identified as fin-clipped, so it can be reasonably assumed the entire 1957 catch consisted of fish that had been planted in previous years. There has thus been no direct evidence of spawning in recent years; and further, the age distribution previously presented (Fry and Budd 1958) almost precludes the possibility of any mature fish having been present since the fall of 1951.

The net catches were made in two different types of gear: pound nets fished in May, June and early July, and gill nets fished later in the season. The pound nets took 578 fish and the gill nets 794. All fish taken in pound nets were tagged and released after scale samples had been secured and fork length measurements taken. All recaptures were recorded and released.

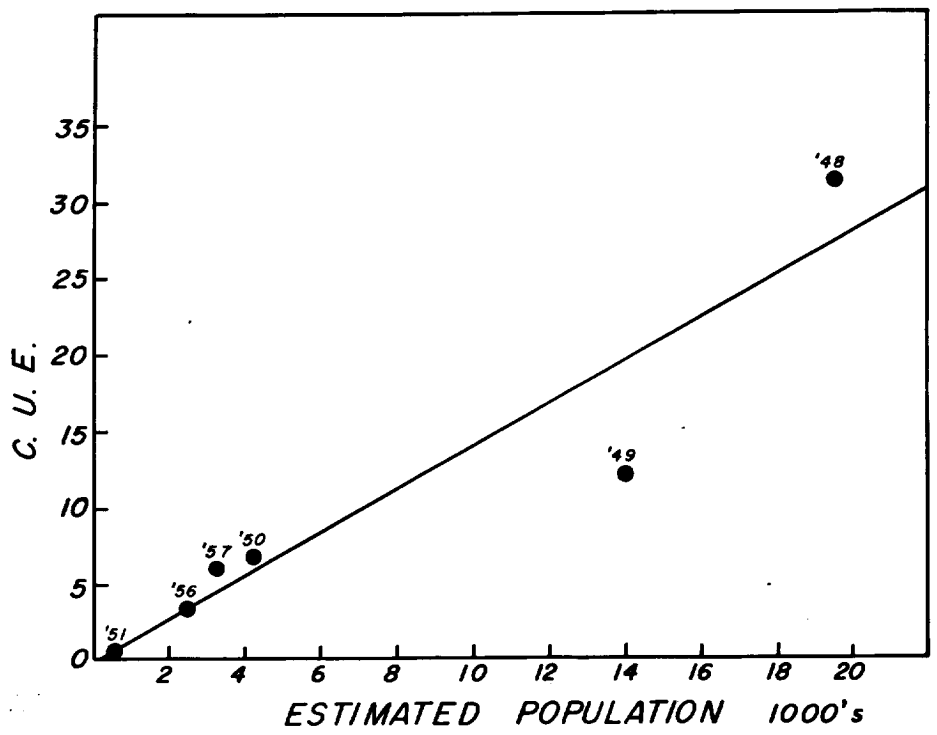
The five pound nets used in this study have been fished in the same locations since the lake trout investigation in South Bay started. Therefore, the catch per lift or catch per unit effort should give some indication of the relative population size over the years. As previously explained (Fry and Budd 1958) catch per unit effort (C.U.E.)

is defined as the average number of trout taken per pound net lift during the month of June. The 81 lifts of five pound nets made in June 1957 took 491 fish which amounts to an average of 6.1 per lift. The only years with higher catch per unit effort values were 1948, 1949 and 1950, when the values were 31.4, 11.8 and 6.9 respectively. The 1956 value was 3.2. In each of these years, except 1956 when figures are based on a Petersen estimate, enough fish were tagged to allow Schnabel type population estimates. It is of interest to compare the population estimates with the C.U.E. data. Fry (1953) presents population estimates for the years 1948, 1949 and 1950; Fry and Budd (1958) present the 1956 estimate. These estimates and the C.U.E. data are shown in Table I.

TABLE I

Year	C.U.E.	Population Estimate
1948	31.4	19,500
1949	11.8	14,000
1950	6.9	4,200
1951	0.6	600
1952	0.1	insufficient data for estimate
1953	1.4	insufficient data for estimate
1954	1.3	insufficient data for estimate
1955	0.3	insufficient data for estimate
1956	3.2	2,500
1957	6.1	3,200

FIGURE 1



A very close parallel can be drawn between the 1950 and 1957 figures. The 1950 estimate derived from 606 tagged fish and 50 recaptures was 4,160; the 1957 estimate from 530 tags and 42 recaptures was 3,200. The catch per unit effort values for the two years were 6.9 and 6.1 respectively.

Figure 1 shows the data contained in the table. Catch per unit effort is plotted against the population estimates. Estimates range between 500 and 19,500 and C.U.E. values between 0.6 and 31.4. Over this range there seems to be a good correlation between the estimated population and the C.U.E. For the years in which estimates are not shown, C.U.E. values ranged between 0.3 and 1.5, but recaptures were too few to allow meaningful population estimates. In any case, it can be seen that for the years 1952-1955 there were certainly less than 2,000 fish vulnerable to the pound net fishery.

Size, Age Composition and Mortality

Table II summarizes the age composition of the 1957 catch by the two types of gear. The complete absence of fish seven years of age and older, and the relatively few fish in the V and VI age groups is very striking. Estimates made in 1956 placed the number of age V fish at 500 (Fry and Budd 1958). When the estimate made in 1957 (Table I) is apportioned among the various age groups, an estimate of 40 is derived for the VI age group. This indicates a mortality in excess of 90 per cent for fish that were V in 1956 and would have been VI in 1957. Similarly, the mortality between age IV and age V was approximately 70 per cent. No estimate of the age III fish is available for 1956, but the age IV estimate made in 1957 does not indicate excessive mortality in this age group.

TABLE II

Age Distribution 1957—South Bay Lake Trout

Age	Pound Net	Gill Net	Total
III	310	598	908
IV	188	153	341
V	69	34	103
VI	5	3	8
No age	6	6	12
TOTAL	578	794	1372

(The Roman numerals indicate the number of completed annuli on the scale).

It is of interest to compare these figures with those from Fry (1953). Since Fry was dealing with essentially a single year class, that of 1944, his estimates in successive years gave total mortality from one age group to the next. Thus his estimate of 19,500 fish in 1948 and 14,000 in 1949 gave approximately 30 per cent mortality between age IV and age V. Using his population figures for 1949 and 1950 (Table I) mortality between age V and age VI is estimated at 70 per cent while the 1950-1951 pair of values, gave an estimated mortality of 86 per cent between the ages of VI and VII. These figures are comparable to those in the preceding paragraph obtained using 1956 and 1957 data broken down by age groups, except that between the years 1956 and 1957

the fish are one year younger when they sustain comparable mortality. Since data presented by Fry (1953), Fry and Budd (1958) suggests that lamprey predation is most severe on the larger fish, an increase in growth rate would account for the age difference.

Table III and Figure 2 summarize the growth data for the 1957 South Bay lake trout. Comparable data for the native fish for the years 1947-1950 (Fry 1953) are also shown. Since planting was discontinued in 1955 no age II fish were present in 1957. It can be seen from the table that fish of a given size were approximately one year younger in 1957 than during the period 1947-1950. If, as suggested later, the lamprey are selectively taking the largest, fastest growing individuals, these figures do not represent maximum potential growth.

TABLE III

Growth of South Bay Lake Trout, 1947-1950 and 1957

(Fork lengths inches and weights pounds—1947-50 data from Fry 1953)

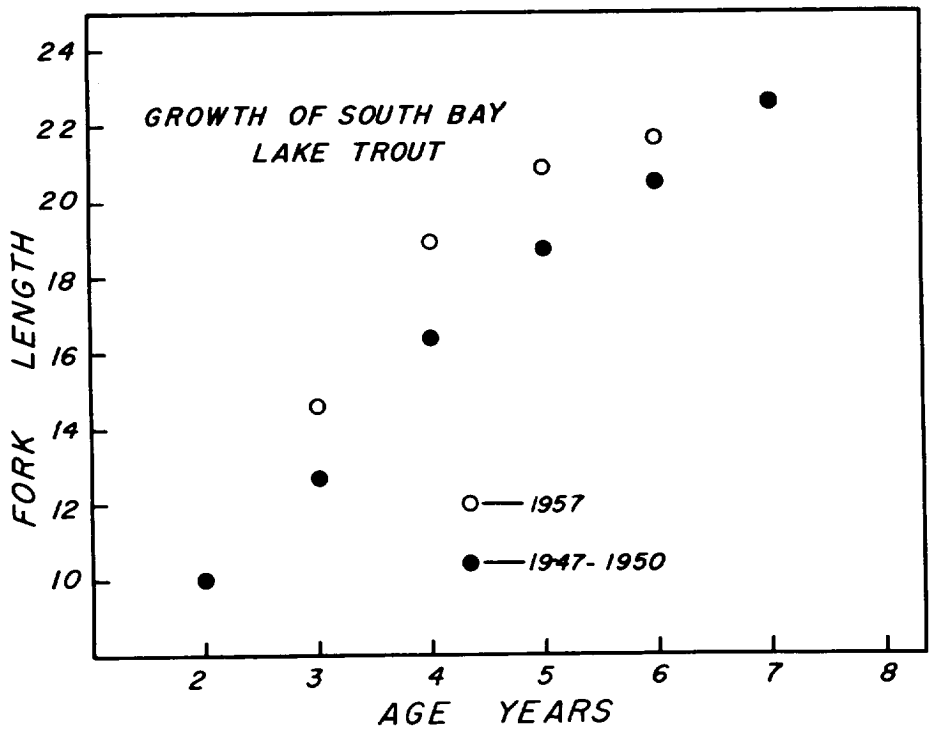
Year	Age Group					
	II	III	IV	V	VI	VII
1957 pound net—length	not present	14.9	19.0	20.9	21.4	0
1957 gill net—length	not present	14.4	19.1	20.9	22.1	0
weight	not present	1.2	3.0	4.1	5.0	0
1947-1950 mean values all gears—						
length	10.0	12.7	16.5	18.8	20.6	22.7
weight	0.4	0.7	2.1	2.8	3.8	6.7

Number of fish comprising means can be obtained from Table II.

Growth increments from tagged fish recaptured one year after tagging also showed a higher growth rate in 1957 than was shown in 1950. The 1949-1950 increment (Fry 1953) was 1.8 inches, while the 1956-1957 increment based on fifteen fish was 2.8 inches. The range was from a minimum of 1.2 inches to a maximum of 5.5 inches. This increase in growth rate is probably the result of an explosive increase in the alewife population that has taken place in Lake Huron over the past several years (Miller 1956). The 1951 South Bay catch of alewives consisted of a single individual, while the 1956 and 1957 catches were of the order of 20,000 pounds.

Since nearly all of the pound net fish were captured in May and June, and the gill net catch was spread over the period July 16-October 25, one could expect the gill net fish to reflect the growth of the 1957 season by an increase in average length. An examination of Table III shows that mean lengths, except in age groups VI where the number of fish is very small, are nearly identical for pound net and gill net fish. This relationship holds true for the age IV and age V fish, but the age III pound net fish are 0.5 inches larger than the gill net sample. The age IV and age V fish are completely vulnerable to both the pound and gill net fishery, while the age III fish are not; the smaller individuals of this group are not taken by the pound nets in proportion to their abundance in the population.

FIGURE 2



The explanation for the lack of seasonal growth can be obtained from the data on lamprey scars shown in Table IV. There is a marked increase in the percentage of lamprey scars with an increase in length. It is assumed that the largest, fastest growing individuals are the fish most likely to be attacked and killed by sea lampreys, and

TABLE IV

Incidence of Lamprey Scars on 1957 South Bay Lake Trout

	under 17.0	17.0-17.9	18.0-18.9	19.0-19.9	20.0-20.9	21.0-21.9	22.0 and up
Number of fish	863	98	89	106	77	76	42
Number scarred	23	18	22	53	49	48	22
Number of scars	25	20	25	72	95	76	29
Percentage scarred	3	18	25	50	63	63	52

	Age			
	III	IV	V	VI
Number of fish	908	341	103	8
Number scarred	38	130	68	5
Number of scars	45	192	95	10
Percentage scarred	4	38	66	63

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that these fish are selectively removed as the season progresses. For this reason, the average fork length does not show the expected increase.

Lamprey Scarring

All of the fish handled in the course of the lake trout study were examined for lamprey scars. Scars were classified as either fresh or healed, but for the sake of simplicity, only the figure for total scarring will be presented. Fish under 17 inches fork length show relatively few scars (Table IV). From that length upward, except in the 22-inch and up group, there is a progressive increase in the percentage bearing scars, and also in the number of fish bearing multiple scars. Two interpretations are possible: that single attacks are more likely to kill the smaller fish, and therefore small fish with scars are not often taken. It seems more probable from the data on survival previously presented that some difference in distribution relative to temperature and depth keeps the small trout and sea lampreys from the same area at the same time. It is known that the small trout are more numerous in the deeper waters of South Bay, while the larger fish are most often taken in shallower water just at the bottom of the thermocline.

Scarring percentages range from three per cent on fish under 17 inches to 63 per cent on fish in the 20-22 inches class. With lamprey populations continuing at the present level, we can expect the last of the planted lake trout to disappear from South Bay during the 1960 season. Since female lake trout in South Bay do not mature until age VII it is highly unlikely that any egg deposition will have resulted from the 78,900 marked yearling fish which were planted over the years 1949-1955. Without lamprey predation, plantings of this magnitude would certainly have established a self-sustaining population with a normal age distribution.

Survival in the Absence of Lamprey Predation

Some data are available which allow one to compare the survival of hatchery-reared yearling lake trout to age VI in the presence and in the absence of sea lamprey predation. In October of 1952 fin-clipped yearling lake trout from the same parents and otherwise similarly treated were planted both in South Bay and Lake Manitou.

Lake Manitou, an adjacent lake on Manitoulin Island, is similar to South Bay in size and depth, and in the type of fish population it supports. Both bodies of water have smallmouth bass, pike, perch, smelt, ling, lake trout and whitefish populations. The major difference lies in the absence of a sea lamprey population in Lake Manitou.

An intermittent creel census has been conducted on Lake Manitou since 1947 to compare angling there with that in South Bay. In 1957 this creel census was intensified and an attempt made to examine as much of the lake trout catch as possible in order to record recaptures of the marked fish.

The South Bay plant consisted of 23,100 fish, while 10,100 were planted in Lake Manitou. The total 1957 South Bay catch of age VI fish (no native fish of this age were taken) was eight (Table 2), five were taken in pound nets, three in gill nets and none in the limited angling fishery that took 12 fish. Survival of the 23,100 fish to age VI is estimated to be 40 or approximately 0.2 per cent. By contrast, 16 of a total of 68 lake trout examined in the Lake Manitou creel census were identified as

from the 10,100 planted in that lake in 1952. It is estimated that at least a further 100 of the same planting were handled during the course of spawn taking operations on Lake Manitou in October of 1957. Since the lake trout population of Lake Manitou is known to be large, such recovery would indicate a much higher percentage survival to age VI.

Angling

The yearling fish planted in South Bay have provided very little angling. This is in contrast to the native population described by Fry (1953) where some 3,500 fish from an estimated population of approximately 20,000 were taken by anglers. In 1950, when estimates based on pound netting were very similar to the 1957 estimates, anglers took at least 418 fish, while in 1957 only 12 were recorded. With the decline in the trout population from the 1948-1949 level, there has been a decided lack of interest in angling for lake trout, and many of the guide boats that formerly spent considerable time trolling for trout are now either no longer operating or are used entirely for fishing bass and pike. Summer weather, with fresh afternoon breezes on most days, tends to discourage most owners of small outboard boats from fishing the open waters where the lake trout are commonly taken at that season. It is unlikely that any interest in the lake trout angling fishery will be shown until a population of trout similar to that present in 1949 is again established. It would seem that this must await lamprey control.

Conclusion

The data presented suggest that if the sea lamprey is controlled, there will be no difficulty in re-establishing a lake trout population in South Bay. Survival of planted yearlings to age IV is good, but the fish are completely eliminated by the sea lamprey before any of the females reach sexual maturity at age VII. To gain time, plantings should begin two or three years before complete control is in effect, and plantings of from 10,000 to 20,000 yearling of as large size as possible should be made for five or six years. At the end of this period, it could be expected that a population with a normal age distribution would be present. This population would then become self-sustaining.

There is reason to believe that these same conclusions would be valid for Lake Huron proper, the North Channel and Georgian Bay. Every effort should be made to gather data on former lake trout spawning grounds and on the former distribution of small lake trout in these waters, so that plantings may be made in the areas where optimum survival could be expected.

Acknowledgements

The co-operation of the entire staff of the South Bay Fisheries Research Station made this study possible. Especial thanks are due to J. B. Smith who read the scales and to W. I. Chapman under whose able direction the fishing was carried out.

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80174-6—3½

Variation in Vertebral Count in F_2 Hybrids of *Salvelinus Fontinalis x S. Namaycush*

by

W. J. Christie

Division of Research, Ontario Department of Lands and Forests.

Introduction

The "splake", as the F_1 hybrid between *Salvelinus fontinalis* and *S. namaycush* has come to be known in Ontario, has been considered as a replacement for the Great Lakes lake trout, which is suffering greatly from the ravages of the parasitic sea lamprey. Lake trout seem particularly vulnerable to the attacks of the lamprey and it is felt that one of the chief reasons for this vulnerability is the length of their reproductive cycle (five to seven years to first spawning). Fry (1957, pers. comm.) has suggested a long-term programme of selective breeding to obtain a fish combining the three-year reproductive cycle of the speckled trout with the propensity of the lake trout for the benthic environment. As a preliminary to this programme, the segregation of parental characters in the second filial generation was investigated by the examination of a single meristic character, the vertebral number, in a sample of 200 specimens.

Materials and Methods

The fish used were hatched from eggs obtained from the first stock of splake produced in Ontario, at the Dorion Hatchery of the Department of Lands and Forests in 1951, of which some matured in 1954. Two thousand of the second generation hybrids produced from these survived to 1957 at the Hill's Lake hatchery.

At Hill's Lake the hybrids were kept in a large concrete raceway and raised on a poultry mash, liver and cod liver oil formula. Probably because of the extremely low water temperatures at this northern hatchery, growth was quite slow. The sample of these two year-olds of which the vertebrae were counted averaged only 5.1 inches (fork length), and ranged from $3\frac{1}{4}$ to $9\frac{1}{2}$ inches. First generation hybrids have commonly reached four inches in length by the end of the first year (Baldwin, 1956).

Considerable variation was noted in the appearance of the fish. First generation splake which have been planted in different lakes often differ somewhat in coloration and markings, but, in general, deviation from the characteristic intergrade form is usually slight. With the F_2 hybrids, on the other hand, much variation was noted. Caudal fin shapes, for example, ranged all the way from the square tail characteristic of the speckled trout to the typically forked tail of the lake trout. There was no apparent relation between size and the appearance of these characters. That is, large hybrids resembling speckled trout seemed to occur as frequently as those resembling the lake trout and *vice versa*. The accompanying photograph (Plate 1) illustrates the variation in form and markings.

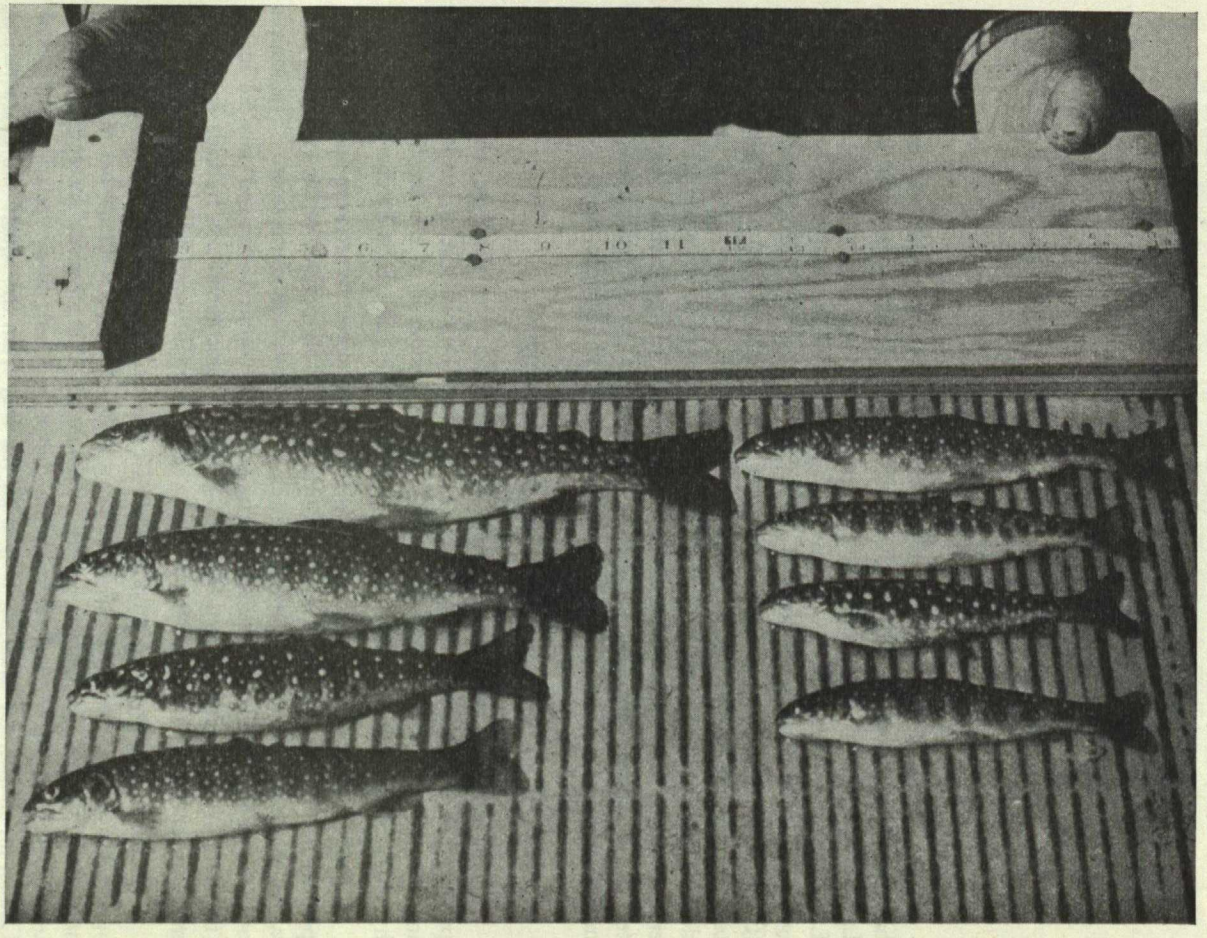

PLATE I.—*Photograph of F_2 splake showing variation in size and markings.*

The vertebral counts were made from X-rays of live fish anaesthetized with MS222 (tricaine methane sulfonate). The fish were selected by choosing every eighth fish as the raceway was emptied of hybrids. However the number of fish had been underestimated by 661, and these remained after the selection of the 200. It was assumed that these specimens would not differ in size from the rest of the stock, so they were simply measured and released with the rest. This assumption unfortunately proved wrong. The mean length of the surplus was 4.7 inches, compared with 5.1 inches for the sample selected to be X-rayed. There is a highly significant difference (0.01 level of confidence) between these means. While the selection was in progress, it was found more convenient to dipnet the fish at the upstream end of the pen in which they had been concentrated, and apparently the residual fish were the smaller weaker specimens which did not fight the raceway current as strongly. There was no relation however, between size and vertebral count in the sample examined.

The facilities of the Kirkland Lake General Hospital were made available on March 10. The hospital's radiologist, Dr. Burrows, and his technician took the X-ray photographs during two hours of the afternoon. They had previously experimented with dead fish supplied by the Department of Lands and Forests to develop the technique so no time was lost on this account. The fish were kept outside the hospital in a tank aboard a hatchery truck and carried in lots of twenty to the radiology room, as needed. Once X-rayed they were immediately returned to the truck and placed in a separate tank.

For the X-ray photography, photographic plates in their packages were placed under the tube, marked with small metal numerals and covered with dampened newspaper. The fish were anaesthetized, measured to the fork of the tail (to the next lower one-eighth inch), and placed on the plate. They were arranged in a staggered fashion, ten to the plate, with the left side up and heads to the left. This arrangement allowed the measurements for individual fish to be related to their photographs.

The exposure was set at six milliamp.-seconds at 60 kilovolts but varied somewhat with the mean size of lots of fish. "Ilfex" film was used and it was developed at 68°F. for $4\frac{1}{2}$ minutes.

Vertebral counts were made from the X-rays over a light table. Two counts were made for each fish: the vertebrae were counted twice from the occipital region back to the tail, then from the tail forward. The first anterior vertebra was discerned as that carrying the first neural process posterior to the occiput. The third centrum carried the first pair of ribs. Owing to the fineness of the bones in these small fish many of the individual elements of the caudal skeleton were obscure. The last caudal vertebra could not be distinguished in the X-ray plates from the "caudal bony plate" (Vladykov, 1954) dorsad and the bases of the 4th, 5th, 6th, and 7th hypural bones posteriad. However, as can be seen in Plate II, this complex of bones appeared as a conspicuous dense area and was counted as the last caudal vertebra in each case.

To ensure the accuracy of the vertebral counts a larger ($15\frac{1}{2}$ inches fork length) dead lake trout was subsequently X-rayed and dissected. It was found that the above description of the caudal skeleton, as observed on the X-ray plates, conformed exactly with that of Vladykov (*loc. cit.*) for salmonoid fish, making the X-ray vertebral counts exactly comparable with the counts made from dissections by that author.

PLATE II.—*X-ray photograph of a lake trout. Scale is in centimeters.*

Since it is hoped in future to select those hybrids best adapted for a deep-water existence, it was of interest to determine whether or not the size of the swimbladder is meristically determined. To this end the total visible length of each swimbladder (which appeared as a dark area) was measured to the nearest one-eighth inch.

Results

Vertebral counts for the hybrids ranged from 56 to 66, averaging 61.4 with a standard deviation of ± 1.7. These data are shown in Fig. 1 as a frequency polygon. Counts on 13 speckled and 23 lake trout from Vladykov (*loc. cit.*) are similarly plotted for comparison. Since meristic characters are influenced by thermal experience during embryonic development (Tåning, 1952 and others), caution must be exercised in comparing the curves. It is obvious, however, that the hybrids exhibited a great deal of variation in vertebral number, and the range for this sample exceeds the total range for the other two curves. Each of the speckled and lake trout samples had a coefficient of variation of 1.9 per cent. The coefficient for the hybrid sample was 2.8 per cent.

The three measurements made on the hybrids were compared by means of a partial correlation analysis on data from 100 of the fish X-rayed. The results of this analysis are shown in Table 1.

TABLE 1

Partial Correlation Analysis. A—fork length; B—vertebral number; C—swimbladder length

$r_{AB} = 0.02448$	$r_{BC} = 0.0650$	$r_{AC} = 0.8733$
$r_{AB.C} = -0.06641$	$r_{BC.A} = 0.08958$	$r_{AC.B} = 0.8733$
	$R_{B.AC} = 0.09282$	

The only correlation coefficient (r) which is significant is that for the regression between fork length and swimbladder size, and the vertebral number has no relation to either of these variables. The multiple correlation coefficient (R) for the relation between vertebral number and the other two variables is far below the level of significance (.2 at the .05 level). This analysis demonstrates that the size of the swimbladder is related only to the size of the fish. The size of the swimbladder is probably not a good criterion of a fish's ability to retain its swimbladder gas under pressure. It also appears that the length bias in the sample had no effect on the distribution of vertebral counts.

Discussion

The wide range of vertebral number in this sample and perhaps also the range in size, appear to be good evidence of normal pairing of chromosomes and subsequent segregation in the F_2 generation. Speckled trout and lake trout both have 84 chromosomes in somatic tissue (Buss and Wright, 1956) and this presumably accounts for the viability which apparently reaches 75 per cent (Stenton, 1952) when lake trout eggs are fertilized with speckled trout milt. If the two parent chars had been genetically distinct for a period long enough for major changes in the chromosomes to have occurred, normal synapsis would have been impossible and the F_2 hybrids could only have been produced through polyploidy or from gametes carrying a preponderance of chromosomes from one or the other of the parental species. Had meiosis in the F_1 generation been abnormal, one could have expected low fertility and off-spring either distinctive with respect to heritable meristic characters or closely resembling one of the parent

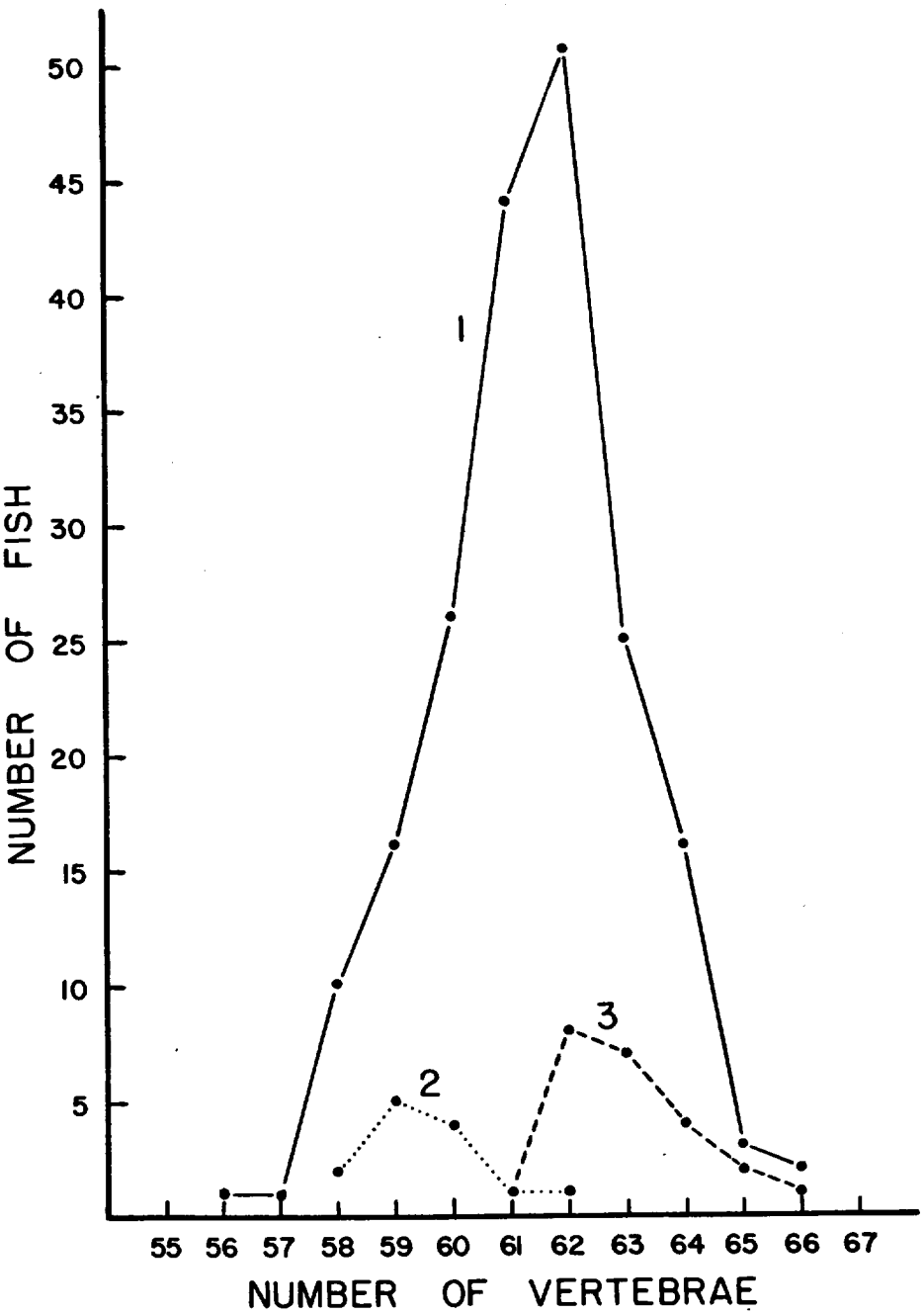

FIGURE 1.—*Frequency distribution for vertebral counts on samples of F_2 hybrids (No. 1, 200 spec.), S. fontinalis (No. 2, 13 spec.) and S. namaycush (No. 3, 23 spec.). Data for numbers 2 and 3 from Vladykov, (1954).*

species. Since segregation took place for vertebral number, it is likely safe to assume that this would be true for all genetically determined characteristics. We can therefore tentatively conclude that the splake is a true hybrid, from recently evolved parent species, and selection for desirable characters to produce a new form is theoretically possible.

It further seems evident that in lakes which provide satisfactory habitat for one or the other of the parent species, planted splake will only retain their identity for a few generations.

Acknowledgements

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Comparative Tagging Returns Employing Three Different Anaesthetics

by

R. A. Ryder

Biologist, Ontario Department of Lands and Forests, Port Arthur, Ont.

In the spring of 1955 a population study of the yellow pickerel, *Stizostedion v. vitreum* (Mitchell), was initiated in the Nipigon River, Lake Superior, and adjoining tributaries. A total of 2,200 yellow pickerel had affixed to them a red plastic streamer tag as outlined by Joeris (1953). Five hundred and forty-nine of these pickerel are not considered in this study as they were caught first in small meshed gill nets. It was readily observed that even with the precautions taken the mortality among these fish (as evidenced by subsequent tag returns), was noticeably higher than those fish initially captured by other methods, regardless of the anaesthetic employed.

Procedure

Consequently, the returns from a total of 1,651 tagged yellow pickerel were considered in this study. The majority of these fish were captured by dip net in the lower Nipigon River, six miles upstream from Nipigon Bay of Lake Superior. The remainder were captured by seine or by angling at the same site or at other sites in the same water system. Most of the pickerel were tagged at night immediately prior to spawning, by a crew of three working with headlamps. All fish were handled in the same manner; measured first, sexed when possible, tagged and returned to the water immediately.

The project was started using commercial ether, ethyl oxide, as an anaesthetic, as urethane, ethyl carbamate, could not be obtained locally at that time. After urethane became available, it was chiefly employed as the anaesthetic and ether reverted to only in case of an ermergency shortage of urethane. Urethane was discontinued in 1956 when its carcinogenic qualities were published (Wood, 1956). In its place M.S. 222, tricaine methanesulfonate was used for the remainder of the tagging operations.

Comparison of Anaesthetics

In every case the anaesthetic was not used in predetermined amounts, but was first tested on a few of the pickerel until a satisfactory concentration was obtained. The liquid ether was found to dissolve rapidly in the water but its high volatility made frequent replenishment necessary, and fumes from the solution were extremely unpleasant to those working in the vicinity. On at least two occasions the author became partially narcotized from prolonged exposure to these fumes. The pickerel took longer to become anaesthetized with ether than when urethane or M.S. 222 were employed. It was found that even after anaesthesia had taken place with ether the

fish would still produce spasms when handled, making tagging difficult. When fish were completely overcome by ether, either by prolonged exposure or an overdose, subsequent revival rarely occurred. Fish in this condition were placed in a back eddy in the river and observed during the remainder of the tagging operation for that night. Only rarely did a fish right itself and swim away.

Urethane was found to be highly satisfactory for this project. It anaesthetized the fish more rapidly than ether and emitted no objectionable fumes to the operator. It was found difficult to dissolve in cold water (34°F. to 38°F.) in which most of the tagging operations took place. Anaesthesia was realized more rapidly than in the case of ether but a longer period of time was needed to completely anaesthetize the fish. Most of the latter fish again showed signs of life when returned to fresh water. Urethane required replenishment only when the mucus covering from the fish and other debris became excessive in the solution. Fish which were anaesthetized in urethane were easy to handle, spasms occurring less frequently than when ether was employed.

M.S. 222, although at first resorted to as an emergency measure, has been found more satisfactory in all respects than either ether or urethane except in the rapidity of dissolution. In this respect it dissolves more rapidly in cold water than does the urethane crystals, but not as rapidly as the liquid ether solution. No objectionable odour is apparent, and the fish appear to become anaesthetized more rapidly than with either ether or urethane. Violent spasms rarely occur thereby greatly facilitating the tagging operation. Fish which were overcome by M.S. 222 can usually be completely revived in a short while with apparently no ill effects. Most of the fish could be left in the solution longer than with urethane or ether. M.S. 222 solutions, like urethane solutions, required changing only when overladen with slime and debris.

TABLE I

Percentage tag returns following use of three anaesthetics in tagging procedure

Anaesthetic Employed	Number of Fish Tagged	Number Tags Returned After 2 Years	Percentage Return of Tags
Ether	178	24	13.5
Urethane	969	175	18.1
M.S. 222	504	160	31.7

Tagging Returns

Tag returns of pickerel anaesthetized with ether, urethane and M.S. 222 vary greatly (Table I). As the majority of these fish were tagged and released under similar conditions most variables will be eliminated. All fish were tagged by the author, two assistants helping in capturing the fish and recording data. It must be remembered that this tagging project was primarily designed to be a portion of an extensive population study and was not set up to test the relative merits of the three anaesthetics. Hence constant concentration levels were not used as the molality of the solution was in general increased (by adding more of the solute) with a decrease in water temperature. Had the experiment been designed to test ether, urethane and M.S. 222 and compare the

same, consistent concentrations of each should have been employed, and three equal groups of pickerel tagged each night employing each of the three anaesthetics separately.

The rate of tag return will also vary according to the varying rates of natural mortality over the tagging and recapture period, combined with variability of the effectiveness of harvesting agencies (in this case commercial fishermen and anglers). These variables would have been greatly reduced had a controlled experiment as outlined above been employed. Lastly, the tagged fish must be considered to be randomly distributed within the total population. Enough information is not available at present to establish this condition.

M.S. 222 exhibited a far greater return of tagged pickerel than did either ether or urethane (Table I). Of 504 fish released, 31.7 per cent were subsequently returned during the following two year period. Urethane showed a return of only 18.1 per cent and ether 13.5 per cent from a release of 969 and 178 tags respectively. The lower rate of return for fish anaesthetized with ether and urethane can possibly be attributed to an assumed higher mortality shortly after tagging. This mortality could be caused from a toxic or other deleterious effect of the anaesthetic on the fish, or external or internal injuries caused by the operator by squeezing the fish when spasms occurred. Hence possible injury effected in this manner would be directly proportional to the number and vigorousness of the spasms produced. It would follow then that internal injury caused by pressure on the fish would be greatest when ether was employed as the anaesthetic and least when M.S. 222 was used. Removal of mucus from the fish probably occurred most often with ether and least with M.S. 222 and would also be directly proportional to the spasms produced and hence the relative facility with which the fish could be handled.

Summary

From the available data tag returns from a total of 1,651 yellow pickerel tagged were greatest when M.S. 222 was employed as an anaesthetic. Much lower rates of return were experienced with fish anaesthetized in urethane or ether. The increased rate of tag return resulting when M.S. 222 was employed was possibly due to a lesser toxic or other deleterious effect, or to a more complete narcosis of the fish and thereby greatly facilitated the handling and increased the rate of tagging when fewer spasms were produced.

Acknowledgements

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Mr. G. C. Armstrong critically read the original manuscript.

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A Possible Source of Error in Assessing the Survival of Pacific Salmon Eggs by Redd Sampling

by

J. G. McDonald

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

Introduction

The survival of salmon eggs during incubation in the gravel has been commonly assessed by redd sampling at some period after deposition. This sampling method has been described by Hobbs (1937) and involves excavating the nest or redd and collecting the eggs and/or alevins in a net as they are swept downstream by the current. The ratio of the number alive to the number dead is taken to represent the survival in the area examined.

Some doubt has arisen as to the validity of survival values obtained by this method. There is some evidence that dead eggs may be lost to the investigator through various agencies either before or at the time of sampling. Carl (1939) planted a known number of coho eggs (*Oncorhynchus kisutch*) in gravel and found upon later examination that all the eggs he originally planted could not be accounted for. Shaw and Maga (1943) and Briggs (1953) reported similar results also on coho. W. M. Cameron of the Fisheries Research Board, Biological Station at Nanaimo, B.C. investigated the possibility of dead eggs disintegrating during the redd sampling procedures. He found a significant loss of coho eggs occurred when dead eggs were planted in gravel and then immediately dug up.

Sockeye (*Oncorhynchus nerka*) redd sampling was carried out by the author at Scully Creek, Lakelse Lake, B.C. In many instances, particles of dead eggs were observed in the gravel and on the collecting net while redds were being dug, indicating that disintegration and loss of eggs had occurred. Also a smaller number of eggs were recovered per sample in the spring than in the fall, although the effort expended per sample was considered about the same in each season. A review of Cameron's data suggests a similar occurrence in pink salmon redds (*Oncorhynchus gorbuscha*). He examined over 60 redds at various times after deposition. The average number of eggs recovered per sample decreased as the time spent in the gravel increased. Redds sampled within 50 days of deposition averaged nearly 1,000 eggs. This figure dropped to less than 700 after 150 days. Assuming that the effort expended on each sample remained the same throughout the sampling period, it would appear that a considerable loss of eggs occurred.

Method

In order to determine the conditions under which the loss of eggs may occur and to obtain some idea of the extent of such loss, sockeye eggs were placed in artificial redds and their fate recorded.

Artificially fertilised eggs were placed in 15 screened boxes containing gravel of various sizes. The boxes, 12″ x 8″ x 10″ deep, were made of plywood. The ends were covered with common metal fly screening to permit water circulation through the gravel. Five boxes of small, medium and large gravel were used. The small gravel consisted of particles less than $\frac{1}{4}$″ in diameter; the medium was greater than $\frac{1}{4}$″ but less than 1″; the large gravel was between 1″ and 2″ in diameter.

Fifty cc. of eggs were placed in each box in the following manner. A layer of gravel, approximately 3″ deep was placed in the bottom of each box. The box was then placed under water and the measured quantity of eggs placed in a small pocket made in the gravel. The eggs were gently covered with gravel to avoid crushing and the box filled to within 1″ of the top. The boxes were placed on the bed of a small stream, in moderate current and under at least 6″ of water.

Fertilization and planting was carried out on August 27, 1953. Nine, 50 cc. samples of eggs were counted to estimate the number placed in each box. This was found to be 258 (standard deviation 13.5). All boxes were examined seven months later, just prior to the time that fry emergence usually takes place. Care was taken that all eggs present in the boxes were recovered. Notes were kept of the condition of the gravel in each box, the condition and stage of development of the eggs and the presence or absence of other organisms.

Results

It was found when the boxes were examined that almost total mortality had occurred by the time the mid-eyed stage was reached. One individual had survived to alevinage but had died prior to the examination. This mortality was attributed to excessive silting of the gravel as a result of freshets in the previous fall and also to the nature of the containers which no doubt restricted water circulation in the gravel. Eyed and un-eyed eggs in various stages of decomposition were recovered from each box. In addition, many minute particles of dead eggs were observed. The small size of these particles prevented even a rough estimate of the number of whole eggs they represented. Decomposition was more advanced and egg particles were more numerous in the boxes containing medium and large gravel. The eggs in the small gravel were relatively firm and had retained much of their original shape and colour.

The number of whole eggs recovered is given in Table I. In all but three boxes the number recovered was significantly less than the number originally planted. The most probable number of eggs planted in the 14 boxes examined (one of the 15 originally seeded was lost) was 14 x 258 or 3612 eggs. The total recovered was 2810 or 78 per cent of the probable number planted. A loss of about 22 per cent, therefore, took place during the period in the gravel.

As suggested above, the loss of eggs was greater in the medium and large gravel than in the small. The number of whole eggs recovered from the four boxes containing small gravel ranged from 212 to 263 compared to 105 to 237 in the medium and 160 to 209 in the large. In Table I the apparent and actual survival of the eggs to the eyed stage is given. The apparent survival was calculated from the number of eggs recovered in each box while the actual survival was calculated from the number of eggs planted in each box. These values are compared graphically in Figure 1. The medium and

TABLE I

Contents of egg boxes examined April 5 to 14, 1954
Average of 258 eggs (standard deviation 13.5) planted per box

	No whole eggs recovered	No. dead			% survival to eyed stage	
		Pre-eyed	*Eyed*	*Alevins*	Apparent	Actual
Small gravel—						
Box No. 1....	212	183	29	—	13.6	11.2
2....	256	256	0	—	0	0
3....	226	226	0	—	0	0
4....	263	263	0	—	0	0
					Mean 3.4	2.8
Medium gravel—						
Box No. 1....	237	106	131	—	55.3	50.8
2....	188	97	91	—	48.4	35.3
3....	105	101	4	—	3.8	1.6
4....	203	109	93	1	46.3	36.4
5....	186	163	23	—	12.4	8.9
					Mean 33.2	26.6
Large gravel						
Box No. 1....	209	57	152	—	72.7	58.9
2....	160	72	88	—	55.0	34.1
3....	178	100	78	—	43.8	30.2
4....	177	86	91	—	51.4	35.3
5....	209	46	163	—	78.0	63.2
					Mean 60.2	44.3

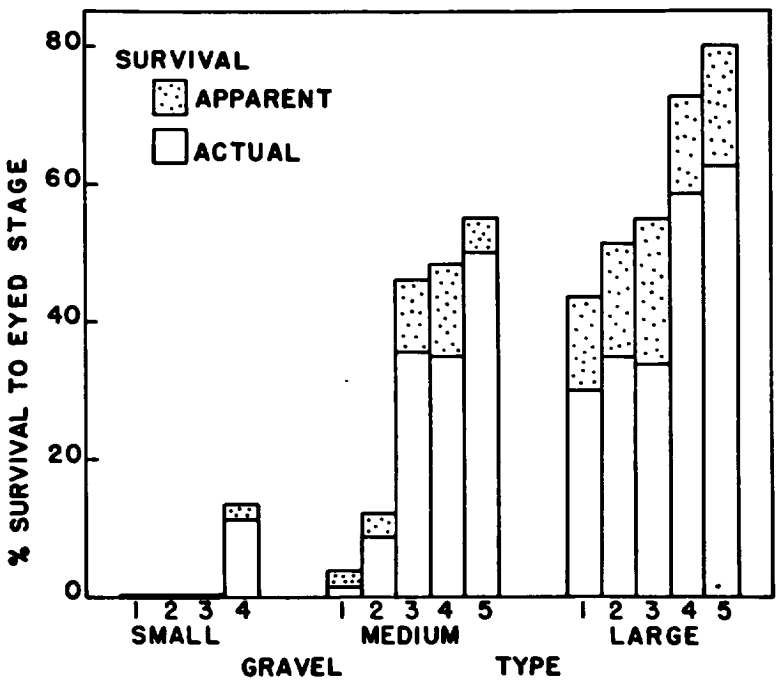

FIGURE 1.—*The apparent and actual survival of sockeye salmon eggs to the eyed stage.*

large gravel was most conducive to survival and also to the disintegration and loss of eggs. The apparent survival was, therefore, correspondingly higher than the actual in these two gravel types than in the small gravel.

A number of aquatic forms were found to be closely associated with the egg clusters. Insect larvae and nymphs were frequently encountered and occasionally a few oligochaetes and lamprey larvae were found. The abundance of these organisms varied from box to box and varied in each type of gravel. Extensive fungus growths and numerous insects were found in the medium and large gravel while the small gravel was relatively "sterile" and contained very few of these forms. The larvae or "blood worms" of the Tendipididae were found in large numbers both on and inside the eggs. Entry into the eggs was made through a small sharp edged hole in the shell. It was presumed that the bloodworms were subsisting on the dead materials inside. Stonefly nymphs, (*Chloroperlidae*), and cranefly larvae, (*Tipulidae*), were also present but in smaller numbers than the bloodworms. Whether or not they subsisted on the egg materials was not certain, but the fact that they were often found in the midst of the egg clusters, suggests they did. Eggs in all stages of fungusing were evident. Fungus had attacked the eggs singly or in clusters wherein it was often difficult to separate out the individual eggs.

Discussion and Summary

The evidence indicates that a considerable loss of dead eggs may occur during the incubation period in the gravel. The agencies responsible for this destruction include fungus, midge and cranefly larvae, and stonefly nymphs. Although there was evidence to show that dead eggs were consumed, it could not be determined if living eggs were attacked.

The extent of the loss which occurred was related to the type of gravel in which the eggs were planted. This in turn apparently determined the abundance of organisms which acted as agents of destruction. Large gravel was more suitable for the survival and development of the sockeye eggs, and also presumably more suitable for the existence of fungus and insect forms. Loss or destruction of eggs in the larger gravel was, therefore, greater than in the other types. Total non-recovery in all three types was estimated to be in the order of 22 per cent of the number planted. Although the conditions under which the eggs existed were artificial, there is reason to believe that in comparable conditions of restricted water flow and silting, such losses would occur naturally. Survival values determined from redd sampling may, therefore, be erroneously high, particularly in large gravel where disintegration of dead eggs most frequently occurs.

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A Modified Roller Press for Scale Impressions

by

M. H. Baker and H. H. Brohm

Division of Research, Ontario Department of Lands and Forests

The use of scale impressions in determining the age of fish has steadily increased since its early development (Nesbit, 1934). Several of the methods employed require the use of hydraulic presses (Greenbank and O'Donnell, 1950), pneumatic presses (Butler and Smith, 1953), or roller presses (Arnold, 1951), (Smith, 1954).

The roller press, preferred by many workers, has one disadvantage. In order to obtain the correct pressure the space between rollers has to be set accurately. If the cellulose acetate slides and scales are uniformly thick, adjustments of the machine are infrequent and of minor concern. When slides vary in thickness adjustments are frequent and a relatively high percentage of the scales require re-rolling. This difficulty can be overcome by placing the upper roll of a jeweller's rolling press under air pressure held constant at any desired pressure up to 200 p.s.i. Uniformly good impressions are obtained despite differences in slide and scale thickness and at a relatively high speed.

A jeweller's rolling press was modified as shown in the accompanying photographs. The entire manual roll pressure adjusting mechanism and hand operating parts were discarded. In place of these, the unit was motorized and the desired roll pressure was obtained by means of a pneumatic diaphragm.

This diaphragm can be connected to any convenient source of compressed air. In this case, compressed air cylinders are used. The required roll pressure, to suit the particular species of fish scale under examination, is adjusted and held constant by means of a pressure reducing valve. The diaphragm air hose, compressed air cylinders and reducing valve are clearly shown in the photographs.

To equalize the roll pressure, the diaphragm push rod acts on a yoke, which in turn presses on each end bearing of the upper roll. These bearings are free to move up and down in vertical guides. Adjusting nuts on this yoke serve to set the initial gap between the rolls. This gap is essential for ease of inserting the slides. Small irregularities in the slide thickness are automatically compensated for, with negligible change in the roll pressure, by the up and down movement of the yoke and diaphragm, as the slides pass between the rolls. Part of this yoke can be seen at "A" in Figure 1.

For speed and ease of operation, this device is driven by a $\frac{1}{4}$ h.p. motor, belt-connected to a 50 to 1 worm reductor, which in turn is directly coupled to the driving roll. A maximum rotation speed of the roll of about 35 r.p.m. is desirable. Excessive speed tends to flip the scales from the slide as they enter the machine.

Figures 1 and 2 show the essential features which have been incorporated, both for ease of operation and for the safety of the operator.

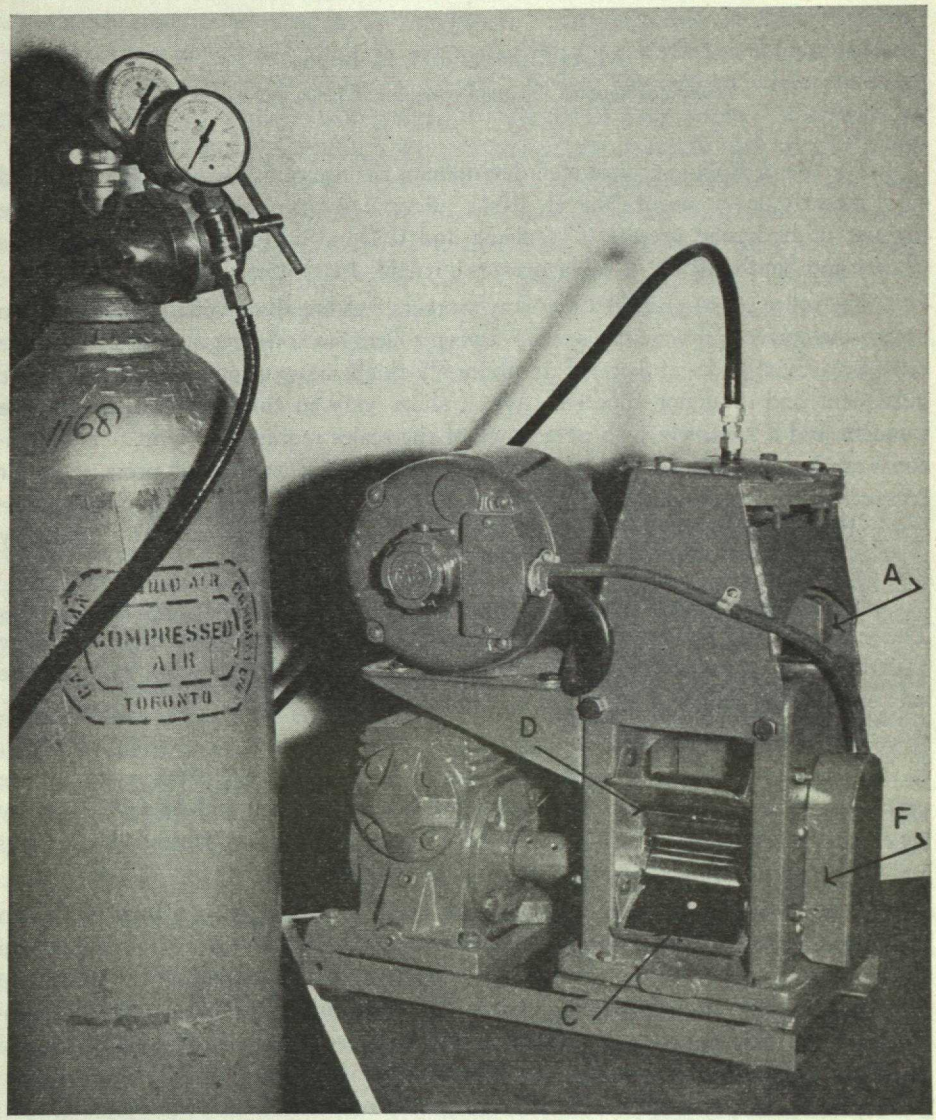

FIGURE 1. *The outlet side of the rolls. "C" is the slide chute, "D" shows plexiglass wipers to remove any scales that stick to the rolls, and "F" is the roll gear drive guard.*

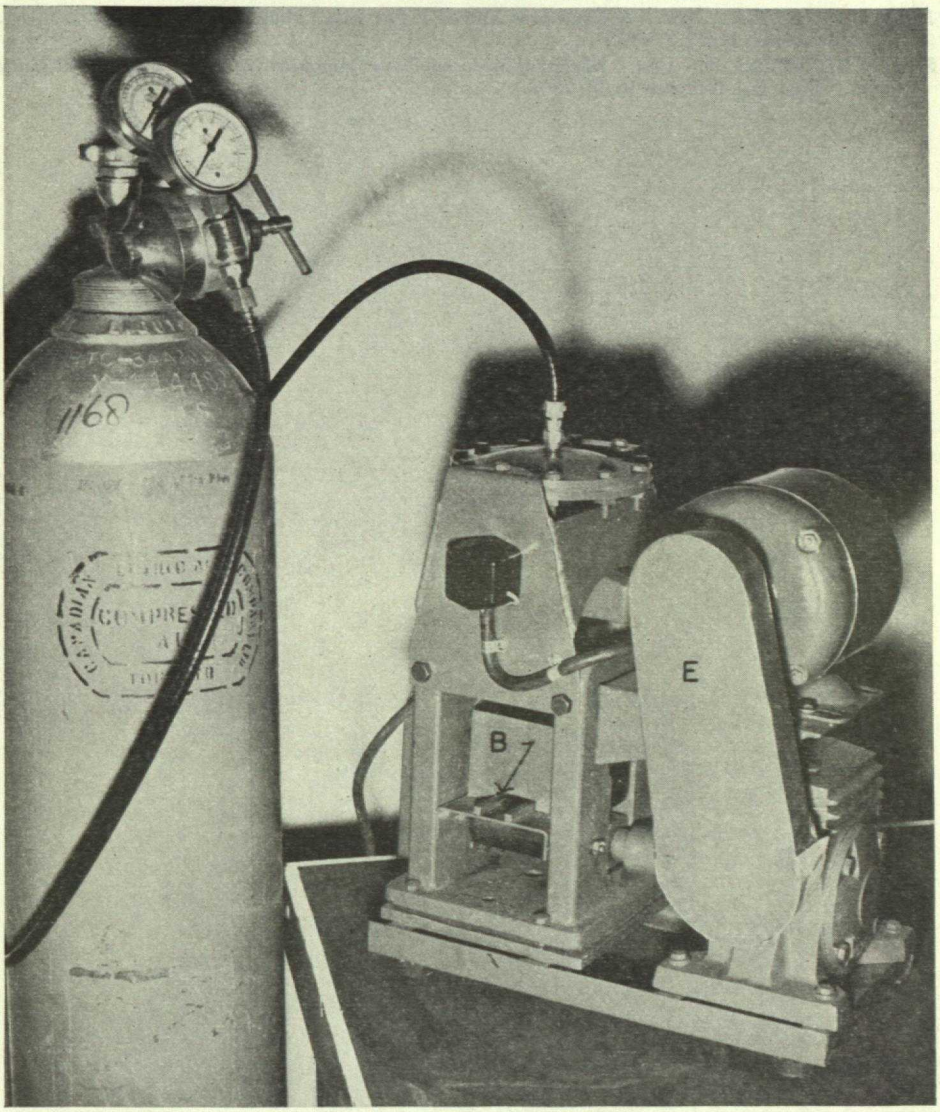

FIGURE 2. *The inlet side of the rolls. "B" is the combined slide platform and finger guard, and "E" is a guard for the drive belt between the motor and the worm reductor.*

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W. E. B. Young

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The Robertson Creek Spawning Channel

by

K. C. Lucas

Department of Fisheries of Canada, Vancouver, B.C.

The largest salmon spawning channel constructed to date in Canada or the United States was put into partial operation in late October, 1959, at Robertson Creek, near Port Alberni, B.C. It is known as the Robertson Creek Spawning Channel, and was planned and constructed by engineers and biologists of the Fish Culture Development Branch of the Department of Fisheries of Canada. The object of this paper is to review the history, design considerations and construction features of this new spawning channel.

History of Spawning Channel Development

Man-made spawning channels are a very recent advance in the field of fisheries conservation and development. The two main advantages of spawning channels are: first, the survival of deposited eggs to emergent fry which occurs in natural spawning areas can be increased substantially by establishing stable and optimum physical conditions, and second, new spawning areas can be created where none previously existed. Under natural conditions the survival of Pacific salmon eggs and alevins varies widely, but is generally a small percentage of the number spawned. Royce (1959), in reviewing various investigations of egg to fry survival in Alaska and British Columbia, reported that on the average, less than 10 per cent of the eggs of pink (*Oncorhynchus gorbuscha*), chum (*O. keta*) and sockeye (*O. nerka*) salmon hatch and leave the streams as free-swimming fry.

There are many factors which can limit survival of salmon eggs and alevins; however, the major causes of low survival which can be greatly reduced or virtually eliminated by the use of man-made spawning areas are as follows:

1. *Erosion of spawning beds.* Floods occurring after egg deposition often erode stream beds to such an extent as to uncover and wash away eggs and alevins. Hydrographs of typical southerly coastal streams of British Columbia invariably show the maximum freshets occurring in the months of November through January, therefore the problem of erosion of spawning beds is particularly evident there on streams with no appreciable natural lake storage to modify extreme runoff. Evidence from studies at Nile Creek by the Fisheries Research Board of Canada from 1947 to 1952 indicated that protection of the spawning beds from freshets could significantly increase egg to fry survival as reported by Wickett (1952).

2. *Silting of spawning beds.* Many normally clear salmon spawning streams become turbid with suspended silt during floods. Recession of these floods often results in the deposition of heavy layers of silt on spawning areas, thus reducing the rate of interchange of surface and subterranean water and hence lowering the amount of dissolved oxygen available to eggs in the gravel. The International Pacific Salmon Fisheries Commission carried out laboratory experiments in 1954 which demonstrated lower survival for sockeye eggs placed in gravel which was covered with silt (Personal communication).

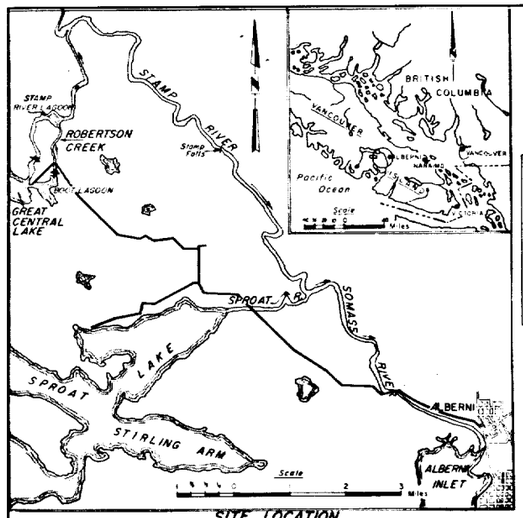
3. *Lack of adequate flow through the gravel.* The supply of dissolved oxygen to developing eggs and alevins depends on the percolation of subterranean flow through spawning beds. In streams, this subterranean flow is a function of the surface flow in the stream and the porosity of the gravel in the stream bed. As pointed out in (2) above, a covering of silt reduces sub-surface percolation, and a reduction in surface flow in a stream also reduces percolation. This latter point is important, as the flow in many British Columbia coastal streams becomes very low during relatively short, cold spells during the winter. The effects of low oxygen levels on developing eggs such as would be the case during temporary low flow periods, and a definition of critical levels of dissolved oxygen for egg survival are reported by Alderdice, Wickett and Brett (1958). Notwithstanding silting or low surface flows the porosity of stream gravels depends on its physical makeup, or *grading*, and can vary widely in nature. Areas of finer stream bed materials have a lower porosity and hence a slower rate of flow through the gravel. Wickett (1954) found by standpipe measurements that a low survival of chum salmon eggs was caused by low oxygen levels associated with a low percolation rate of water through the gravel. In choosing areas to spawn, salmon apparently use the more permeable areas of a stream bed; however, natural gradation of stream gravel probably does not provide optimum percolation in most areas. In the construction of spawning channels, the spawning gravel can be screened and washed to remove all fine material, and thus provide a much higher porosity than can be found in nature.

While it is recognized that there are many factors which can limit survival of salmon eggs and alevins, the elimination of the major physical factors outlined above is the primary aim in the construction of spawning channels.

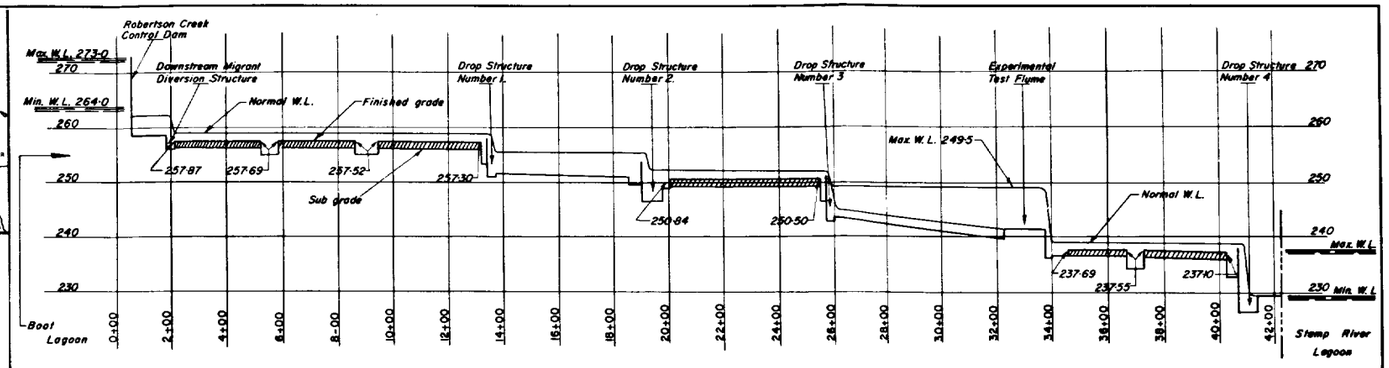
The first large man-made spawning channel was constructed at Jones Creek near Hope, B.C. in 1954. The Jones Creek spawning channel was built by the British Columbia Electric Company as a result of recommendations by engineers and biologists of the Fish Culture Development Branch for saving the stocks of fish in this stream in the face of a hydro-electric diversion from Jones (Wahleach) Lake. This channel, described by Hourston and MacKinnon (1957), is an artificial stream having a surface width of 14 feet and a length of 2000 feet. It carries an average flow of 20 c.f.s. and was constructed alongside the natural stream bed of Jones Creek. This natural stream bed was retained as a flood channel with a small headworks diverting flow into the new channel, and a weir located just above the spawning channel outlet directing all salmon into the new area. The channel gradient, depths of water, and gravel size were based on measurements recorded on natural spawning areas on several streams in British Columbia.

Complete biological studies of spawning, incubation, survival and downstream migration have been maintained at Jones Creek since completion of the spawning channel in 1954 (Hourston and MacKinnon, 1957). This stream is frequented primarily by pink salmon during the odd-numbered years and also by small numbers of chum salmon and coho salmon (*O. kisutch*) every year. Measured survival of potential egg deposition to migrating fry for pink salmon has been 36 per cent in 1955-56 and 38 per cent in 1957-58. The survival of pink salmon eggs to fry in an even-year planting experiment in the channel by the Fisheries Research Board of Canada in 1954-55, as described by Neave and Wickett (1955) was measured at 37 per cent.

FIGURE 1.—*Location Maps, general site plan and profile of the Robertson Creek spawning channel.*



SITE LOCATION



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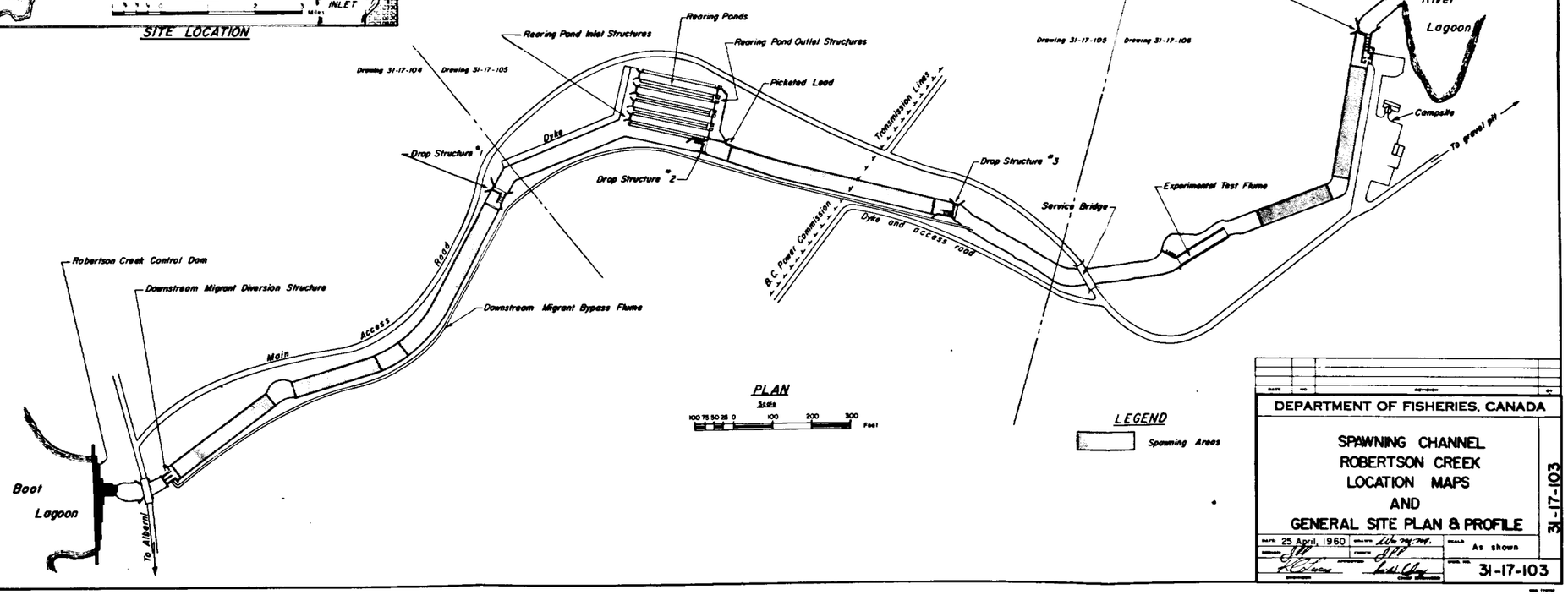

PLAN

Scale
100 75 50 25 0 100 200 300 Feet

LEGEND

Spawning Areas

DEPARTMENT OF FISHERIES, CANADA

SPAWNING CHANNEL
ROBERTSON CREEK
LOCATION MAPS
AND
GENERAL SITE PLAN & PROFILE

DATE 25 April, 1960 | DRAWN | SCALE As shown
DESIGN | CHECKED APP | APPROVED | DWG. NO. 31-17-103

31-17-103

The second sizeable spawning channel on the Pacific Coast was constructed in 1957 by the U. S. Army Corps of Engineers on the Oregon shore of the Columbia River immediately below McNary Dam. This channel was designed to carry out research of the production of fall chinook (spring) salmon (*O. tshawytscha*) in artificially created spawning areas as a means to provide compensation for losses of fish at dams. It is operated by the Washington State Department of Fisheries under a contract with the Corps of Engineers. The McNary spawning channel has a water surface width of 31 feet, a length of 2545 feet and carries an average flow of 60 c.f.s. Water supply for the channel is by pipeline from the dam and the channel discharges into the Columbia River. The channel water depths, velocity and gravel composition were based on a study of salmon spawning grounds in natural areas carried out from 1953 to 1955 by the Washington State Department of Fisheries (Chambers, Allen and Pressey, 1955). No definite information on egg survival has been published, however the channel is apparently operating with some success (personal communication). A detailed description of the facilities and their operation is given in the Annual Report of the Washington State Department of Fisheries 1958.

The Robertson Creek project is then the third large spawning channel to be constructed on the Pacific Coast of North America. However it is the first such channel to be constructed primarily as a fisheries development project (i.e. extension of natural spawning grounds) rather than a fish salvage or research operation in conjunction with hydro-electric power development.

Development of Flow Control on Robertson Creek

Robertson Creek is a secondary outlet of Great Central Lake near Port Alberni, B.C. (See site location map on Figure 1), the primary outlet being the Stamp River which flows southerly into the Somass River and thence into Alberni Inlet, on the west coast of Vancouver Island. Robertson Creek joins the Stamp River about one mile downstream from Great Central Lake.

In its natural state Robertson Creek, also known locally as Robson Creek, was not a perennial stream but only flowed when the water surface of Great Central Lake rose above elevation 263.5 (geodetic). This elevation corresponded to a flow of about 2500 c.f.s. at the Stamp River outlet. A review of past water records at Great Central Lake Stamp River outlet shows that Robertson Creek in its natural state only carried water a total of three months in any one year, and then only a maximum of two months continuously.

About 1923 a logging control dam was constructed at the Stamp River outlet of Great Central Lake which controlled lake levels in the approximate range of elevations 262 to 269. This dam enabled logs to be floated to a large sawmill which was operated on Boot Lagoon (Figure 1) in the 1920's, and after a fire destroyed this mill the dam was apparently not operated and fell into disrepair. Water flowed more frequently in Robertson Creek after construction of this dam; however, there were still dry periods when flows were interrupted, and also freshet periods when floods caused by high lake levels swept down the relatively narrow, steep little creek.

Meanwhile an expansion of the sulphate pulp mill at Alberni in 1956 made necessary the provision of water storage in Great Central Lake to supplement low summer

flows to prevent pollution at the mouth of the Somass River by pulp mill wastes. In 1957 the old dam at the Great Central Lake outlet was replaced with a higher and more permanent concrete structure incorporating an extensive fishway system. Since storage levels in the lake were to be raised to a maximum of elev. 273, a dam was also built at the upstream end of Robertson Creek to provide control of flows there. This dam was built of treated timber and had incorporated a small fishway and a flow outlet works designed to pass a continuous flow in Robertson Creek of about 50 c.f.s.

Indigenous Fish Populations

Although no definite records are available, Department field personnel have reported spawning of small numbers of coho and spring salmon in Robertson Creek in most recent years. It may be assumed that recently the creek provided spawning area for 100-500 coho and spring salmon and also served as a migration route for a small number of coho into Great Central Lake. The largest number of spawning fish actually recorded in Robertson Creek was 550 coho and 100 spring salmon in 1956. A biological survey on this year reported that there were only two areas where suitable spawning gravel occurred, viz. 75 yards of stream at the extreme upstream portion and a 100-yard reach immediately above the creek mouth. Both these areas were heavily spawned in 1956, with the upper area used exclusively by coho and the lower area by coho and springs.

It was for the protection of these runs of fish, which must have been built up since the original dam construction about 1923, that provisions for a continuous flow release and upstream fish passage were made in the Robertson Creek Control dam built in 1957.

Objectives and Development of a Spawning Channel at Robertson Creek

With the completion of the Robertson Creek dam and flow control works in the fall of 1957, Robertson Creek became a perennial stream for the first time in its history. It became apparent to the Fish Culture Development Branch that Robertson Creek was ideally suited as a site for a man-made spawning channel since works for the complete control of flows already existed, no provision for flood flows had to be made, no serious silting problem from inflow water was anticipated, temperature of the stream remained moderate and the area was readily accessible.

In the light of the facilities and favourable conditions available, it was felt the Department of Fisheries would be remiss in not taking full advantage of the situation in order to accomplish two major objectives. The first of these was to work towards the solution of fisheries problems associated with the proposed Somass River system hydro-electric power development, particularly on the problems of requirements for rearing pre-migratory spring and coho salmon and replacing natural spawning areas of these same species with artificial areas. The second was to institute a fisheries development project aimed at (a) introducing and supporting runs of pink salmon in the Upper Somass River sytem, and (b) increasing the present minor numbers of coho and spring salmon to the full potential of Robertson Creek.

Preliminary design of a channel to carry a flow of 50 c.f.s. was begun early in the fall of 1958. However the concurrent design of another project, an experimental test

flume on the same creek described later in this report, dictated an increase in the average design flow to 100 c.f.s. Maximum design flow capacity of the channel was finally set at 250 c.f.s. as governed by the requirements at the test flume.

A total of $150,000 was spent on construction of the Robertson Creek channel in 1959. This amount provided for the completion of all subaqueous channel facilities and almost all control structures, thus enabling the channel to be put into operation at reduced flows in October, 1959. A further $90,000 will be spent in 1960 to add an additional control structure at the entrance of the channel incorporating a fish trapping works, to provide appurtenant experimental fry rearing channels, and to construct a downstream migrant bypass system parallel to a portion of the channel. By October 1, 1960 it is anticipated that all major works on the channel will be complete and in operation, and a normal channel flow of 100 c.f.s. will be maintained after that time.

The following sections of this report will deal with the detailed description of the channel works, including design considerations. The reader should refer to the general site plan of the channel on Figure 1 in following this description of works.

Spawning Channel

The total length of Robertson Creek from the dam at its upstream end to the Stamp River at its lower end is 4200 feet. Twenty-five hundred and fifty feet of this length has been developed as spawning channel and the remainder is taken up by the control structures, rearing ponds, experimental flume, bypass and fish transportation channels. The gradient of the natural stream bed was substantially greater than was required for the spawning channel, therefore several drop structures were provided to localize the unwanted extra drop.

The hydraulic design criteria for the spawning channel cross-section were as follows:

1. Normal channel flow during spawning period to be 100 c.f.s.

2. Average velocity and depth of water in the channel at 100 c.f.s. discharge to be 1.5 f.p.s. and 1.5 feet, respectively. However provision to vary these amounts by at least 50 per cent to be provided.

3. Maximum water depth to be 2.5 feet.

4. Maximum discharge capacity of channel, governed by test flume studies, to be 250 c.f.s.

A uniform trapezoidal cross-section was chosen having a bottom width of 35 feet and side slopes of 2:1 (Figure 2). Thus the water surface width at normal flow will be 41 feet. The value of Kutter's or Manning's roughness coefficient n for the channel was assumed to be in the range 0.023–0.025 for water depths in the range of 2.5 to 1.0 feet based on laboratory measurements made for the McNary spawning channel (Webb and McKinley, 1955). A channel bottom slope of 0.0006 was chosen, which is slightly steeper than the predicted water surface slope of 0.0004 calculated for uniform flow. It was suspected that the channel might be slightly rougher than the design assumption allowed, and in any case it was considered to be preferable to have the flexibility of flow control remain at the drop structure rather than depend wholly on channel parameters.

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The variation of channel depth is accomplished by manipulating adjustable sector gates on the drop structure crests, and the average velocity in the channel for a given depth will be varied by altering the discharge in the channel by operating the gates at the control dam.

The channel side dykes have a minimum height of three feet above channel bottom, giving a freeboard of six inches at maximum discharge. The maximum average velocity in the channel when it is carrying the peak discharge of 250 c.f.s. will be 2.5 f.p.s.

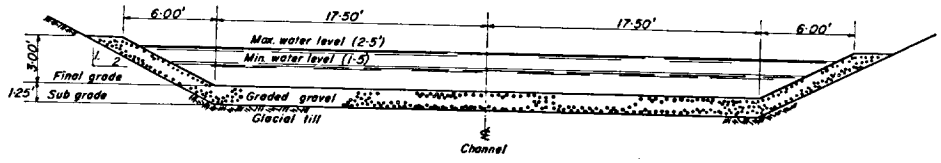

FIGURE 2.—*A typical cross-section of the spawning channel.*

The drop structures divide the spawning channel into three sections. The upper section, extending from the downstream migrant diversion structure to drop structure No. 1 is 1150 feet long. This section contains three holding pools for fish: one immediately upstream of the drop structure and two at bends in channel alignment. These pools are about 40 feet long and five feet deep. The middle spawning channel section is between drop structures No. 2 and No. 3 and is 650 feet long. The two holding pools in this section are located immediately upstream of drop structure No. 3, and immediately downstream of drop structure No. 2. The lower spawning channel section is located between the experimental test flume and drop structure No. 4 at the mouth of the creek. This section is 750 feet long and contains three holding pools: one just upstream of drop structure No. 4, one at a bend in the channel and one immediately below the test flume. Hence the Robertson Creek channel actually consists of three sections of channel, and although each must carry the same discharge as released from the Robertson Creek control dam, the water depth and velocity in each section may be individually controlled within certain limits by the adjustable gates on the crest of each drop structure.

The right-of-way of the spawning channel generally followed the old creek bed, however considerable clearing and excavation was required to prepare the channel subgrade. Figure 3 shows a section of the channel right-of-way before work began and Figure 4 shows a section excavated to subgrade.

The spawning gravel has been placed directly on the channel subgrade, which is composed of an impervious glacial till in most areas. The spawning gravel in the upper and middle sections of the channel was placed to a minimum depth of 15 inches, while in the lower section the depth was increased to 20 inches, since this section is tentatively planned for use by spring salmon, the largest species. Figure 5 shows the spawning gravel in place in the upper section of the channel. The spawning gravel was specified to lie within certain limits on a grading curve (Figure 6), with 100 per cent passing a 4" screen and 100 per cent retained on a $\frac{3}{4}$" sieve. The 4700 cubic yards of gravel required for the channel was washed and screened at a pit near Alberni, 13 miles from Robertson Creek.

FIGURE 3.—*Channel right-of-way looking downstream towards site of rearing ponds bypass channel before construction.*

FIGURE 4.—*Channel excavated to subgrade upstream of drop structure no. 4.*

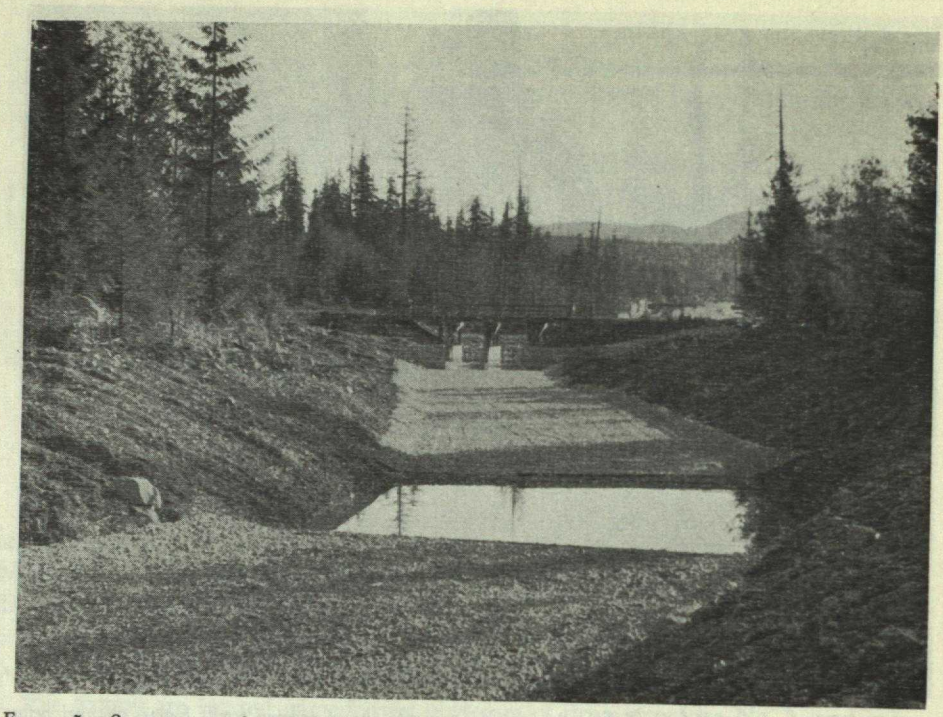

FIGURE 5.—*Spawning gravel in place in upstream section of spawning channel. Note holding pool at bend in foreground and invert controls.*

The gravel grading curve for the Robertson Creek channel was a refinement of the grading curve recommended for the Jones Creek spawning channel. Experience at Jones Creek showed that natural erosion and silting very quickly added fine material to the original screened material placed in the spawning channel, and the channel had soon become quite consolidated with resulting lower sub-surface percolation rates. As a result, the Jones Creek channel bed has had to be loosened and flushed almost every year and in 1959, only five years after it was first constructed, the gravel was completely removed, screened, washed and replaced. Hence, in designing the spawning gravel grading curve for the Robertson Creek channel, the upper (coarse) limit of the Jones Creek curve was maintained but the lower (fine) limit was drastically curtailed. The Jones Creek spawning channel gravel grading curve is reproduced in Figure 6 for comparative purposes.

One other feature of the spawning channel is the provision of invert controls at intervals on the channel bottom to control erosion and movement of the spawning bed. These invert controls are constructed of pressure-treated 6″ × 6″ timber members supported on posts driven firmly into the channel subgrade. The tops of the invert controls are flush with the finished grade of the spawning gravel and since they are suspended 9 to 14 inches above the subgrade, they do not interfere with subsurface water percolation in the spawning gravel. These timber invert controls are provided at each end of the holding pools, and are also installed at maximum intervals of 200 feet on all tangents. Figure 7 shows the invert controls being placed in position before the spawning gravel was laid.

A typical section of spawning channel as it appears with a flow of 100 c.f.s. is shown in Figure 8.

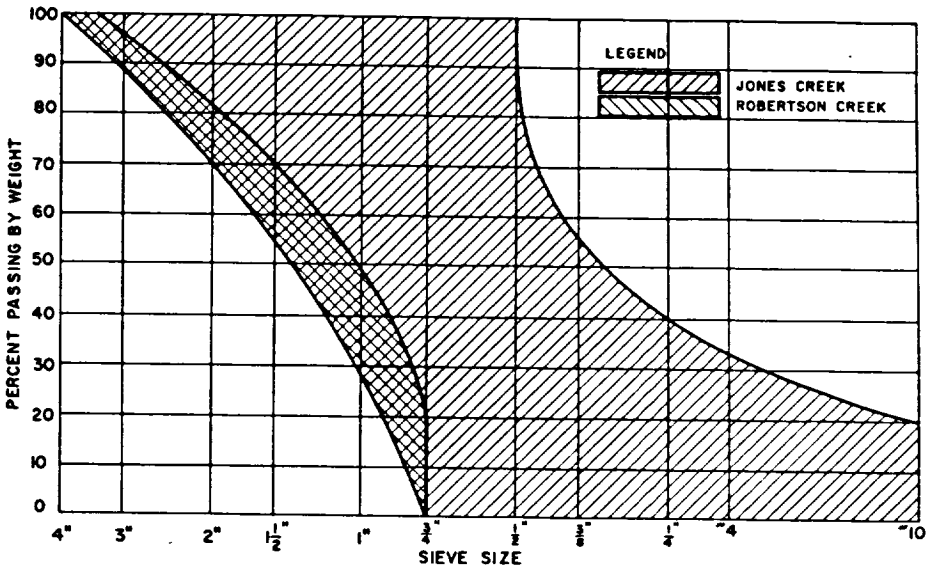

FIGURE 6.—*Grading Curve limits of spawning gravel at Robertson Creek and Jones Creek spawning channels.*

Drop Structures

As mentioned earlier, it was necessary to provide a total of four drop structures at intervals along the channel to localize the excess drop in the creek gradient.

Drop structures Nos. 1, 2 and 3 are very similar in design. The water surface drop at structures No. 1 and No. 2 is three feet, and at drop structure No. 3 varies from $2\frac{1}{2}$ to $5\frac{1}{2}$ feet, depending on the backwater effects from the experimental flume. They are constructed of reinforced concrete and consist of a large base slab from which are cantilevered the walls of the structure. The base slab is designed as a spread footing with full hydraulic uplift assumed. Prevention of sliding and control of underseepage at drop structure No. 1 is handled by a keyway and dowels into bedrock and at structure No. 2 by a concrete cutoff wall cut into the glacial till, while at drop structure No. 3 it was necessary to use interlocking steel sheet piling driven a minimum distance of ten feet below the base slab to meet this problem.

The drop, or crest, wall at each structure is 20 feet long and is divided into two sections by a centre pier. A pair of steel sector gates are affixed to the top of the crest wall to control the depth of flow in the channel reach upstream. When fully lowered, the top of these gates is the same elevation as the invert of the spawning channel immediately upstream. The gates can be raised a maximum of 14 inches from the fully lowered position by manually operated cranks which move a tandem coupled pair of rack and pinion mechanisms located at each end of the gates. Each gate is operated individually to allow finer hydraulic control. Rubber seals are supplied at the sides and bottom of the gates to prevent excess leakage and prevent any loss of fry. Figure 9 is a perspective view of a typical drop structure crest wall showing the sector gates and gate-lifting mechanisms.

FIGURE 7.—*Invert Controls being placed in position in middle spawning channel. Centre section removed to allow passage of gravel trucks.*

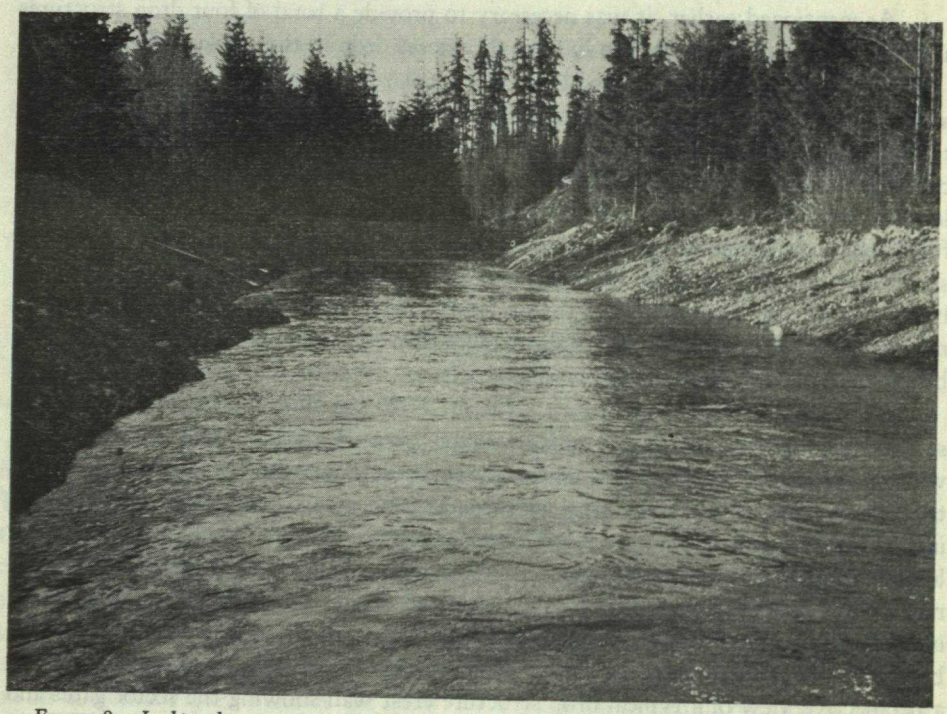

FIGURE 8.—*Looking downstream at completed upper spawning area with channel discharge at 100 cfs.*

Stoplog guides are located upstream of the gates on the crest wall to allow the insertion of vertical fish retaining screens to keep adult fish from leaving or entering each channel section when it is desired to hold them in certain sections. The stoplog guides will also allow the dewatering of one of the gates for maintenance or repair while channel flows are maintained through the second gate.

Inclined plane traps capable of passing the maximum channel flow of 250 c.f.s. are planned for all drop structures to provide for the collection and enumeration of downstream migrant juvenile fish. These traps will be fastened to the downstream side of the drop structure crests. Permanent livebox pits have been provided at each drop structure for the collection of downstream migrants from the inclined plane traps.

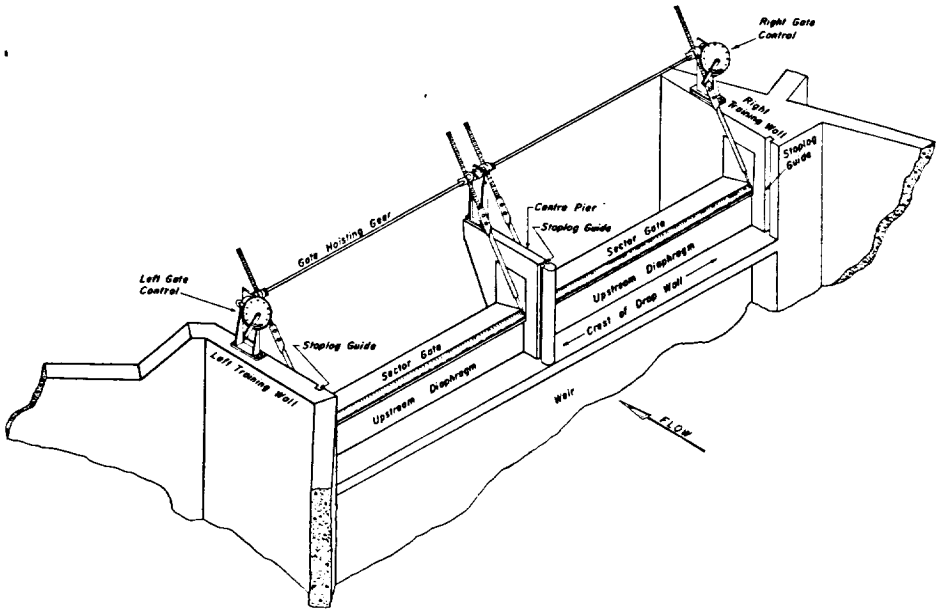

FIGURE 9.—*Typical crest wall of a drop structure showing sector gates and gate-lifting mechanisms.*

Each drop structure has been equipped with a pool and weir type fishway to provide for the natural migration of adult fish between each spawning section, if desired. Fish holding and collection works are also provided at drop structure No. 4, and these are described later. Fishways with four baffles each are provided at drop structures No. 1 and No. 2, while the fishways at drop structures No. 3 and No. 4 have five and nine baffles, respectively. Fishway pool size is six feet wide and eight feet long, with a four-foot minimum depth and a maximum pool differential of one foot. The concrete walls of the fishways are supplied with stoplog guides at baffle locations, and manually adjustable steel stoplogs are used to form the baffle weirs.

The fishway at each drop structure will also serve as a flow diversion channel if it is found necessary to dewater both sector gates or the weir crest of a drop structure without interrupting flow in the whole spawning channel.

A rock-paved stilling basin is provided below each drop structure to dissipate the hydraulic energy of the fall. Figure 10 shows a photograph of a typical drop structure in the upper sections of the spawning channel.

Drop structure No. 4 at the mouth of Robertson Creek is much larger than the other three structures and it also incorporates a fish holding and collection system. The water surface drop at this structure varies from $1\frac{1}{2}$ to $8\frac{1}{2}$ feet, depending on the stage of the Stamp River, which controls the water level at the mouth of the Creek. The normal water-surface drop at this point is about six feet. This drop structure and appurtenances is constructed of reinforced concrete and is of the same general design as the other three structures. The foundation at this point is gravel, and a steel sheet pile cutoff wall is provided to prevent sliding and underseepage. The crest of the drop wall is provided with the same type of adjustable sector gates as the other structures, however the drop wall, or weir, is skewed at an angle of 20 degrees from the perpendicular to the channel centreline to provide a more attractive flow pattern to the fishway entrance for fish approaching the drop structure. Since the water-surface drop over the structure will not always be sufficient to prevent fish from ascending into the channel by leaping over the weir, fish will be forced to use the fishway as their migration route by the provision of a blocking device on the drop structure crest in the form of an inclined plane screen which will also be used for enumeration of downstream migrant fish.

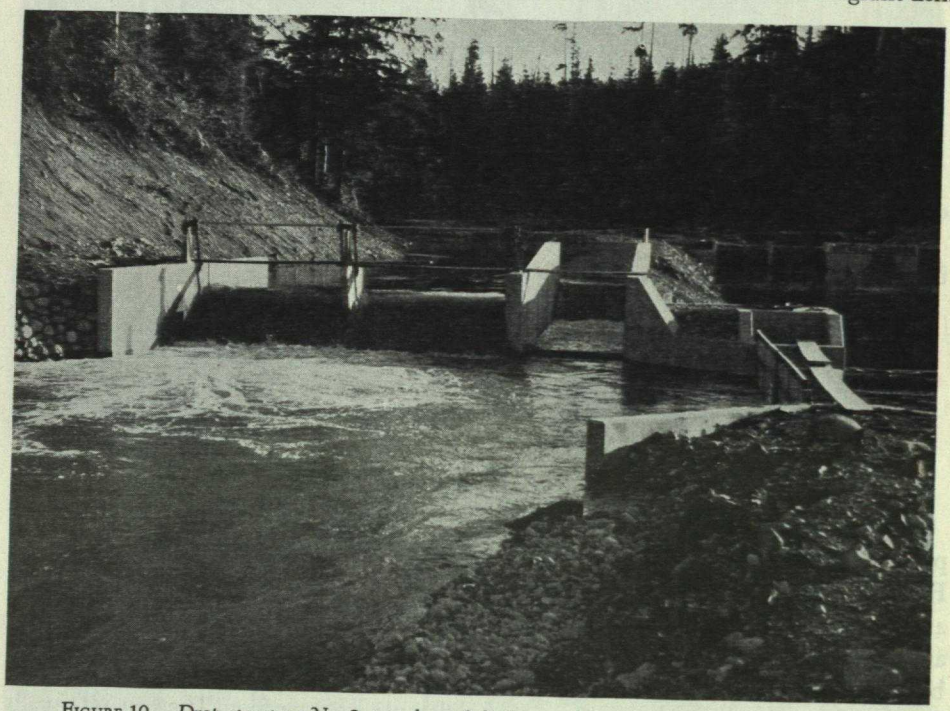

FIGURE 10.—*Drop structure No. 2 at a channel discharge of 100 cfs. Fishway not in operation.*

The fishway facilities at drop structure No. 4 are designed to either pass upstream migrant fish right through the structure and into the lower spawning channel, or to hold and collect these fish for transfer into a tank truck and thus enable placing of desired numbers, species, etc. into any of the three spawning areas.

Figure 11 shows an outline plan of drop structure No. 4. It can be seen that this structure is very similar to the other three as far upstream as fishway baffle 7, where the fishway broadens out into a combined holding and brail pool. At baffle 7 a finger

trap on the weir crest prevents adult fish from returning downstream. In the case where free movement of upstream migrating fish into the channel is desired, fishway baffles 8 and 9 will be in position and all fishway flow will originate from the fish exit. For the case when it is wished to collect fish for transfer to a tank truck, which is likely to be the case most of the time, all of the fishway flow will be admitted through a floor diffuser in the holding pool as regulated by a separate intake system.

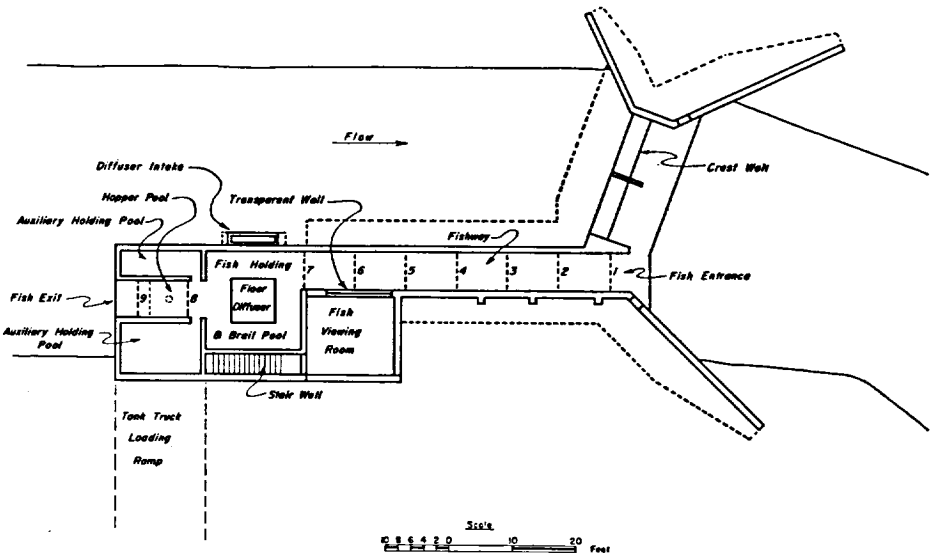

FIGURE 11.—*Outline plan of drop structure No. 4.*

The fish collection system is a simplification of those systems already used at several locations, such as on the Capilano River. The 15-foot square holding pool is equipped with an electrically-hoisted brail. The fishway between baffles 8 and 9 becomes the hopper pool and a steel superstructure carries an electric hoist and monorail enabling the raising and lowering of a six-foot square fish hopper from the fishway to a tank truck. When fish are to be moved from the holding pool, the brail will be raised and flow will be introduced into the hopper pool to create an attractive current. A system of screen gates between the brailing pool and the hopper pool will also enable the directing of fish into auxiliary holding pools in case sorting of several species of fish is required. Fish from these two auxiliary holding pools can later be transferred to the fish hopper by the operation of crowders and brails provided in these smaller pools. The designers have attempted to provide as much flexibility as possible in these facilities to provide for possible future experimental work, in addition to the more straightforward development requirements.

One additional feature of drop structure No. 4 which should be mentioned is the provision of a fishway viewing window on one side of one and one-half pools of the fishway. A closed-in fishway viewing room has been provided adjacent to this window. The window consists of a series of panels of one-inch thick acrylic plastic set in a structural steel frame. Provision has been made to replace the plastic with steel plate when the window is not in use. The purpose of the window is to allow the study of the relation of fish passage in the fishway to the hydraulics of various types of fishway

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baffles. The window covers a full wall of the fishway for one pool length downstream of a baffle, and one-half a pool length upstream. The stoplog guide provided at the baffle location will allow an easy interchange of various baffle types. It is expected that all-orifice fishway baffles will mainly be studied since observation will not be hampered by entrained air in the water. The fish viewing room is 14 feet long, which will allow the use of cinematography to record observations. A sump pump is provided to control seepage and a ventilation system will be used to control water condensation on the windows.

Flow Control Works

All flow through the spawning channel is controlled at the Robertson Creek dam. As mentioned previously this dam was constructed in 1957 by the MacMillan, Bloedel and Powell River Company in connection with the storage of water in Great Central Lake. The original outlet works at this dam provided a minimum discharge capacity of 35 c.f.s. at lowest lake levels through a 30-inch diameter gated pipe. To increase this minimum capacity to at least 100 c.f.s. at lowest lake levels and 250 c.f.s. at normal levels, the Department of Fisheries constructed an additional 48-inch diameter gated pipeline through the dam. This new pipe was constructed on the floor of the fishway at the dam, and since this fishway had a generous depth, it was possible to retain the fishway in good working order in the redevelopment at this site. A concrete apron was provided at the outlet of the new pipe to protect the toe of the dam from erosion by the enlarged flow. The Robertson Creek control dam may be seen in Figure 12.

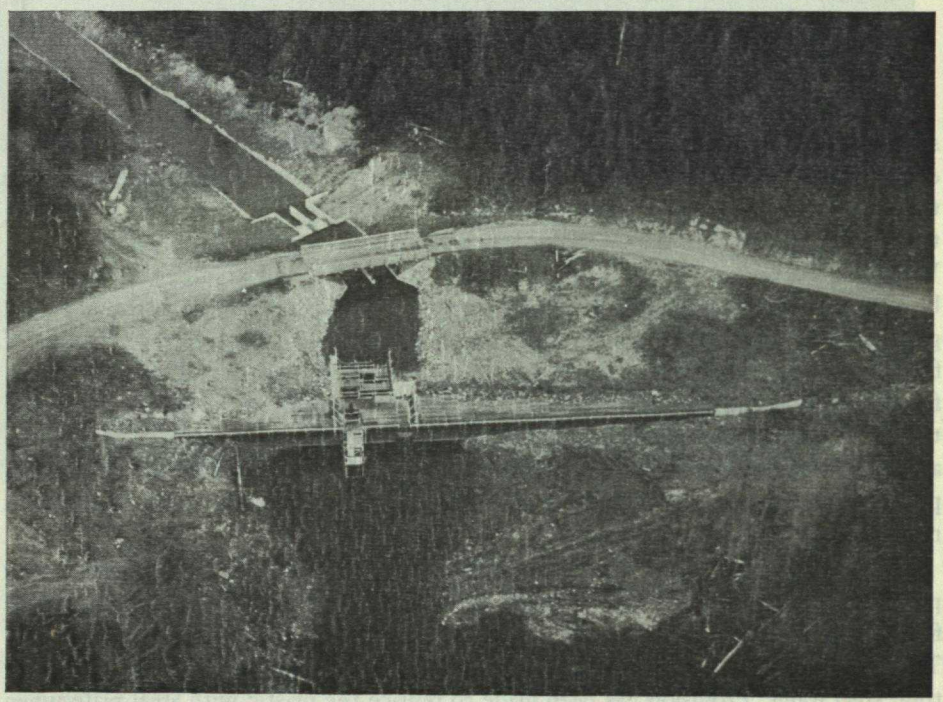

FIGURE 12.—*Aerial view of the upstream end of the spawning channel showing the control dam in the foreground, the highway bridge, the partially built downstream migrant diversion structure and a portion of the upper spawning channel.*

Downstream Migrant Diversion Structure and Flume

The downstream migrant diversion structure is located about 150 feet downstream of the Robertson Creek control dam, just below the highway bridge across the channel. The purpose of this structure is to prevent any downstream migrating fish which come through the outlet works at the dam from passing into the spawning channel proper and thus adulterating experimental stocks of fish. Large annual downstream migrations of sockeye and coho salmon yearlings have used this route in leaving Great Central Lake in recent years, and it is expected that their numbers will increase in the future with higher flows in Robertson Creek. The lake is also populated with steelhead trout (*Salmo gairdnerii gairdnerii*) and many other species of freshwater fish, thus the exclusion of these from the channel is also important to prevent predation on young salmon fry.

The fish diversion structure basically consists of two parallel reinforced concrete flumes, each containing a large inclined screen. The stream flow passes downwards through the screens and then passes through two large rectangular sluicegates set in the weir at the downstream end of the structure. The head on these sluicegates is two feet, or in other words the water surface drop over the structure is two feet. The upward inclined screens are each ten feet wide and $13\frac{1}{2}$ feet long, and are each made up of 30-inch wide by 10-foot long screen panels which can be individually rotated through 180 degrees to allow cleaning by backflushing action. About 10 c.f.s. of flow containing the downstream migrant fish will pass over the crest of the upstream screen where it will then fall through an inclined plane trap supplied with manually adjustable shutters. This trap will be operated so that not more than five c.f.s. of flow will be allowed into the collection trough along with the downstream migrants. Flow from the collection trough is led to a downstream migrant diversion flume which will be explained below.

The downstream migrant diversion structure design is based on the principles of the floating inclined plane trap or "scoop net" which is commonly and successfully used by biologists on the Pacific Coast for sampling runs of downstream migrant fish. The reason for passing more water than is needed for diversion over the crest of the trap screens and then providing an adjustable inclined plane trap to obtain just the required amount of flow for the bypass flume, is to overcome the problem of gross flow changes over the screen crest caused by partial clogging of the screens by debris between cleanings. The downstream migrant diversion structure can be seen in Figure 12.

In order to pass the downstream migrant fish around a portion of the spawning areas, a diversion flume is provided on the right bank of the spawning channel. This structure is a 30-inch diameter semicircular woodstave flume which is designed to carry a maximum flow of five c.f.s. A concrete transition section directs the flow from the collection trough of the downstream migrant diversion structure into the flume. The diversion flume is 2330 feet long and terminates just downstream of drop structure No. 3 where it spills into a stilling basin. It is necessary to return the downstream migrants to Robertson Creek at that point so that the sockeye and coho smolts in particular can pass on downstream through the experimental test flume where they are required for guiding studies. The fish pass through 600 feet of natural unimproved creek channel between the end of the diversion flume and the experimental test flume.

Thus downstream migrants entering Robertson Creek from Great Central Lake are bypassed around the upper and middle spawning sections, but do pass through the

lower spawning area. If required in the future, a diversion flume could be built from the inclined plane traps at the end of the experimental flume to the mouth of the creek to bypass the lower spawning area.

Experimental Rearing Facilities

Experimental rearing facilities are provided between drop structures No. 1 and No. 2 to enable study of the problem of rearing pre-migratory young salmon. The rearing sub-channels are so designed that they may also be used as small spawning channels for studies of adult spawning, or to provide a location for egg plants.

Permanent concrete inlet and outlet works are supplied for the rearing area, which has gross dimensions of 206 feet in length by 140 feet in width. This area will be sub-divided by gravel and earth dykes into four parallel sub-channels, or ponds. The adjustable weir crest at drop structure No. 2 and the individual pond inlet works provide a very flexible hydraulic control which will enable the diversion of any portion of the channel flow through these ponds. Screens at the inlet works will prevent the entry of any outside fish to the ponds and screens and inclined traps at the pond outlet works enable retention of fish in the sub-channels or enumeration of their emigrations. The total water surface drop through the rearing area inlets and outlets is three feet. Figure 13 shows a photograph of the experimental rearing facilities partially constructed.

FIGURE 13.—*Aerial view of partially constructed experimental rearing facilities looking downstream. Drop structure no. 2 at centre and middle spawning channel at top centre.*

Each of the four sub-channels is about 200 feet long and 20 feet wide. Provision has been made to make each of these channels divisible longitudinally into two equal parallel channels 200 feet long by 10 feet wide by the erection of a temporary centre partition. Provision has also been made for four lateral subdivisions in each pond to form four 50-foot long sections in either 20 or 10-foot widths. Timber beams resting on concrete footings have been provided on the sub-base of the rearing areas for these possible future divisions.

The sub-grade of the four sub-channels will be formed between earthen dykes, and 15-18 inches of standard spawning gravel, similar to that used in the regular spawning channel, will be placed on the sub-channel bottom and sides. Sub-channels Nos. 1, 2 and 3 are designed to carry a normal water depth of one and one-half feet, while sub-channel No. 4 has a normal water depth of three feet, nine inches. Figure 14 shows a plan of the experimental rearing area with the four sub-channel layout.

All these experimental installations are designed to have maximum flexibility so that a large range of studies can be made with a minimum of modification. However, if gross modifications were ever required, the rearing areas could easily be dewatered and the whole area excavated and redesigned without endangering the spawning channels downstream with silt, or interrupting the water supply.

Miscellaneous Structures and Works

Since the spawning channel passes underneath the Department of Highways bridge over Robertson Creek, revisions had to be made to the stream bed under the bridge to increase the discharge capacity of the channel. The two timber box culverts under the bridge were removed, the stream bed deepened several feet and a twenty-foot wide concrete flume structure built to protect the bridge pile bents from erosion. This revision can be seen in Figure 12.

A service bridge had to be built across the spawning channel about 1000 feet upstream of the mouth of the creek to provide access to the lower one-third of the channel. A thirty-foot span glue-laminated beam bridge designed for H-20 loading (20 tons) spanning between concrete abutments was constructed for this purpose.

A 700-foot long dyke and access road was constructed on the right bank of Robertson Creek upstream of the new service bridge. The dyke was necessary to prevent flooding of a large bush area adjacent to the channel, and the road on top of the dyke replaces the flooded-out access road along the B.C. Power Commission's Ash River transmission line which crosses the spawning channel at about its mid-point.

A chain-link security fence and gate are provided around the upstream end of the spawning channel to restrict vehicular traffic along the channel and to discourage unauthorized persons from tampering with equipment and works. It is eventually planned to place a shelter for a watchman-maintenance man at the gate when the biological programme at the channel fills out.

The 400-foot section of channel between drop structure No. 1 and the rearing pond inlets could not be developed into a spawning section because of unfavourable soil conditions. This area was formerly a swampy section of the creek and when channel excavation commenced it was discovered that this whole area consisted of rotted sawdust over ten feet thick in places. Obviously this material originated from the former

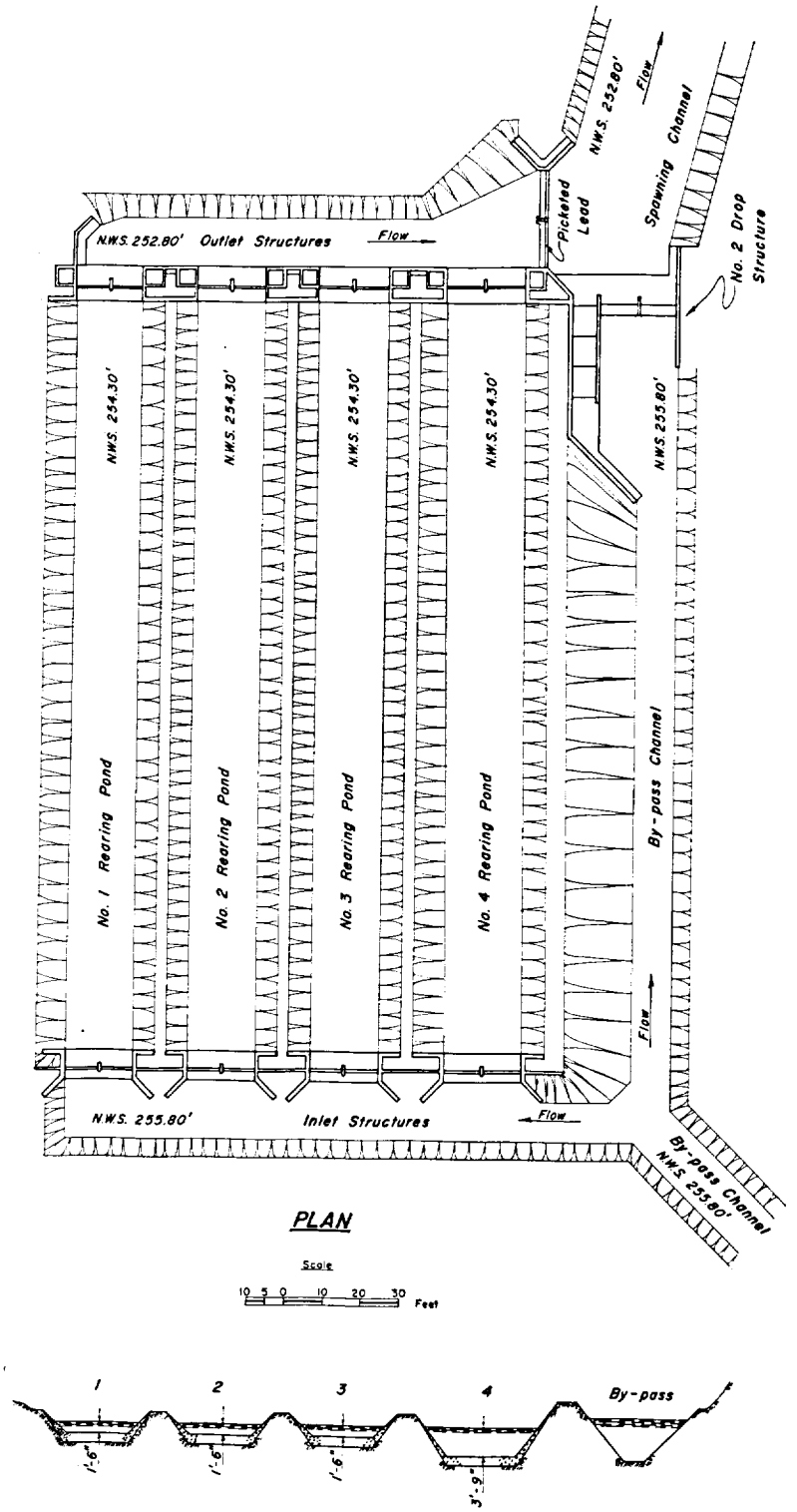

FIGURE 14.—*Plan and typical cross-section of experimental rearing facilities with four sub-channel layout.*

sawmill on Boot Lagoon. When no firm ground could be found on which to build a spawning channel, it was decided to merely excavate a deep bypass channel through this area, dimensioned so that average water velocities would not exceed one foot per second and thus prevent erosion. Excavation in this area proved to be very difficult, with large pads having to be used under all machines.

Since the discharge from the rearing area sub-channels would naturally attract upstream migrating adult fish, a picketed lead, or barrier, was constructed across the exit of the rearing pond outlets discharge channel. The picketed lead consists of a concrete base and piers supporting a vertical steel rack with the individual pickets angled so as to lead upstream migrants towards the fishway entrance at drop structure No. 2. The picketed barrier may be seen on Figures 13 and 14.

Experimental Test Flume

This structure, located about midway between drop structures No. 3 and No. 4, is not considered a part of the Robertson Creek Spawning Channel facilities. However it is mentioned here because its presence has governed the design of the spawning channel to a certain extent.

The test flume project was conceived one year before the spawning channel was proposed, however, when it was decided to proceed with the spawning channel, the construction of the two projects were integrated. The Fish Culture Development Branch has constructed the flume, however, the Fisheries Research Board of Canada has assumed about a one-third portion of the project's $72,000 cost.

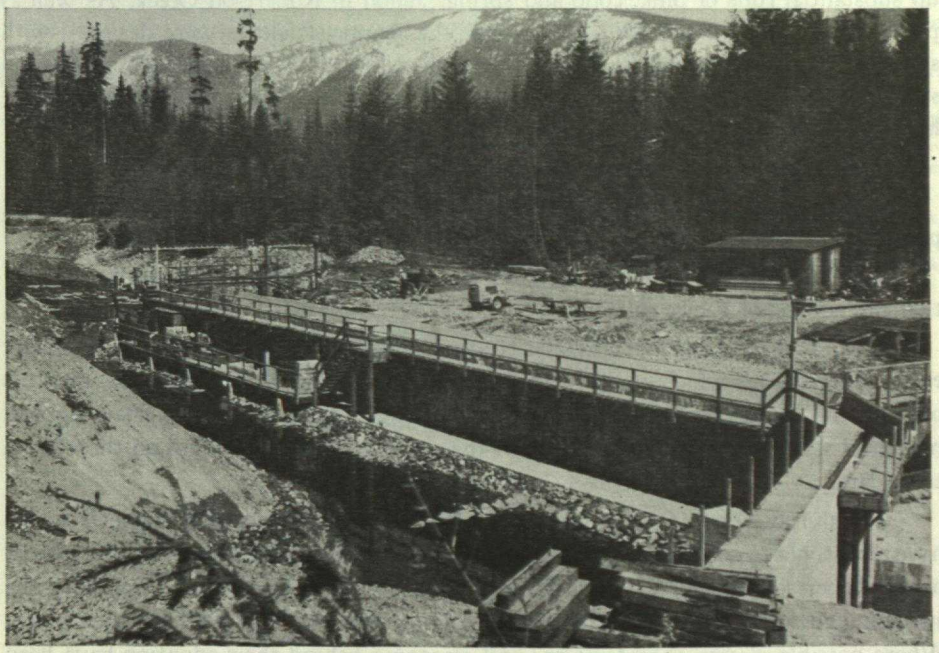

FIGURE 15.—*Looking downstream at the Robertson Creek Experimental Test Flume being prepared for 1960 louver studies.*

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The flume will be used by the Fish Culture Development Branch for the study and testing of canal-type downstream migrant fry and smolt guiding devices. Plans for 1960 and 1961 call for a continuation of the study of louvers begun at the Puntledge River test flume in 1957. Future work is tentatively planned on other types of screening and deflection apparatus, alternative types of bypasses, etc. Figure 15 shows a photograph of the flume as it was being prepared for the 1960 louver studies.

The Pacific Biological Station of the Fisheries Research Board of Canada plan on using the flume for the study of energy requirements of swimming adult fish. This work would also be a continuation of studies begun at the Puntledge River test flume in 1958.

Field Camp Facilities

A field camp to service the Robertson Creek Spawning Channel and Experimental Test Flume Projects will be complete by the summer of 1960. The camp consists of a living quarters and office to accommodate six men and a detached warehouse and fenced storage yard. The warehouse contains about 800 square feet of storage and work space and also has a room set aside as a small biological laboratory. The warehouse and storage yard share a two-ton travelling overhead hoist. Total cost of the camp facilities will be about $16,000.

Discussion and Summary

The immediate operational plan for the spawning channel is to introduce and build up substantial runs of pink, coho and spring salmon in Robertson Creek. As well as providing for this development programme, the channel facilities were designed with sufficient flexibility to enable the carrying out of a host of applied and fundamental studies aimed at overcoming current multiple water-use and fisheries development problems. The objectives of such studies might be as follows:

1. To assess, modify and improve fish culture techniques.

2. To investigate the conditions necessary for most efficient use of water in rearing pre-migratory young salmon.

3. To gain additional background information on the migration, spawning, incubation and rearing of Pacific salmon.

It is not in the scope of this paper to attempt to outline the possible biological and engineering studies which could be carried out to meet the above objectives, but it is obvious the list of possible studies would be long. The priority on certain applied biological studies is quite high and it is expected that work will begin on these at an early date.

The purpose of this paper has been to review salmon spawning channels which have recently been constructed and to describe the objectives and details of development of the Robertson Creek Spawning Channel. A detailed engineering description of the spawning channel and its appurtenant facilities as they stand in 1960 has been given. Where possible, design considerations and reasoning behind their adoption have been given.

The biological staff of the Fish Culture Development Branch have already begun to utilize the new spawning channel facilities. The preliminary results of the first project are reported by MacKinnon (1960) elsewhere in this issue.

Acknowledgments

The Robertson Creek spawning channel was the product of the combined efforts of several of the staff of the Fish Culture Development Branch in the Pacific Area.

Those associated directly with the project were J. P. Parkinson, project engineer on detailed design and construction, and P. Ryan on design and field supervision.

L. Edgeworth, senior engineer, was consulted because of his experience in the design of the Jones Creek channel. D. MacKinnon of the biological staff and R. E. McLaren, Chief Biologist, collaborated on the biological requirements. C. H. Clay, Chief Engineer, Pacific Area, was responsible for overall direction, and also read this report and made many helpful suggestions.

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A Successful Transplant of Salmon Eggs in the Robertson Creek Spawning Channel

by

D. MacKinnon

Department of Fisheries of Canada, Vancouver, B.C.

Abstract

A relatively large-scale eyed egg transplant of pink salmon into a newly-constructed spawning channel produced a fry output of 95% (91% of the number of eggs taken from fish). This extremely high survival is credited to near optimum conditions in the channel.

Introduction

One of the major objectives of the Robertson Creek spawning channel, described in detail by Lucas (1960) elsewhere in this issue, is to establish a population of pink salmon (*Oncorhynchus gorbuscha*) in the Somass River system. This river system, located in the Alberni area of Vancouver Island, B.C., supports well-established populations of all other species of anadromous Pacific salmon and steelhead trout (*Salmo gairdnerii gairdnerii*). The only major runs of pink salmon on the west coast of Vancouver Island occur in the northernmost part. Minor runs are present in a number of streams along the remainder of the west coast of Vancouver Island. Occasional sightings of pink salmon are reported in the lower reaches of the Somass river system in some years. This species has never been reported above the Stamp or Sproat River falls (Figure 1), where the major spawning grounds of spring salmon (*O. tshawytscha*), coho salmon (*O. kisutch*), sockeye salmon (*O. nerka*) and steelhead trout are located. These falls have always been partial barriers to coho, spring, sockeye and steelhead, and might have been total barriers to weaker swimming pinks. Well-designed fishways recently installed by the Department of Fisheries at these falls have made upstream passage relatively easy.

It is not known whether pink salmon were once present in large numbers in this system and for some reason have declined to negligible numbers. It may be that this river has never supported a large population of this species. It is believed, however, that if a population of pink salmon could be established in this river such that some of their numbers would distribute themselves through the upstream area of the system, it could successfully maintain itself, as have the populations of the other species in this river system. It appears to be a characteristic of this species to remain at low population levels after the numbers in one generation have been reduced below a "recovery level". The existence of barren years in pink salmon streams is a common phenomenon. One possible explanation of this is that the rigid two-year life span, unique to this species, precludes recruitment from other cycle years. It seems evident that the small numbers of pinks in the lower reaches of this river will never establish themselves in numbers large enough to fully utilize the potential of this system without the aid of fish culture measures.

The Department of Fisheries has considered the possibility of establishing pink salmon in this system for some time. The construction of the Stamp River falls fishway in 1955 and the Robertson Creek spawning channel in 1959-60 made the project appear feasible. Consequently, large-scale transplants of pink salmon eggs were planned to be made each year for at least two and possibly four consecutive years in the Robertson Creek channel. Since the subaqueous portions of the channel were to be completed and flows could be provided by late October 1959, an eyed egg transplant was possible in that year. The remainder of the construction schedule was such that the migrating fry could be counted out of the channel before flows in the channel were reduced in late April 1960.

This part of the programme has been carried out and the purpose of this paper is to report the success of the transplant to the present stage.

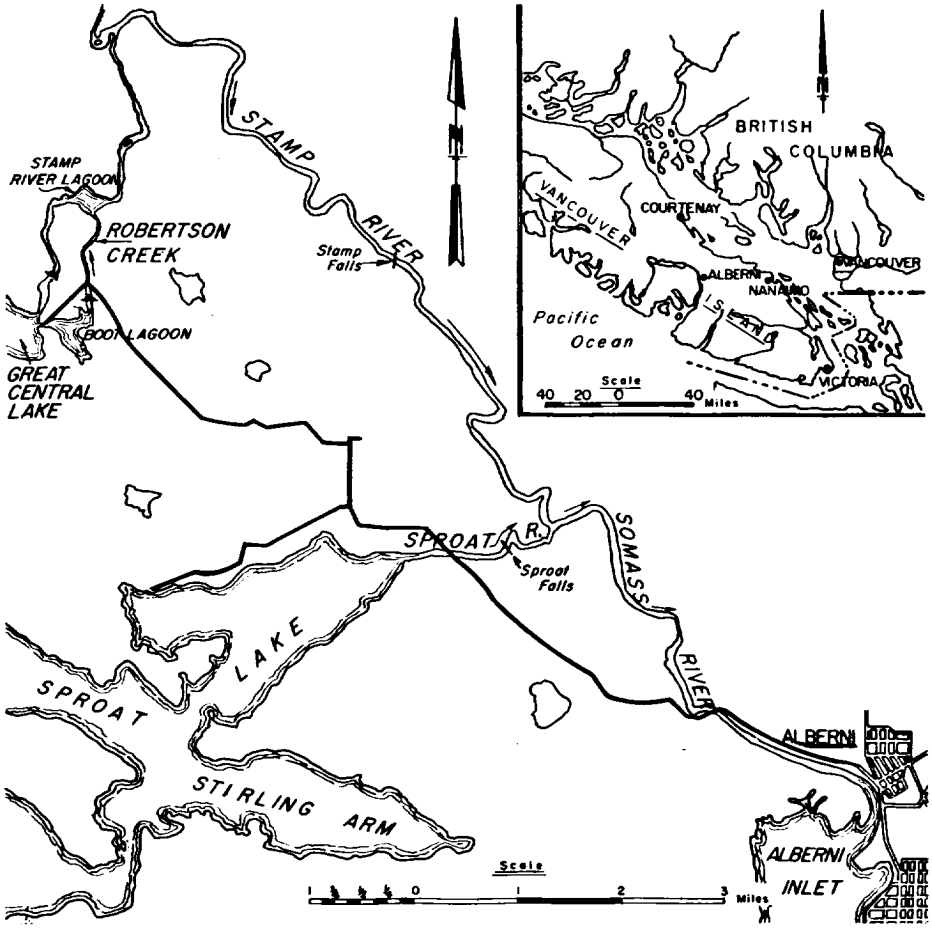

FIGURE 1.—*A portion of the Somass River System showing the main rivers.*

Methods

It was planned that all eggs for this transplant would be taken from the usually large pink salmon escapement to the Tsolum River near Courtenay on Vancouver Island, B.C. Collecting facilities were installed at the counting weir near the mouth of this river and egg taking operations began. However, a small escapement to the Tsolum (approximately 15 per cent of the expected) necessitated moving the egg-taking operations to the Indian River in the North Arm of Burrard Inlet near Vancouver. As a result of the failure of the Tsolum River plans and difficult conditions for taking eggs on the Indian River, approximately 1.7 million eggs were collected instead of the 3·5 million originally planned.

The eggs were stripped, fertilized, and water hardened in the conventional manner. Five-gallon tinned cylindrical cans were used for egg transport. First these cans were filled with water to overflowing, the fertilized eggs were entered to replace the water to the $\frac{3}{4}$ mark on each can, then covered with tight-fitting lids. Between September 23 and October 14, 1959, the eggs were transported to the Puntledge Hatchery[1] near Courtenay, Vancouver Island, B.C. by means of either boat and truck or aircraft and truck. The eggs were gently stirred once an hour during transportation and the water lost through stirring was replaced. In all cases the eggs were in the hatchery by the evening of the day they were removed from the fish.

At the hatchery the eggs were placed in 16″ × 24″ wire baskets and placed in water-filled troughs. The inflow taps and outflow pipes were regulated so that six gallons of water per minute were flowing to cover the eggs with two inches of water. Eash basket held approximately 24,000 eggs and each trough held 6 baskets. One application of eight fluid ounces of malachite green was applied to each trough each day from a stock solution prepared by dissolving one-half lb. of malachite green into five gallons of water. Dead eggs were counted and recorded throughout the operation to determine the hatchery and transportation mortalities.

Eggs were held in the hatchery until they were distinctly eyed. This took approximately eight to ten weeks at temperatures ranging between 33° F. and 51° F. The eyed eggs were then hazed and dead eggs were removed prior to packing in standard egg trays and shipping cases. A measuring container was calibrated by averaging the counts of the number of eggs in this container filled three times. The trays were then lined with cheesecloth and filled with a measured number of eggs. Each tray held an average of 4176 eggs (actual sample counts: 3993, 4215, 4320) and each shipping case held 13 trays. The loaded cases were thoroughly soaked with water and transported the 75 miles to Robertson Creek by truck.

The eggs were planted across the 35-foot width of the channel in trenches three feet apart dug to a depth of 12 to 16 inches. During planting the water flow was temporarily reduced to provide a water depth of approximately one inch. This flow was sufficient to provide an exchange of water in the planting trenches without sweeping the eggs downstream. The eggs were poured from the trays underwater into the trenches at the rate of approximately 4000 per linear yard of trench. Ten trays of eggs were placed in each trench row and carefully covered with gravel. Since the centres of the

[1]*The Puntledge River hatchery facilities were loaned to the Department of Fisheries through the courtesy of the Provincial Department of Recreation and Conservation.*

planting rows were three feet apart, the density of planting was approximately 4000 eggs per square yard. The eggs were planted in three lots to insure that they were well eyed before planting. The following planting schedule was followed:

Nov. 18th, 1959	298,718 eyed eggs
Nov. 27th, "	750,732 " "
Dec. 3rd, "	592,206 " "
Total	1,641,656 eyed eggs

Of this total, 376,530 eggs were collected at the Tsolum River and the remainder were taken at the Indian River.

During the planting each of four baskets (10 meshes to the inch of wire screening) measuring 5" × 5" was filled with channel gravel containing 200 eggs. These were sealed and planted in representative sections of the channel. In addition, one large basket measuring 12" × 12" × 18" was filled with gravel containing 1000 eggs. This basket was planted in mid-stream. At the completion of planting the intake gates to the channel were set to allow an inflow of approximately 20 c.f.s. This flow was the maximum permissible in the channel at the existing stage of construction and it provided a water depth of six to eight inches with a surface velocity of one to 1.3 ft./sec.

One of the basket plants was removed January 21, another on February 6, and a third on February 19, 1960. The remaining small basket and the large basket were removed on April 22 at the completion of the fry migration. These egg samples were examined for survival and the progress of incubation. Additional checks were made by digging into the planting rows on February 6 and on March 1.

Surveys of the river system were made in September, 1959. Attention was paid to the portion of the lower river where occasional sightings of adult pink salmon had been made in previous years. Attention was also paid to certain points in the river where pink salmon, if present, would be observed. Since adult pink salmon were not seen at these points in 1959 it is felt that evidence of this species anywhere in the system in 1961 may be considered a result of the transplant.

On March 15 a Wolfe-type fry trap was installed approximately 1000 ft. downstream of the planting area. All fry were trapped as they migrated out of the area. These fry were counted during the early part of the migration and estimated by weighing when the runs increased. All fish that were not counted were weighed in 210-gram lots and released. Periodically throughout the night's run one of the 210-gram samples was counted. The average of these samples counted during the night was multiplied by the number of weighings for that night to provide an estimate of the total night's migration.

Results

The mortality of eggs from the time they were collected until they were eyed in the hatchery totalled 3.9 per cent. An additional 0.2 per cent mortality was recorded during packing and transporting to the planting site.

Sampling of the planted area on February 6 and March 1 failed to reveal any dead eggs or alevins. Several live alevins were observed in each of these separate samples.

The following analysis of the basket plants provides a good indication of the survival rate, the time of hatching, and the stage at which losses occurred.

Jan. 21, 1960	live eggs	119
	live alevins	62
	dead eggs	16
	dead alevins	3
	Total	200
Feb. 6, 1960	live eggs	0
	live alevins	185
	dead eggs	9
	dead alevins	6
	Total	200
Feb. 19, 1960	live eggs	0
	live alevins	186
	dead eggs	11
	dead alevins	3
	Total	200

Table I

Estimations of the Nightly Emigration of Pink Fry from Robertson Creek Channel, 1960.

Date	Total No. of Weighings	No. of Samples Counted[1]	Average No. Fry Per Sample	Range	Estimated Nightly Migration
Mar. 15–28	—	—	—	—	541
Mar. 28–Apr. 4	—	—	—	—	44,751
Apr. 4–5	81	9	700	676–731	61,584
5–6	89	9	697	663–750	68,176
6–7	140	5	731	700–772	105,761
7–8	154	8	775	743–828	124,030
8–9	100	8	756	706–783	81,740
9–10	113	7	775	739–819	93,472
10–11	243	9	755	719–800	183,462
11–12	200	8	767	705–803	153,695
12–13	271	7	777	746–817	210,567
13–14	244	8	784	746–836	192,710
14–15	118	7	784	724–833	93,790
15–16	106	6	775	752–798	77,550
16–17	48	5	705	668–753	30,340
17–18	20	3	720	681–746	12,280
18–19[2]	—	—	—	—	11,138
19–20	—	—	—	—	9,996
20–21	—	—	—	—	2,251
21–22	—	—	—	—	1,135
Total	1927	99	10,501	9967–11,069	1,558,969
Average	138	7	750	712–791	

[1] *The actual counts of samples were added to night's estimates.*
[2] *The trap was removed for construction purposes. The night's migration was estimated by interpolation.*

Examination of the contents of the baskets removed at the completion of the run showed that the majority of the live fry had escaped. The smaller basket contained four dead eggs, one dead fry and 52 live fry and the larger basket contained 15 dead eggs, one dead fry and 58 live fry.

The first fry was trapped March 15, but significant numbers did not migrate until March 28. The size of the nightly migrations remained at a relatively low level for the following week. Virtually all of the fry moved out of the channel during the 13-day period between April 4 and April 16. Table 1 gives the nightly estimates of fry output along with the sampling information used in the calculation of these estimates. The total output of 1,558,969 fry represents a survival of approximately 95 per cent from the eyed egg stage to migrating fry. When hatchery and shipping losses are considered the total survival from eggs stripped from the adult fish to migrating fry is approximately 91 per cent.

Discussion

Survival from egg to fry recorded from naturally spawning pink salmon in British Columbia streams has varied from about one per cent to 23 per cent. It is generally accepted that the pink fry output from an average stream is approximately 10 per cent. The survival from both eggs deposited by naturally-spawning fish and transplanted eggs in the controlled spawning channel at Jones Creek was 37 per cent. (Hourston and MacKinnon, 1956), (Neave and Wickett, 1955).

The exceptionally high survival of the Robertson Creek transplant leads to the conclusion that conditions in the channel were very close to optimum for survival of eggs, alevins and emerging fry. Additional evidence of good conditions for survival is suggested by the fact that a number of abnormal fry were recorded during the trapping and sampling of the migration. Fry with grossly deformed bodies, Siamese twins, and albinos survived and emigrated from the spawning area. In natural streams the morphologically deformed fry generally do not survive emergence from the compacted gravel and the albinos are believed to be readily taken by predators.

The most obvious conditions that can be credited with the high survival in this channel are porosity and controlled flow. Good porosity is essential to supply oxygen to and remove waste products from the developing eggs and alevins. Mortality from physical damage and suffocation during emergence is also reduced in loose clean gravel. Controlled flow precludes mortality from scouring and insulates developing eggs and alevins from some of the deleterious effects of the winter environment. While it is logical to credit the high survival to these factors it is possible that more obscure factors may also have contributed. It is probable that this newly-constructed channel is relatively free of disease-producing bacteria and fungi as well as vertebrate and invertebrate predators of eggs and fry. An interesting thesis in this respect is that if these organisms depend upon dead and decaying eggs and fry to become established in a stream, the high survival of egg to fry recorded here, may never allow these organisms to increase to a level sufficient to cause significant mortalities.

Comparison of this channel and the channel at Jones Creek allows assessment of the reasons for the increment of survival at Robertson Creek that was greater than the 37 per cent recorded at Jones Creek. The most important difference is believed to

be the larger gravel in the Robertson Creek channel. The gravel in Robertson Creek ranges in size from three-quarters of an inch to four inches in diameter, while that of Jones Creek ranges in size from one-quarter to one and one-half inches. Another important difference is the clearer water entering the Robertson Creek channel. Water is supplied to this channel at a dammed outlet of a lake. Water entering the Jones Creek channel passes through a valley characterized by clay banks. Much of the silt carried in this water is deposited on the channel streambed. A third feature that could explain higher survivals in Robertson Creek is the moderate winter conditions. The Jones Creek channel generally freezes over in the winter and ice forms at the baffles located every 100 feet in the channel. Besides altering the hydraulics of the channel this ice can scour alevins out of the gravel during spring breakup. These three differences are believed to provide the best explanation of the differences in survival. Most other features affecting survival are common to both channels.

The immediate significance of the excellent results of this transplant is that the chances of success in establishing a population of pink salmon in the Somass River system have increased. There are, however, still many factors governing the survival from fry to the return of adults, and a transplant of this size even with good survival in future stages can only be expected to provide the nucleus for an established pink run of commercial value.

These results have added significance in the field of fish culture methods. The density of planted eggs was at least twice that possible by naturally-spawning fish. To duplicate this deposition of eggs approximately 2000 pink salmon would have to spawn in a little more than 400 square yards of stream. If this were physically possible it is probable that production would be greatly lowered.

At present the most widely practised substitute for natural spawning is hatchery propagation. Most authorities agree that hatchery-raised fry are considerably less viable in nature than naturally-produced fry. However, one of the better attributes of hatcheries is that they generally achieve high survival of fry. If future survivals in this channel continue to be as high as that of hatcheries, and if the fry from the controlled channel prove to be more viable in nature than those produced in present day hatcheries, then this method of propagation might be considered as an alternative to hatcheries in some situations.

Acknowledgments

The field supervision of this project was shared by Biologists F. C. Boyd, I. S. Todd and W. J. Schouwenburg. R. E. McLaren, Chief Biologist, Pacific Area, Fish Culture Development Branch, aided in the planning of the project and the editing of the paper.

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A Field Experiment to Determine the Effect upon Coho Salmon Fry (*Oncorhynchus kisutch*) from Spraying Sawlogs with an Emulsified Mixture of Benzene Hexachloride

by

K. J. Jackson

Department of Fisheries of Canada, Vancouver, B.C.

Introduction

Field experiments designed to determine the toxic effects on salmon fry resulting from aerial applications of emulsified benzene hexachloride sprays, to control infestation of log booms by Ambrosia beetle, were carried out in June, 1958. Assistance in carrying out this programme was received from personnel of the Fish and Game Branch, British Columbia Department of Recreation and Conservation, and MacMillan and Bloedel Company Limited. Bioassays on chum salmon fry held in sea water solutions of benzene hexachloride were also carried out by Fisheries Research Board of Canada personnel of the Pacific Biological Station.

Log booms in Alberni Inlet, in salt water, and at Sproat Lake, in fresh water, served as sites for the field experiments, Figure 1. Stormy weather immediately preceding spraying in Alberni Inlet destroyed experimental equipment and forced the abandonment of the field experiment at the salt water location. The experiment at Sproat Lake was successfully concluded and is reported below.

Method

Eight shallow floating liveboxes, each containing 15 coho salmon fry were placed in one section of an eight section boom of sawlogs. The liveboxes were made of two 18″ × 24″ pieces of $\frac{3}{8}$″ plywood joined together along the long edge in the shape of a V. The ends were screened with fly screen as shown in Figure 2. To provide buoyancy two pieces of 4″ × 4″ cedar were attached as shown in Figures 2, 3 and 4.

In addition to the shallow liveboxes a large rectangular livebox, one foot square on top, five feet deep, and divided vertically into five compartments of one cubic foot each, was placed within the experimental section of the boom in such a manner that the top compartment was just below the water surface. The bottom compartment was weighted to make the livebox float upright. Ten coho fry were placed in each compartment.

Control specimens were held in five floating triangular liveboxes, joined together and placed in a small protected bay a safe distance from the experimental area. Each livebox contained 15 coho fry, yielding a total of 75 control specimens.

Four floating triangular boxes were moored between logs within the experimental boom, being placed at approximately equal distances from one another across the width

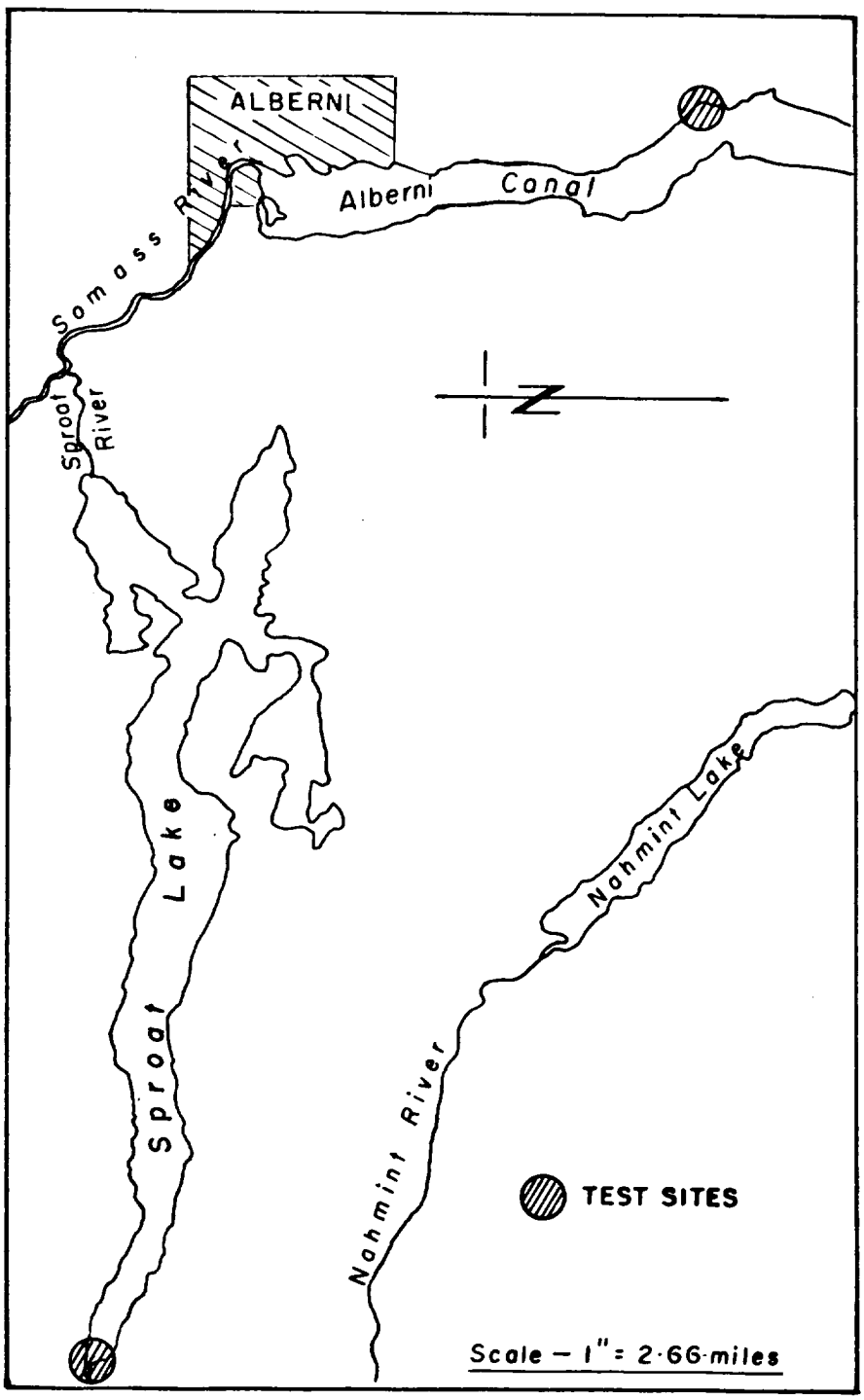

FIGURE 1.—*Map showing the location of experimental sites.*

of the area. Four floating liveboxes were moored between 2″ × 4″ members nailed to and projecting from the peripheral logs. In the results liveboxes moored within the boom are referred to as *inside* (I) and peripheral liveboxes are referred to as *outside* (0). In plan the placement of liveboxes is illustrated in Figure 5.

The aircraft approached from an easterly direction and in several passes discharged the spray material from a height of about 20 feet above the boom (Figure 6). Conditions for spraying were excellent. There was no wind and the water surface was very calm.

The liveboxes in the experimental area were examined as soon as possible after spraying had finished, and the number of fish remaining alive was noted. Water samples for quantitative analysis of benzene hexachloride content were obtained from each floating livebox at the times of the above observations. These were transferred to an insulated box containing dry ice, and taken to Port Alberni where they were frozen solid in a commercial deep freeze to prevent decomposition of benzene hexachloride prior to analysis. The samples were then transported from Port Alberni to Nanaimo in a frozen state and transferred to the Pacific Biological Station where they were re-refrigerated. The analyses were performed by Dr. M. Waldichuk of the Fisheries Research Board. The results are reported as concentrations of the gamma isomer of benzene hexachloride.

Results

The results of holding coho fry in liveboxes exposed to spray materials and the quantitative analyses for the benzene hexachloride content of water samples taken at various intervals from the liveboxes are presented in Tables I, II, III and IV.

Table I

Number of coho fry remaining alive after exposure to spray material in the shallow floating live boxes after various intervals of time.

Livebox Position	0 minutes	+ 15 minutes	+ 32 minutes	+ 105 minutes	+ 9½ hours
1–0	15	0	0	0	0
2–0	15	0	0	0	0
3–0	15	0	0	0	0
4–0	15	0	0	0	0
1–1	15	0	0	0	0
2–1	15	0	0	0	0
3–1	15	0	0	0	0
4–1	15	5	3	3	0

Table II

Number of coho fry remaining alive after exposure to spray material in the vertical livebox after various intervals of time.

Depth below surface	0 minutes	+ 120 minutes	+ 9½ hours
0′–1′	10	1	1
1′–2′	10	10	10
2′–3′	10	10	10
3′–4′	10	10	10
4′–5′	10	10	10

Table III

Number of coho fry remaining alive in the floating "control" liveboxes after various intervals of time.

0 minutes	+ 50 minutes	+ 165 minutes	+ 9¼ hours
75	75	75	75

Table IV

Results of analyses of benzene hexachloride from water samples obtained at various intervals of time from the floating triangular liveboxes.

"Inside" Liveboxes			"Outside" Liveboxes		
Livebox Number	Gamma Isomer (in ppm)	Time	Livebox Number	Gamma Isomer (in ppm)	Time
1–I	1.43	0 + 15 mins.	1–0	1.43	0 + 15 mins.
2–I	1.25	"	2–0	1.60	"
3–I	1.25	"	3–0	1.29	"
4–I	1.60	"	4–0	1.25	"
Average—1.38 ppm.			Average—1.39 ppm.		
1–I	0.338	0 + 32 mins.	1–0	0.165	0 + 32 mins.
2–I	0.448	"	2–0	0.416	"
3–I	0.428	"	3–0	0.544	"
4–I	0.225	"	4–0	0.934	"
Average—0.360 ppm.			Average—0.515 ppm.		
1–I	0.079	0 + 105 mins.	1–0	0.074	0 + 105 mins.
2–I	0.093	"	2–0	0.078	"
3–I	0.126	"	3–0	0.050	"
4–I	0.024	"	4–0	0.085	"
Average—0.081 ppm.			Average—0.072 ppm.		
1–I	0.032	0 + 10 hrs.			
2–I	0.036	"	2–0	0.033	0 + 10 hrs
Average—0.034 ppm.			Average—0.033 ppm.		

To illustrate the nature of the decrease in benzene hexachloride concentration with respect to time, the average concentrations of benzene hexachloride obtained in the inside series of floating liveboxes were plotted against time. The resulting graph is shown in Figure 7.

After two hours the entire experimental boom was examined carefully to determine whether any fish "holding" under the boom had been affected. No living or dead fish were noted. On previous occasions small numbers (two to four) fry had been seen under the booms at a depth of about four feet.

Discussion

All control specimens remained alive, and after 9½ hours all experimental specimens in the floating liveboxes had died. The method of presentation of the results would appear to indicate that all of the fish in the floating triangular liveboxes except 4-1 had died in 15 minutes. It took fifteen minutes, however, to complete the circuit of the liveboxes, to obtain water samples and to record observations. It is likely therefore that the mortality of the coho fry took place in less than 15 minutes. The fish in the first floating livebox examined (1-0) were either dead or had lost their equilibrium when first examined three to four minutes after spraying had finished. At this time water within and surrounding the liveboxes was noticeably "milky". This water condition was judged to have persisted for less than 15 minutes.

It is noted that the survival of fry in the rectangular vertical livebox was very different from those held in the shallow triangular liveboxes. All but one fish held in the top (0-1 ft.) compartment died. All fish in the lower compartments survived, suggesting that a density differential or dilution prevented toxic concentrations of spray materials from reaching fish held at depths of more than one foot below the surface.

The results of the water sampling shown graphically in Figure 7 show that the dilution trend was curvilinear; that a very rapid dilution took place at first and that small concentrations of benzene hexachloride remained in the water surrounding the boom for as much as 10 hours.

The gamma isomer of benzene hexachloride is quoted to be toxic to fish at concentrations as low as 0.05 ppm. and trout fingerlings were disabled by concentrations as low as 1 ppm.[1] On the basis of bioassays carried out with chum salmon fry held in salt water solutions of benzene hexachloride, the suggested "safe" level of mixed isomers was 0.01 to 0.025 ppm.[2] Table IV shows the average concentration of benzene hexachloride (gamma isomer) as much as fifteen minutes after spraying had ended was 1.38 to 1.39 ppm., which is greatly in excess of the cited "safe" level and also exceeds the concentrations cited to be toxic to trout.

Mr. H. Richmond, entomologist with MacMillan and Bloedel, stated that the quantity of gamma isomer applied in this experiment was 12.3 lbs. over eight sections, or 12.3 lbs. per 34,848 square feet. It has been noted that only the coho fry held in the top compartment of the vertical livebox died. The remainder lived. For the purpose of obtaining an approximation of the initial dosage of benzene hexachloride, it was assumed that the spray material was confined to a hypothetical layer of water extending to one foot below the surface. A calculation establishes that the *average* concentration of benzene hexachloride in the hypothetical surface layer would initially have been

$$\frac{12.3}{34{,}848 \times 62.4} \times 10^6 = 5.6 \text{ ppm.}$$

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[1] *Water Quality Criteria. State Water Pollution Control Bd., California, 1952.*

[2] *Resistance of Chum Salmon Underyearlings to Hexachlorocyclohexane in Sea Water. Alderdice, D. F., Fisheries Research Bd. (Unpub.)*

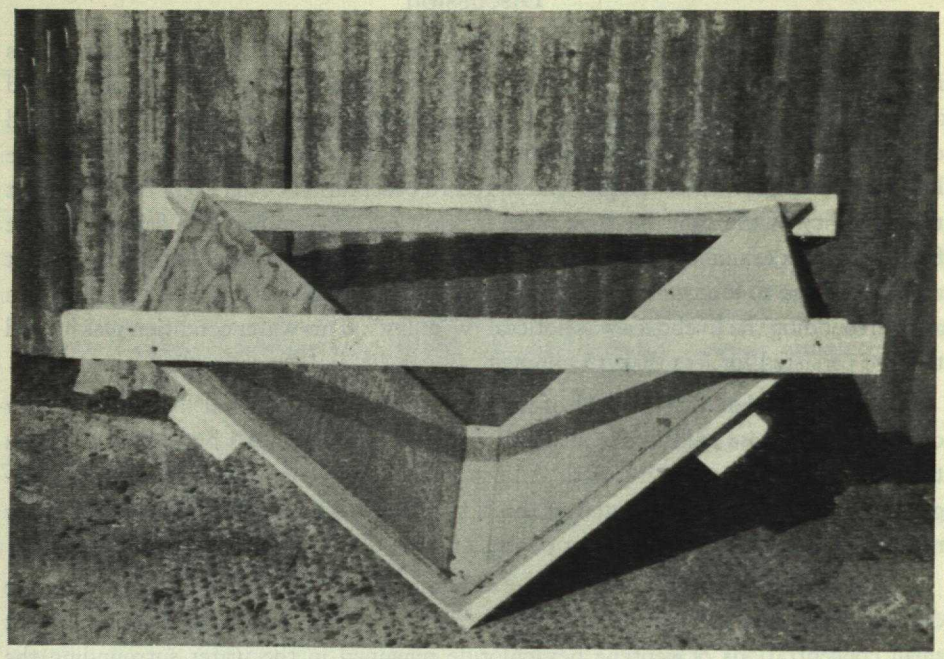


FIGURE 2.—*A typical floating triangular livebox.*

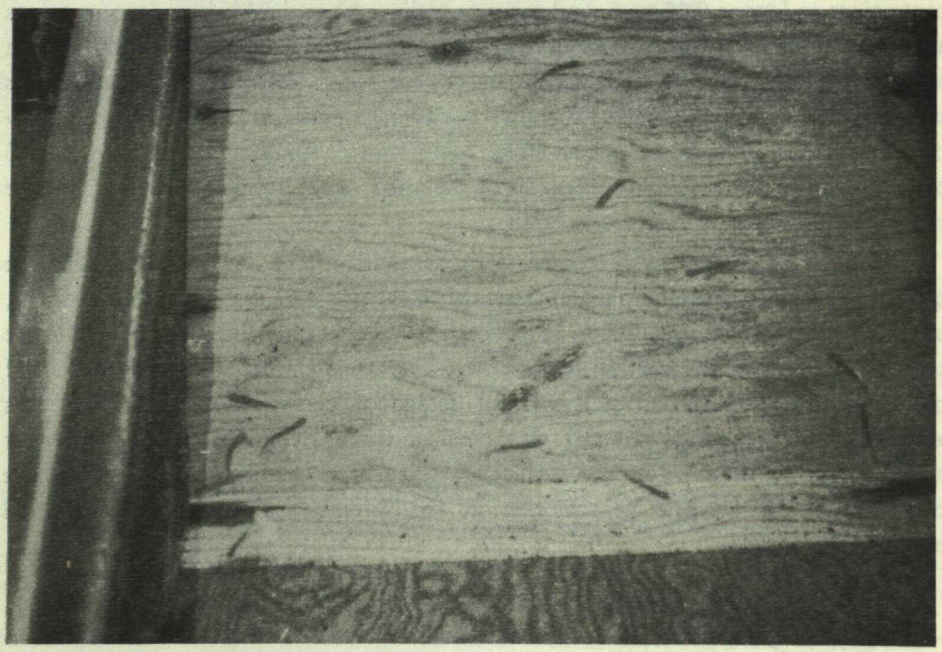


FIGURE 3.—*Coho fry held in a floating triangular livebox.*

FIGURE 4.—*Floating triangular liveboxes on the periphery of the log boom in Sproat Lake.*

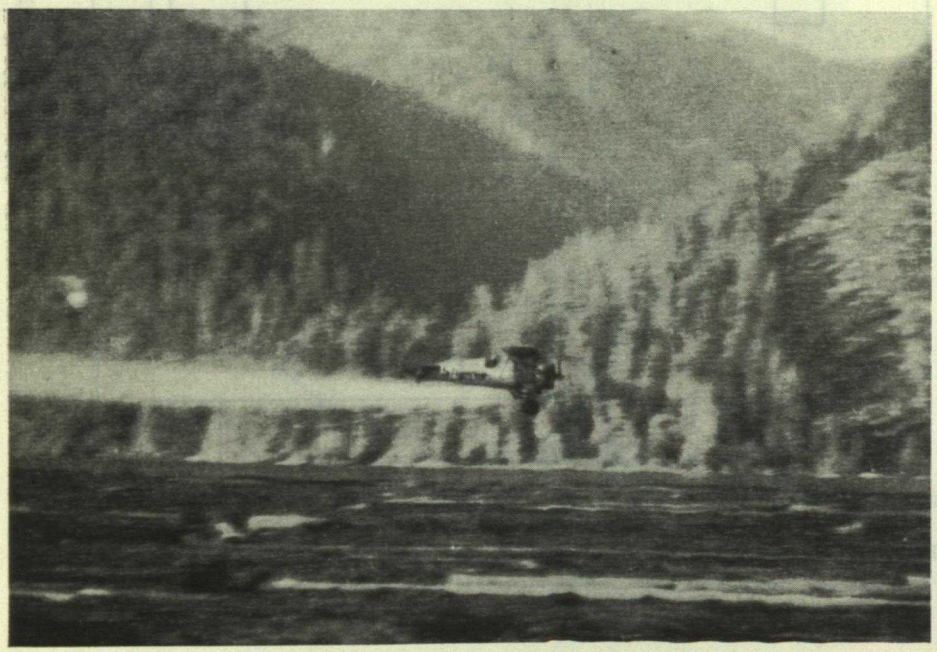


FIGURE 6.—*Aircraft applying spray on the experimental boom in Sproat Lake.*

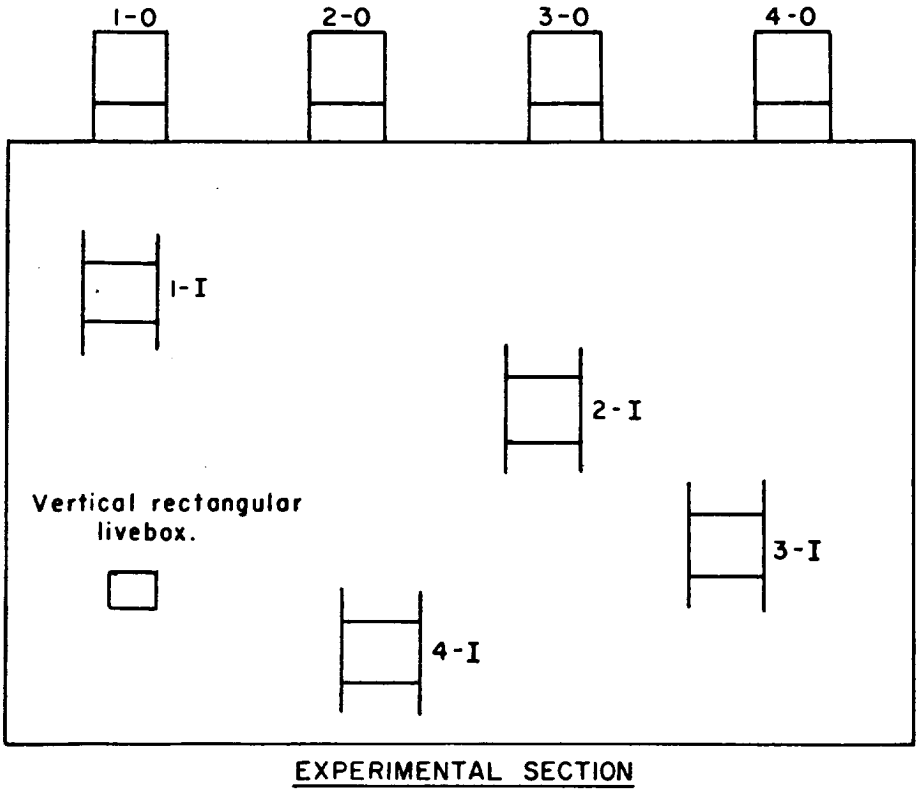


FIGURE 5.—*Diagram showing the placement of triangular floating liveboxes within the boom at Sproat Lake.*

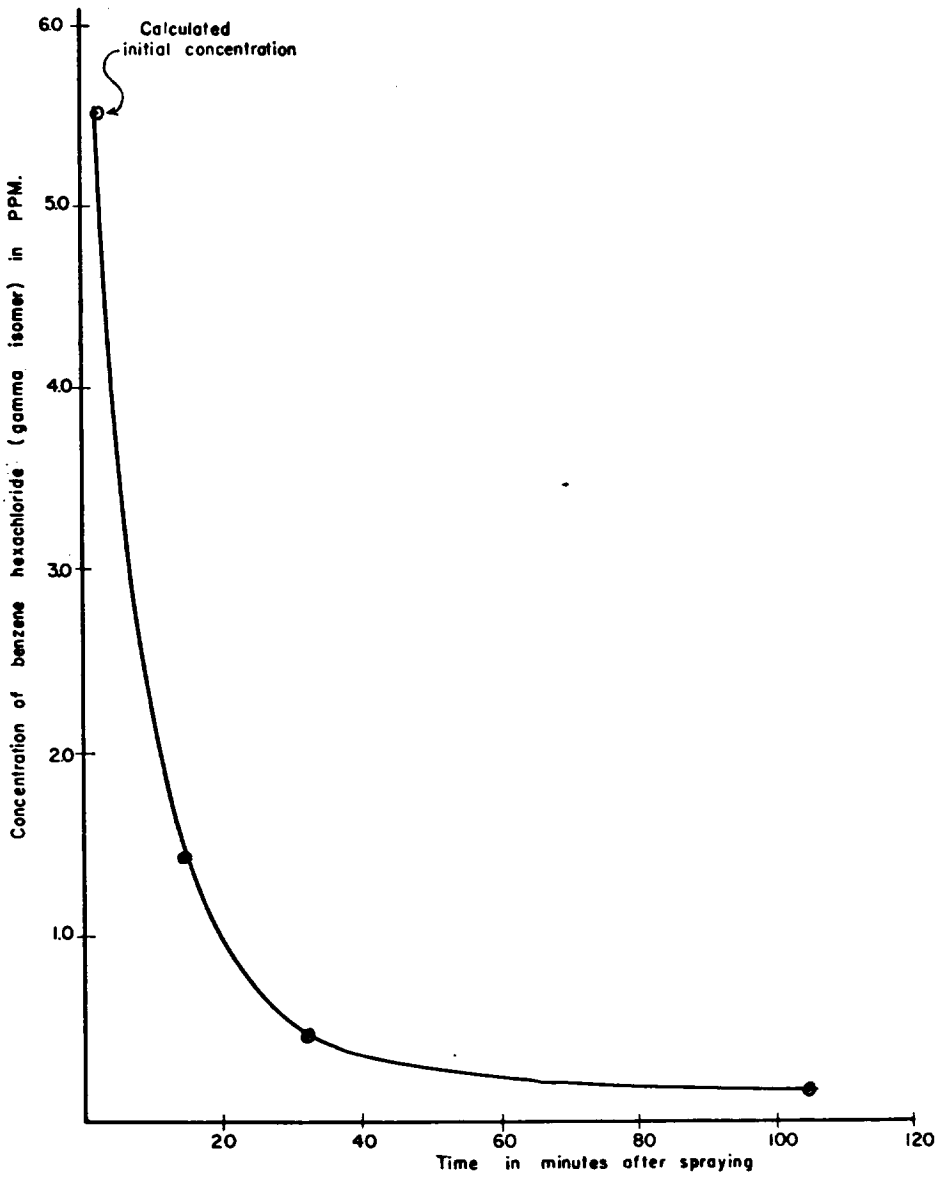


FIGURE 7.—*Curve showing the rate of decrease in the concentration of benzene hexachloride (gamma isomer) following spraying of log booms in Sproat Lake.*

Conclusions

The results of the experiment have shown that applications of emulsified benzene hexachloride at the concentrations cited (12.3 lbs. of gamma isomer per 34,848 square feet) are lethal to coho fry held within 1 ft. of the surface. Fifteen minutes after spraying had ceased the average concentration of benzene hexachloride was still in excess (1.38 ppm) of the 1 ppm, cited as toxic to trout. The decrease in concentration of benzene hexachloride was shown to be exponential, and a calculation of initial concentration based upon the amount of gamma isomer applied indicates that it exceeded 1.38 ppm by a factor of three or four.

The results obtained from holding fish in a vertical gradient show that fish held at depths of more than 1 ft. were not killed.

The results obtained from holding fish in a vertical livebox showed that fish were not killed at depths of more than 1 ft. below the surface indicating that lethal concentrations of spray may be largely confined to the surface.

The livebox method was well suited to this type of experiment. Both the shallow and vertical liveboxes held fish satisfactorily for the duration of the experiment and the results indicated that the mortality from spraying followed a regular pattern.

The Fish Facilities at the Whitehorse Rapids Power Development, Yukon Territory

by

R. N. Gordon, R. A. Crouter, and J. S. Nelson

Department of Fisheries of Canada, Vancouver, B.C.

Introduction

In the spring of 1957, the Northern Canada Power Commission initiated construction of a power development on the Yukon River at Whitehorse Rapids, approximately two miles south of Whitehorse, Yukon Territory. This development, which was designed to supply hydro-electric power to the Whitehorse area, required that a dam be constructed across the river.

The Yukon River in the vicinity of Whitehorse supports valuable stocks of lake trout, grayling and least cisco. It further serves as the migration route for a population of spring salmon which spawns in the upper watershed area, primarily in the M'Clintock River system, tributary to Marsh Lake (Figure 1).

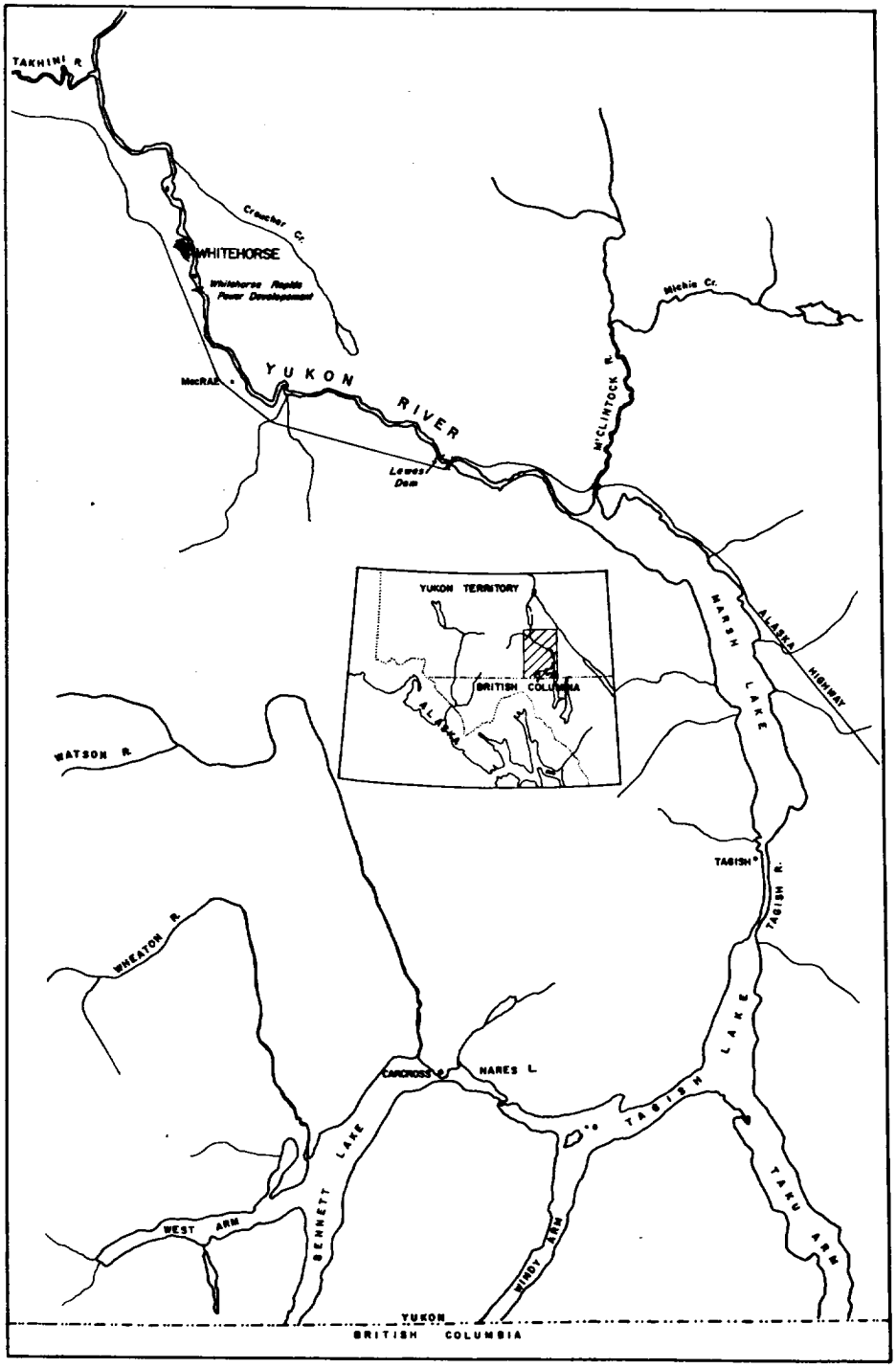
Initial studies of the possible fisheries problems posed by the power development indicated that unless suitable fish facilities were provided to permit free access upstream the important populations of spring salmon and resident species would be seriously affected. Following a series of meetings attended by representatives of the Department of Fisheries and the Northern Canada Power Commission, agreement was reached to provide permanent fish facilities at the dam.

The facilities were designed to pass upstream migrants around the obstruction, but their installation was necessarily deferred pending completion of the power dam. By 1958, construction of the dam had progressed to the point where the structure constituted a complete obstruction to all upstream migration and temporary facilities were installed for operation during the summer of that year.

The permanent fish facilities came into service on June 26, 1959, and during the succeeding months an assessment programme was conducted to determine their efficiency.

Description of the Whitehorse Rapids Power Development

Local conditions at the Whitehorse Rapids power site are such that the most economic damsite is situated upstream from the rapids proper; but if the powerhouse were constructed integrally with, or adjacent to the dam, as is customary at most mainstem developments, the 15-foot fall between the damsite and the base of the Rapids, representing nearly 25 per cent of the contemplated gross head on the plant, would not be harnessed by the proposed development. This undesirable feature of the site was overcome by locating the powerhouse near the base of the rapids and conducting water to it from the forebay of the dam, approximately 2000 feet upstream, by means of a canal.



UPPER YUKON RIVER
(YUKON PORTION)

Scale
4 3 2 1 0 4 8 12 Miles

FIGURE 1.—*Map of the Upper Yukon River Watershed.*

Thus, while the project is essentially of the main-stem type, it presents as well, certain of the characteristics of a diversionary scheme.

Construction of the Whitehorse Rapids power development, the salient features of which are described below, was initiated in the spring of 1957 and the plant came into service in November, 1958 (Figure 2).

(a) Spillway Dam

The spillway dam is situated approximately 1200 feet upstream from the head of Whitehorse Rapids on the Yukon River, two miles south of the city of Whitehorse. It consists of an impervious-core earth-fill non-overflow section with an integral concrete spillway consisting of two 40-foot wide undershot spillway gates and a 10-foot wide regulating gate on the crest of an ogee overflow section. A concrete apron and training walls extend from the toe of the ogee nearly 200 feet downstream where the apron terminates in a flip bucket which directs the spillway discharge into the atmosphere and away from the structure in order to forestall any future problems arising from erosion of the river bed in the immediate vicinity of the dam.

The spillway dam raises the normal river level at the site by approximately 47 feet, and the impoundment so created extends upstream for nearly 20 miles to the Lewes Dam at the outlet of Marsh Lake.

(b) Powerhouse

The Whitehorse Rapids powerhouse is situated at the toe of the Rapids on the left bank nearly 2000 feet downstream from the spillway dam. It houses two 7500-hp propeller-type turbines, each of which draws 1250 c.f.s. at full load under a normal head of 62 feet. Provision has been made for future expansion, however, and the excavation for a possible third unit, adjacent to, and in line with the two existing ones, was completed under the initial contract.

Forebay fluctuations are restricted in practice to a one-foot range, so flow regulation at the site is negligible and the plant is essentially of the run-of-the-river type.

(c) Power Canal

Two impervious-core earth fills, which are approximately parallel at a distance of about 100 feet, form a trapezoidal-shaped canal on the west bank extending downstream from the forebay of the spillway dam to within 200 feet of the powerhouse, where they are terminated in a concrete intake structure by means of which they are interconnected. Plant flows are conducted from the forebay to the intake via the power canal, and since there is no significant head loss in the canal, it is, in effect, simply a downstream extension of the spillway dam impoundment.

Flows in excess of plant demands are passed through the spillway gates to the river below, and since the natural river runoff is normally greater than the plant capacity, spill is expected to occur continuously.

Description of the Whitehorse Rapids Fish Facilities

Studies to develop an efficient economic method for passing fish around the power project were inaugurated in December, 1956. At that time a preliminary assessment of the fisheries problems associated with the proposed development indicated that upstream

migrants would be delayed at the powerhouse and blocked at the spillway dam unless suitable remedial measures were implemented at the outset. No difficulties were foreseen with respect to the powerhouse, where a standard-type collection system and fishway would serve effectively, but what appeared to be insurmountable problems were expected at the spillway dam. In this connection, model studies of the spillway disclosed that the flow pattern at the toe could be expected to vary considerably with varying discharge, and that erosion of the river bed would be such that the tailwater levels and flow patterns would alter unpredictably with the passage of time. There was no assurance therefore that any known type of fish-passing device could be adapted economically to operate effectively under these adverse conditions.

An investigation of several possible alternatives indicated that the most promising method would involve the construction of a fish barrier across the river some distance downstream from the spillway dam, where upstream migrants could be more easily attracted into the facilities. Subsequent detailed studies confirmed this and the design of suitable fish facilities proceeded accordingly. These facilities, as constructed, are described briefly hereunder, (Figure 2).

Powerhouse Fish Facilities

A collection chamber in the form of an eight-foot wide timber flume, resting on the draft tube deck, extends the entire length of the downstream face of the powerhouse, and is linked with the tailrace by three six-foot wide slidegate-controlled submerged orifices spaced uniformly along its length (Figures 3 and 4).

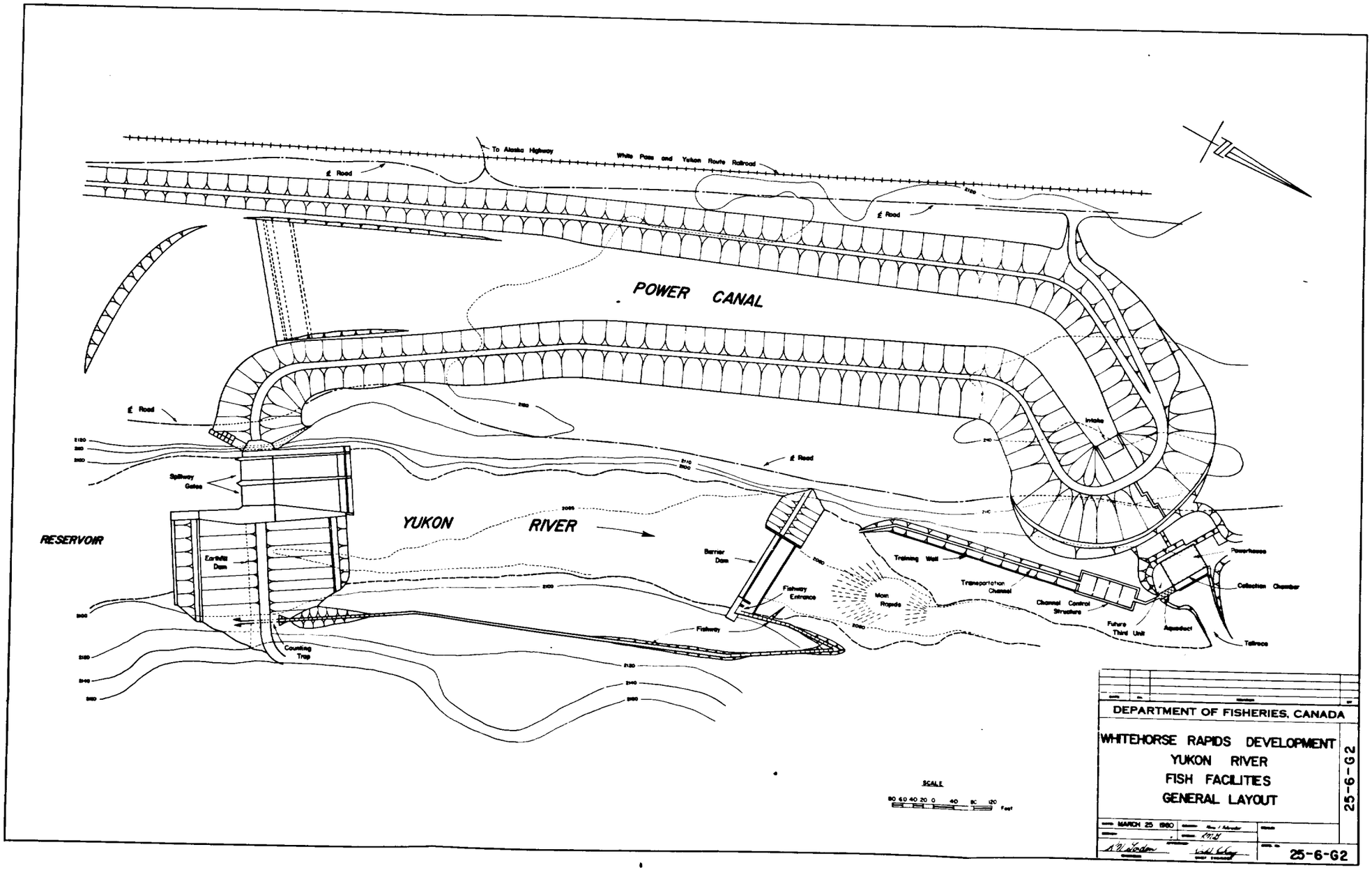
Water is supplied to the collection chamber by means of a trapezoidal-shaped rock-cut (transportation channel) which interconnects with the river near the head of the rapids, several hundred feet upstream from the tailrace (Figure 5). The channel has a minimum width of six feet and the gradient of its floor is such that it provides at least a four-foot depth of flow at all stages.

Velocities in the transportation channel and collection chamber are regulated automatically by a reinforced-concrete control structure consisting of three modified vertical slot type baffles, which provide for average velocities of 1.5–2.5 feet per second throughout the normal range of discharges. Velocity and discharge can be regulated manually as well by manipulation of the slidegates which control the discharge from the entrance ports of the collection chamber.

The facilities are so designed that the water level of the collection chamber is maintained at approximately six inches above that of the tailrace, so attraction velocities are normally in the order of 5–6 feet per second. Maximum head loss through each baffle of the control structure is restricted by design to one foot.

In operation, fish which are attracted into the tailrace locate the entrance ports, enter the collection chamber, and ascend the transportation channel back to the river where they rejoin those that had proceeded up the river directly. All migrants are therefore expected to ascend freely to the head of the rapids so it was necessary to provide only a single set of facilities to convey them from there to the forebay.

FIGURE 2.—*Plan of the Whitehorse Rapids Power Development and Fish Facilities.*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White Pass and Yukon Route Railroad
℄ Road
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POWER CANAL
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Intake
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Earthfill Dam
Counting Trap
Fishway
Barrier Dam
Fishway Entrance
Moon Rapids
Training Wall
Transportation Channel
Channel Control Structure
Future Third Unit
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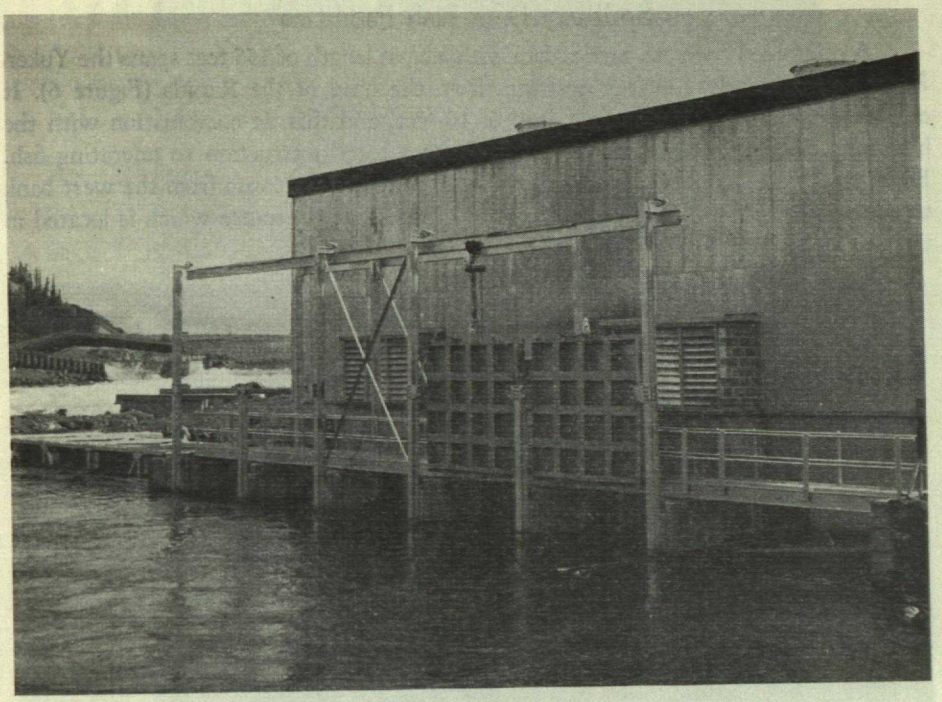

FIGURE 3.—*Powerhouse and Tailrace.*

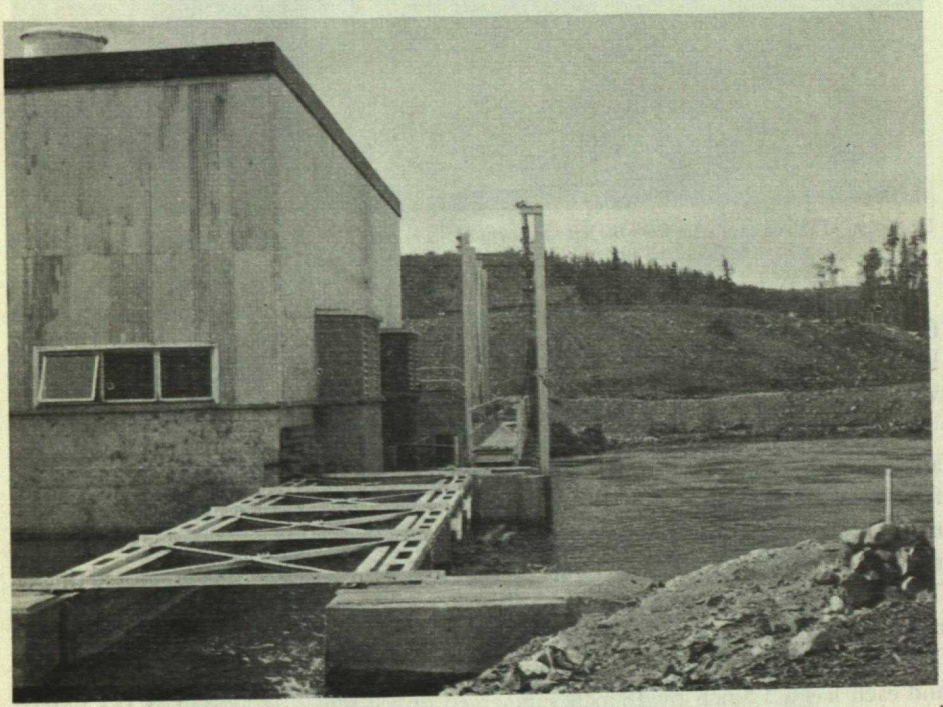

FIGURE 4.—*Lower end of transportation channel showing aqueduct leading to powerhouse collection system and tailrace.*

Spillway Dam Fish Facilities

A reinforced concrete barrier dam with a crest length of 155 feet spans the Yukon River approximately 100 feet upstream from the head of the Rapids (Figure 6). It creates a minimum water surface drop of 10 feet, and this, in combination with the hydraulic characteristics of the overfall, forms a total obstruction to migrating fish. Furthermore, the alignment of the barrier dam is angled upstream from the west bank to the east so that fish will lead naturally to the fishway entrance which is located in the east abutment of the barrier dam.

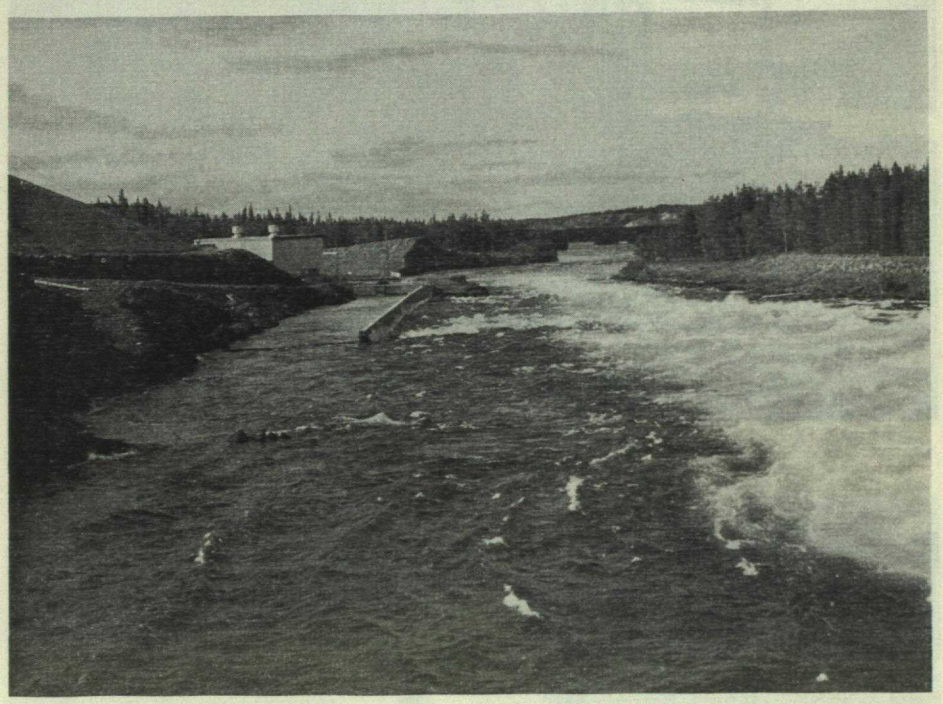

FIGURE 5.—*Downstream view from the left abutment of the barrier dam showing Whitehorse Rapids and the upper leg of the transportation channel.*

The fishway entrance pool is simply a 10-foot by 13-foot recess in the downstream face of the abutment, and upstream migrants gain entry by means of either a 12-inch by 18-inch submerged port or over a six-foot wide manually-operated telescopic weir which is submerged at all stages (Figure 7).

A weir-type fishway, six feet wide, six feet deep, approximately 1200 feet long, and having a vertical rise of 55 feet, conducts migrants from the entrance pool to the forebay of the spillway dam (Figure 8). Its lowermost leg, which is subject to submergence at high river discharges, is constructed of reinforced concrete, as is the culvert section which passes through the spillway dam, but the remainder is of creosoted timber. The fishway has a level centre section nearly 700 feet long and two end sections totalling more than 500 feet in length, each of which has been constructed on a 1:10 floor slope. These sloping sections are fitted with four-foot high weirs spaced at 10-foot intervals, and each has a 12-inch by 18-inch submerged orifice which is located at the bottom corner. These orifices are staggered from side to side at adjacent weirs.

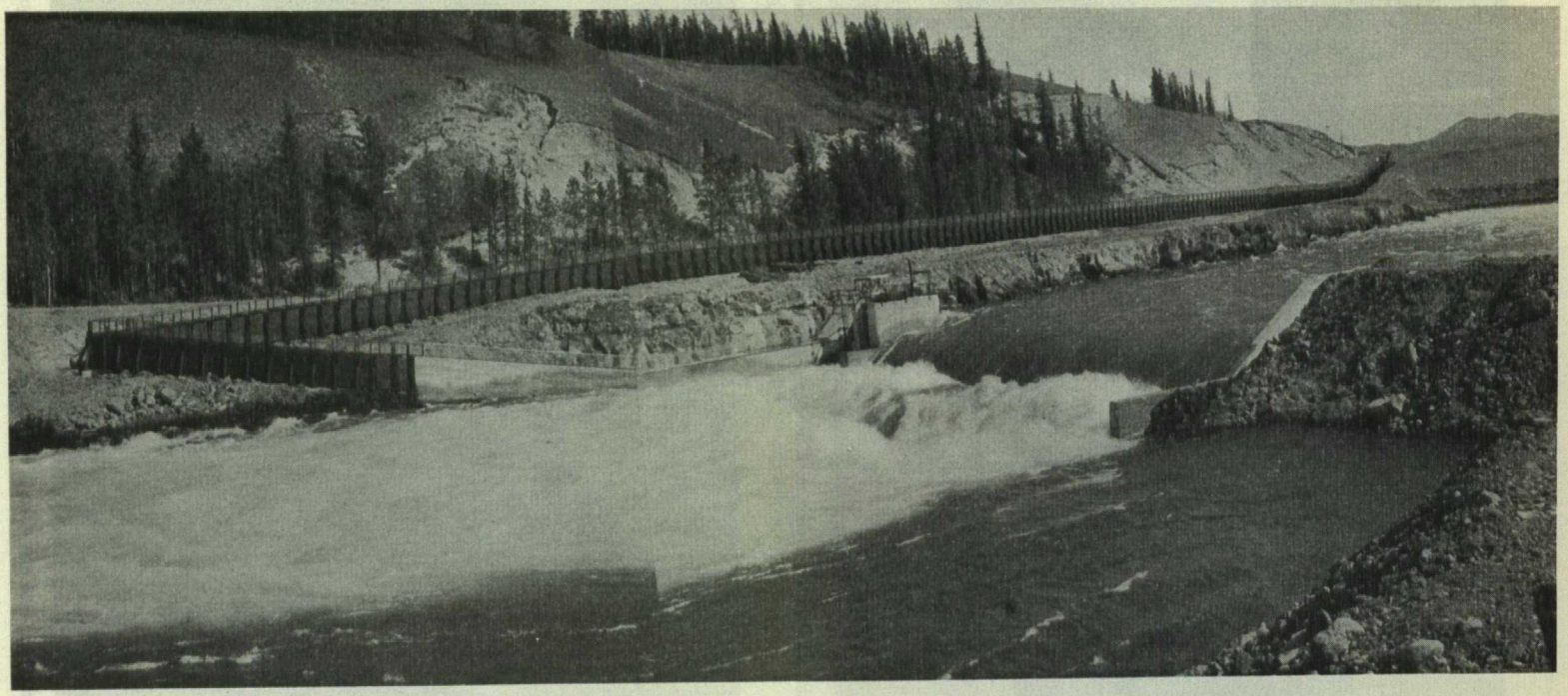

FIGURE 6.—*Barrier dam and fishway.*

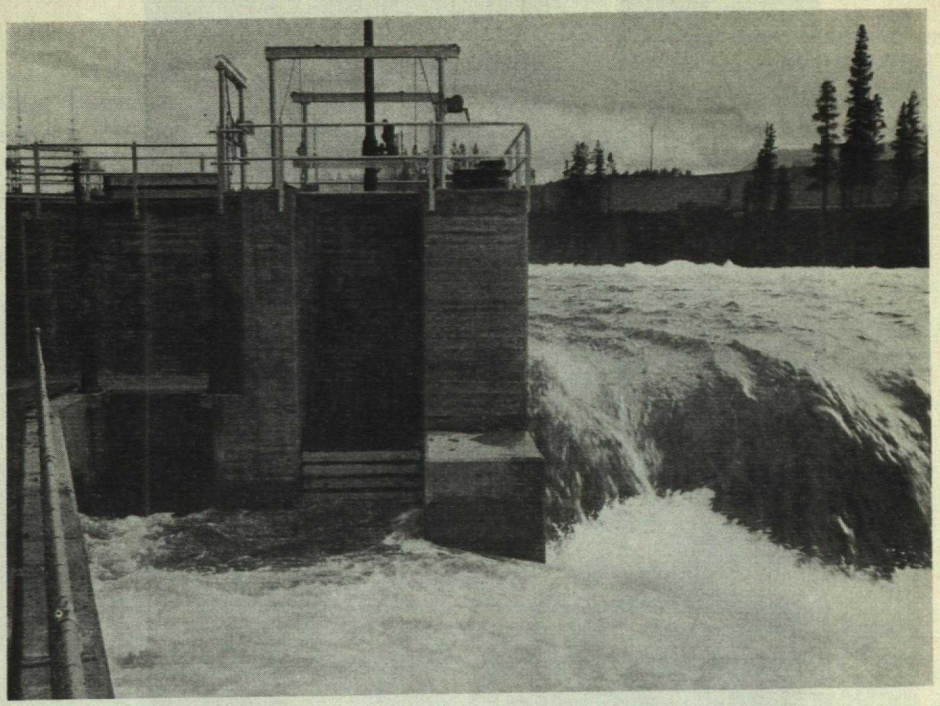

FIGURE 7.—*Fishway entrance as seen from fishway showing telescopic weir entrance at left and stoplogged auxiliary water supply sluiceway at right.*

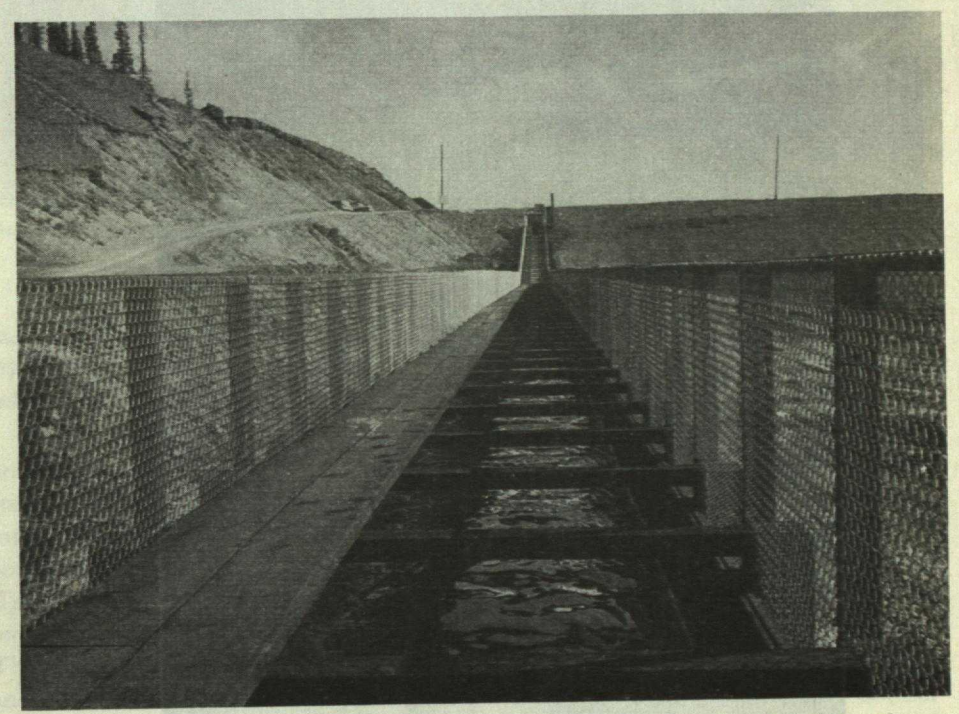

FIGURE 8.—*Level centre section of fishway with counting trap and culvert through spillway dam in distance.*

Water is drawn into the fishway from the forebay of the spillway dam and regulation is effected by manipulation of stoplogs at the fishway exit. The structure is designed to operate with flow depths of from eight to eleven inches over the weirs, so total discharge, including that of the submerged ports, is normally in the order of 25 c.f.s. While this flow is considered to be adequate for transportation within the fishway there was some doubt that it would be sufficient to attract fish into the entrance pool without undue delay. An auxiliary water supply system was therefore provided at the fishway entrance (Figure 9). It consists of a six-foot square slidegate-controlled sluiceway through the east abutment of the barrier dam between the fishway entrance and the overfall. Flows are drawn directly from the pond behind the barrier dam and the works are so designed that this auxiliary flow can be employed either as a direct jet to attract fish into the vicinity of the fishway entrance, or it can be discharged directly into the entrance pool to augment the flow passing over the telescopic weir. The motor-operated control gate is capable of supplying in excess of 600 c.f.s. at all river stages, but its full capacity will probably not be required in practice.

Downstream Fish Facilities

Experience at similar installations suggests that losses at the spillway during downstream migrations will be slight and that those through the propeller-type turbines will also be small. Field tests to be undertaken in future, however, will determine exactly what losses are occurring. If the tests disclose that serious mortality is occurring, consideration will be given to the desirability of installing screens, louvers, or equivalent diverters, and a suitable by-pass, in the power canal.

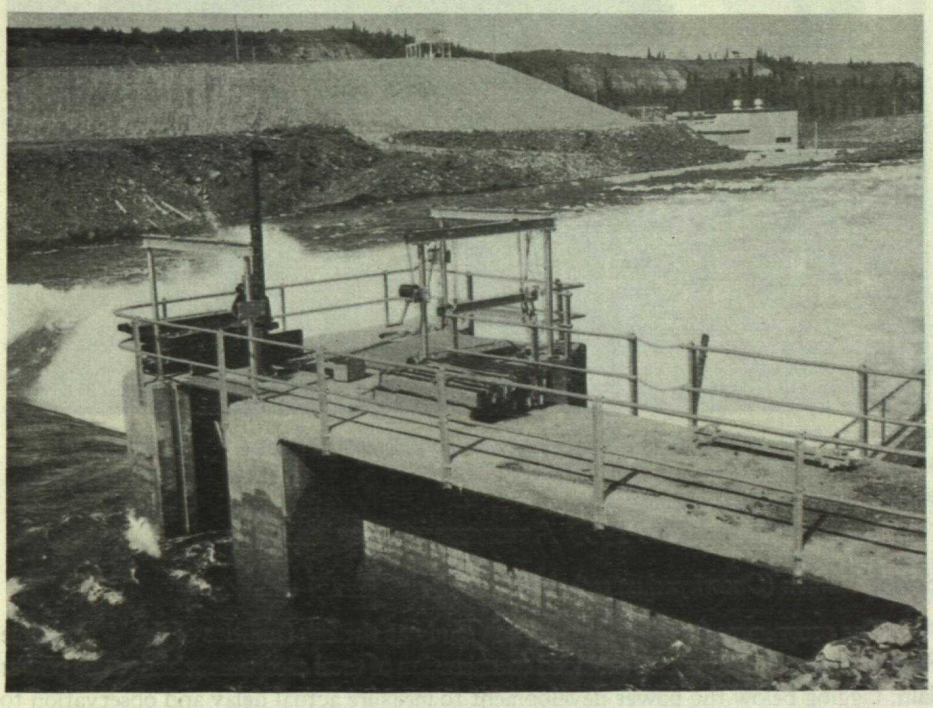

FIGURE 9.—*Upstream face of barrier dam east abutment showing auxiliary water supply intake.*

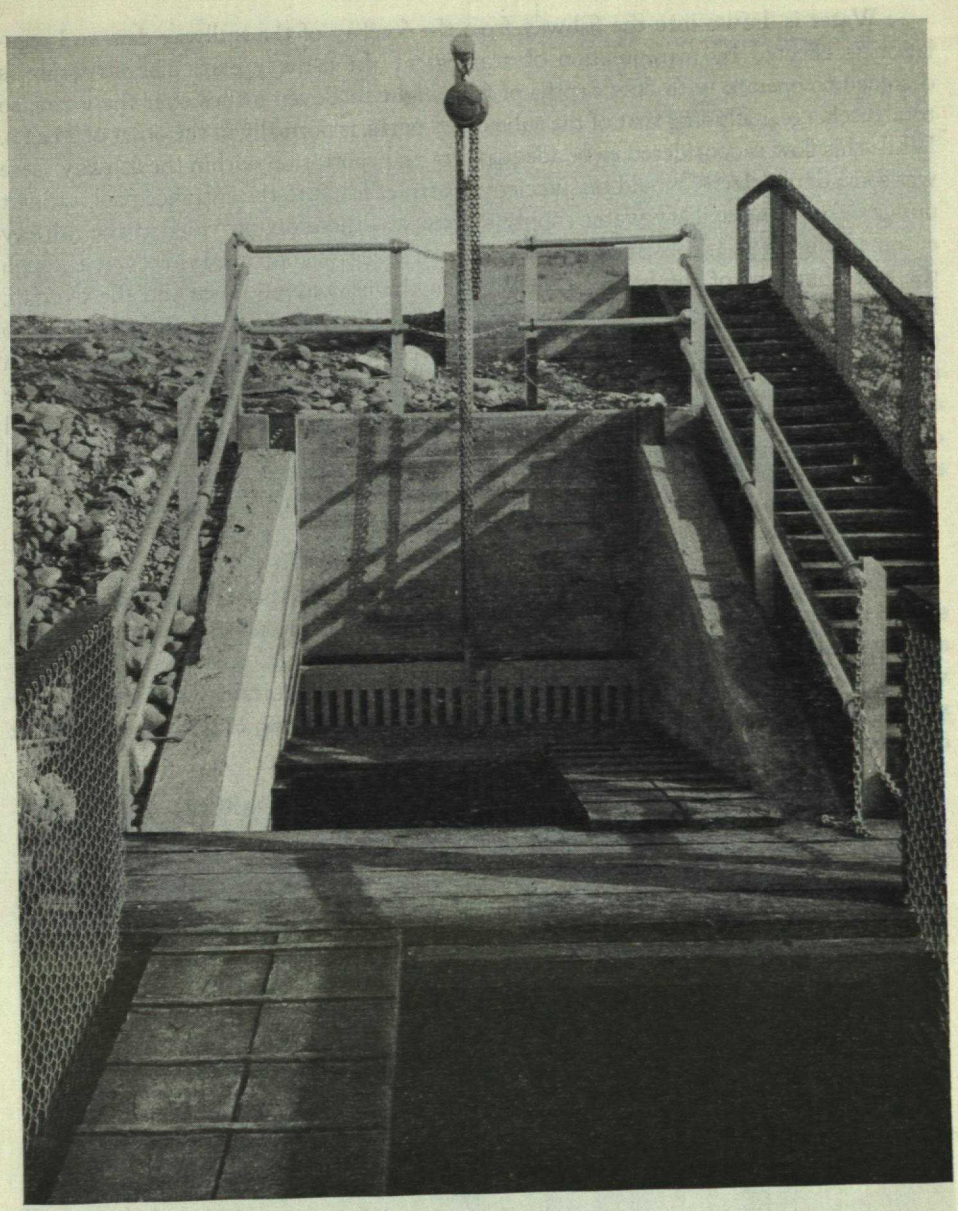

FIGURE 10.—*Vertical slot counting gate in closed position.*

The 1959 Assessment Programme

Spring Salmon (Oncorhynchus tschawytscha)

The programme for the spring salmon study at the fish facilities of the Whitehorse Rapids Power Development, included enumeration of total escapement above the power dam, tagging below the power development to measure actual delay and observation to determine general behaviour of salmon at the facilities.

A total escapement figure was obtained by the operation of a vertical slot counting gate near the fishway exit (Figure 10). The fish were released periodically during the day to avoid delay and consequent accumulation of fish.

The first salmon was sighted by Departmental personnel at the fishway entrance on July 28. Between July 29 and September 24, at which time the programme was terminated, the count at the fishway totalled 1054. Cumulative and daily migration curves are shown in Figure 11.

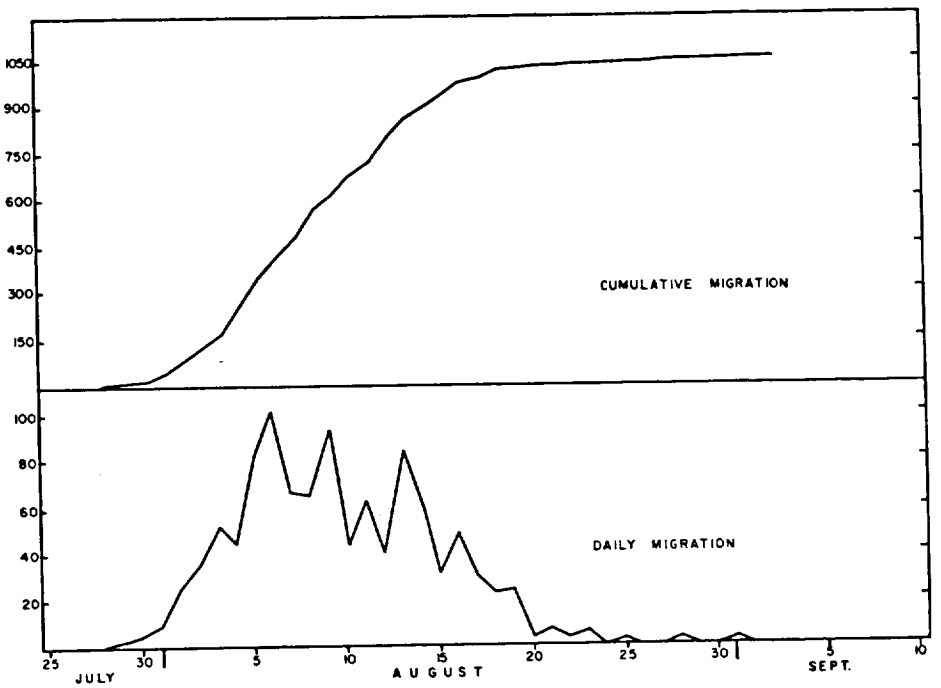

FIGURE 11.—*The Cumulative and Daily Migration of Spring Salmon ascending the Whitehorse Rapids Fishway—1959.*

Attempts to tag were unsuccessful and no reliable measure of overall delay was obtained. Of five salmon tagged on the east bank below the fishway entrance, one entered and negotiated the fishway in 28.5 hours and another in 64 hours. The remaining three were not recovered in the facilities.

Although an accurate direct measure of delay was not obtained there are other indications that the facilities operated satisfactorily. There was no delay to migration apparent on the right bank and although as many as 100 salmon accumulated in a back-eddy on the left bank below the barrier dam, delay to individual fish was probably slight. Salmon migrating on the west bank of the river would have passed through this eddy, which formed a natural resting pool, prior to finding the fishway entrance on the opposite shore. In the extremely rough water conditions prevalent in that section of river, there would be a natural tendency for salmon to accumulate in such an area.

Attraction of salmon into the fishway, as indicated by a lack of any significant accumulation in the area immediately downstream, was very good. Movement through

the relatively long structure was made without noticeable delay, although salmon demonstrated some reluctance to pass through a shaded culvert section which leads from the counting pen to the reservoir.

While a number of salmon attempted to surmount the barrier dam, none was seen in the area between it and the spillway dam. On this basis, the conclusion is drawn that the structure provided a total obstruction and thereby fulfilled the functional requirement.

There were no problems noted at the powerhouse bypass facilities. An occasional salmon was observed at the exit from the transportation channel but none was seen in the channel proper or in the tailrace. The evidence suggests that these facilities either operated very efficiently during 1959 or few if any salmon were attracted into the tailrace. During the summer of 1959 however, the turbines of the plant were discharging only a few hundred c.f.s. as compared with their full capacity of 2500. Consequently, flows issuing from the tailrace may not have been sufficient to attract salmon from the much larger flows of the river.

In terms of overall assessment, the pattern of migration as well as the general condition of the salmon indicate that the migration of this species was not seriously affected. The daily migration curve (Figure 11) does not demonstrate a skewed pattern and additionally shows that 96 per cent of the migration occurred during the 21-day period, August 1 to 20. Together these factors suggest that severe delay did not occur. Condition of the salmon was good and showed very little deterioration throughout the migration. There was also no evidence of injury noted.

An aerial reconnaissance of the area located downstream from the dam was undertaken in view of reports that small numbers of salmon had spawned in that locality in 1958 but none were noted in 1959.

Throughout the latter portion of July, an accumulation of several thousand spring salmon fingerlings, verified by scale analysis to be progeny of the 1958 escapement, were present in the non-functional number three penstock pool and small numbers were noted throughout the remainder of the programme.

Other Species

The fishway counting gate was designed to contain only spring salmon so that data on the movement of other species is based primarily on visual observation. The period of daily observation extended from July 17 to September 4.

1. *Arctic Grayling (Thymallus arcticus)*

No count was kept of the grayling passing through the fishway, however there were generally 30 to 50 individuals present in the fishway during periods of observation. Large numbers of grayling were reported utilizing the fishway for a period between June 26, when water was first introduced into the fishway, and July 17, the commencement date of this programme. The spawning period of this species is reported to be in the late spring and this population may have been on a spawning migration. Adults occurred periodically throughout the diversion channel and tailrace for the duration of the survey and during the latter part of August a number of juveniles, 3.5 to four inches in length, were observed in the transportation channel.

2. *Lake Trout (Salvelinus namaycush)*

Five lake trout were counted through the fishway and others were observed occasionally in the powerhouse collection facilities.

3. *Least Cisco (Coregonus sardinella)*

One least cisco was counted through the fishway but very few were observed in the structure even though large numbers were observed in the collection chamber and number three penstock pool throughout the summer. The migration of this species could possibly occur in the late fall or early winter.

4. *Round Whitefish (Prosopium cylindraceum)*

Round whitefish were not observed in the fishway although a small number were present in the diversion channel throughout the summer. A sample of juveniles, four to five inches in length, was taken in the lower transportation channel during the latter portion of the survey.

5. *Northern Pike (Esox lucius)*

A school of pike was sighted in the lower transportation channel on September 4 but none was seen elsewhere.

6. *Longnose Suckers (Catostomus catostomus)*

Two longnose suckers were counted through the fishway, several others were observed in the structure and schools of this species occupied the powerhouse diversion channel throughout the summer.

Spring Salmon Spawning Ground Surveys

Previous surveys had indicated that the M'Clintock system, specifically Michie Creek, provided the only major spawning area above the dam and that spawning occurred during the period between the last week in August and the last week in September. Based on this knowledge, an aircraft survey was conducted over the M'Clintock River system on August 28 to enumerate the actual spawning population. There were, however, no salmon sighted. Following this the programme was enlarged to include four additional aerial surveys of Michie Creek and one reconnaissance of the area lying upstream from the M'Clintock system. Although the latter included tributary streams of Marsh, Tagish and Bennett Lakes (Figure 1), no evidence of either live or dead salmon was obtained. The Lewes River Dam, a low-head structure near the outlet of Marsh Lake was open all season and careful observation indicated quite positively that it did not present an obstruction at the water levels encountered. This structure is the only known possible obstruction in the reach between the Whitehorse Rapids Dam and the spawning grounds.

Indian Fishery

In past years a local native has operated an aboriginal trap in the M'Clintock River. During the past season this was not done but two gill-nets were fished in the lower reaches of the river. The reported catch totalled only ten salmon which serves only to indicate that salmon reached the M'Clintock system.

Discussion

Although an accurate direct measure of delay to the migrating salmon was not obtained, the pattern and timing of migration as well as the observations made on behaviour and condition of fish at the development site indicate that the fish facilities operated satisfactorily. The fact that the migration pattern is not skewed; that 96 per cent of the migration took place in a 21-day period; that condition of the salmon remained good throughout the migration; that there was no evidence of spawning below the facilities; that there was a lack of injury and that there was an absence of any major accumulation below the barrier dam, all suggest that the salmon were not seriously interrupted in their migration.

Specific observations indicated that each unit of the fish facilities operated satisfactorily. Attraction into and movement through the fishway of salmon and grayling appeared to be good, the barrier dam apparently formed a complete obstruction to migration and there were no migration problems at the powerhouse collection facilities during 1959.

The failure to locate salmon on the known spawning areas above the damsite does not serve as proof of absence. It did, however, prevent any estimation of the success of spawning. The spawning ground survey may not have included all potential areas of the upper system, however, and utilization of areas other than Michie Creek may have occurred, possibly in other portions of the M'Clintock system itself. This possibility is suggested by the catch of salmon in the Indian fishery near the mouth of that system. The presence of relatively large numbers of juvenile spring salmon, progeny of the 1958 adult migration of which the observed spawning population totalled only 15, also suggests that spawning distribution is greater than is presently known.

There are a number of factors yet to be studied regarding passage of fish at the Whitehorse Rapids Power Development. These include the success of salmon spawning above the damsite; the pattern of upstream migration of species other than salmon; turbine mortality and the timing of downstream migration of the major species. Further investigation of these points will be required.

M. E. B. Young

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Editor's Note: The first three articles in this issue were papers presented at a symposium on "Fish Toxicants as a Tool in Fishery Management," conducted in Ottawa on January 8, 1960, at the thirteenth meeting of the Canadian Committee on Freshwater Fisheries Research, under the sponsorship of the Fisheries Research Board of Canada. A fourth paper, "The Development of Selective Toxicants for Sea Lamprey Control," by B. G. H. Johnson, Fisheries Research Board of Canada, Biological Station, London, Ont., is to be published elsewhere under the auspices of the Great Lakes Fishery Commission.

The article "Fisheries Management Development Projects," by Dr. W. Einsele, is the translation of a section of the booklet "Lakes, Rivers and Brooks in Salzkammergut, Austria," published by the Austrian Government for the Fourteenth International Limnological Congress, August, 1959.

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HON. J. ANGUS MACLEAN, M.P.,
Minister of Fisheries

The Use of Rotenone for Management of New York Trout Waters

by
Robert G. Zilliox
New York State Conservation Department, Ray Brook, New York

and
Martin Pfeiffer
New York State Conservation Department, Ray Brook, New York

Introduction

Over 100 lakes and ponds have been reclaimed in New York State since 1950. With few exceptions these waters are located in the Adirondack region of northern New York which contains approximately 2000 lakes and ponds about 8900 square miles in area. Its waters, ranging in size from small bog ponds of less than an acre to 30-mile-long Lake George, are generally cold, infertile, unproductive bodies of water best suited for producing the native brook trout and lake trout. In 1950 rotenone powder, rotenone wettable paste, emulsifiable rotenone 5 per cent and Fishtox were employed in the reclamation programme. Since 1951 emulsifiable rotenone five per cent or emulsifiable synergized rotenone 2.5 per cent have been used. Although the emulsifiable product is more expensive than the non-liquid products, the ease of handling, transportation and application of the liquid product narrows the price differential.

In the Adirondacks two native gamefish species predominated the area: the lake trout and brook trout. The so-called warm water game and pan fish species (other than sunfish) were not native to the region. Native associates of the lake trout and brook trout in the Adirondacks vary from watershed to watershed; but the most common association is the brown bullhead, pumpkinseed, white sucker and horned dace. Less frequently are found the fine-scaled sucker, round whitefish and several species of minnows. Over the past 75 years and mainly in the last 40 years a tremendous change in the fish fauna has taken place. Through misguided stocking, bait pail dumping and invasion from one water in a chain to other waters, there are at present no lakes or ponds open to public fishing, located along roads, that retain their native fish population. Greater than 90 per cent of the total water area in parts of the Adirondacks has been subject to warm water game and panfish introductions, causing a serious decline or elimination of the brook trout fishery and a decline in the lake trout fishery. Many of the smaller waters provide little if any angling for the introduced species due to stunting.

The stocking of hatchery brook trout of various sizes in such waters has given poor returns. In view of the need for reclamation and state ownership of many waters, the Adirondacks has proven to be an excellent region for a sustained reclamation programme. With few exceptions the general public has been very enthusiastic concerning the programme.

Materials and Methods

Equipment

Of 92 waters reclaimed between 1950-1958 only 24 were accessible by motor vehicle. Lightweight but sturdy equipment was necessary for the application of rotenone. Penn Yan cartop boats, weighing approximately 65 pounds with the middle seat removed and fitted with shoulder carrying yokes for transport over trails or through the woods were used for pond work. These boats accommodated a pump, two or three men and up to 25 gallons of rotenone, and were propelled by an outboard motor. The pumps used for spraying were Pacific Marine Pressure Pumpers, Model 5-A-8, weighing about 40 pounds with fittings and carried on pack boards when being transported. A square-stern Adirondack guide boat weighing approximately 65 pounds and equipped with a shoulder carrying yoke, was used for hand pumping swamps, shallow water areas, and for general water transportation.

Application of Rotenone

Emulsifiable rotenone five per cent, a product obtained from several companies, was used at a concentration of approximately 0.5 p.p.m. Emulsifiable synergized rotenone 2.5 per cent, a product of S. B. Penick & Company, was used at a concentration of 0.25 p.p.m. on a number of waters between 1956 and 1958. The method of application insofar as possible was designed to distribute the rotenone equally throughout the pond waters. The pressure pumper, with fire nozzle attached, was used to spray the shoreline area, and a spray bar with eight nozzles, covering a swath approximately 30-40 feet wide, was used to spray the surface. Various lengths of weighted hose were towed behind the boat at various depths of deep pumping. Simultaneously with the pond treatment, another crew treated inlets, outlets, springs and swampy areas, using five gallon fire-fighting hand pumps.

A boat crew could easily treat 50 surface acres per day, including shoreline spraying and deep pumping. In the case of 340 acre St. Regis Pond, the lake was divided into five approximately equal zones and treated on successive days. On some waters two boat crews operating pressure pumps were employed.

Adjuncts of a Reclamation Programme

Barrier Dams

Barrier dams had to be constructed on the outlets of 18 reclaimed waters, in order to prevent reintroduction of undesirable species of fish. These dams are of log crib construction, planked on the upstream surface, with spillways of varying width, depending upon the flow of water. Where possible, barrier dams are designed to provide about a three foot straight fall, with an apron constructed to prevent a deep pool for the "take off" of fish attempting to jump. To build the dam on the best location it is often feasible to locate it considerably downstream from the pond proper (Figure 1).

In watersheds where beaver activity can be expected, site selection is important. Two barrier dams were flooded over in the later years by the erection of beaver dams below the barrier dams. This provides a method of entry into the reclaimed water for those species of fish downstream from the barrier dam, between the barrier and beaver dam.

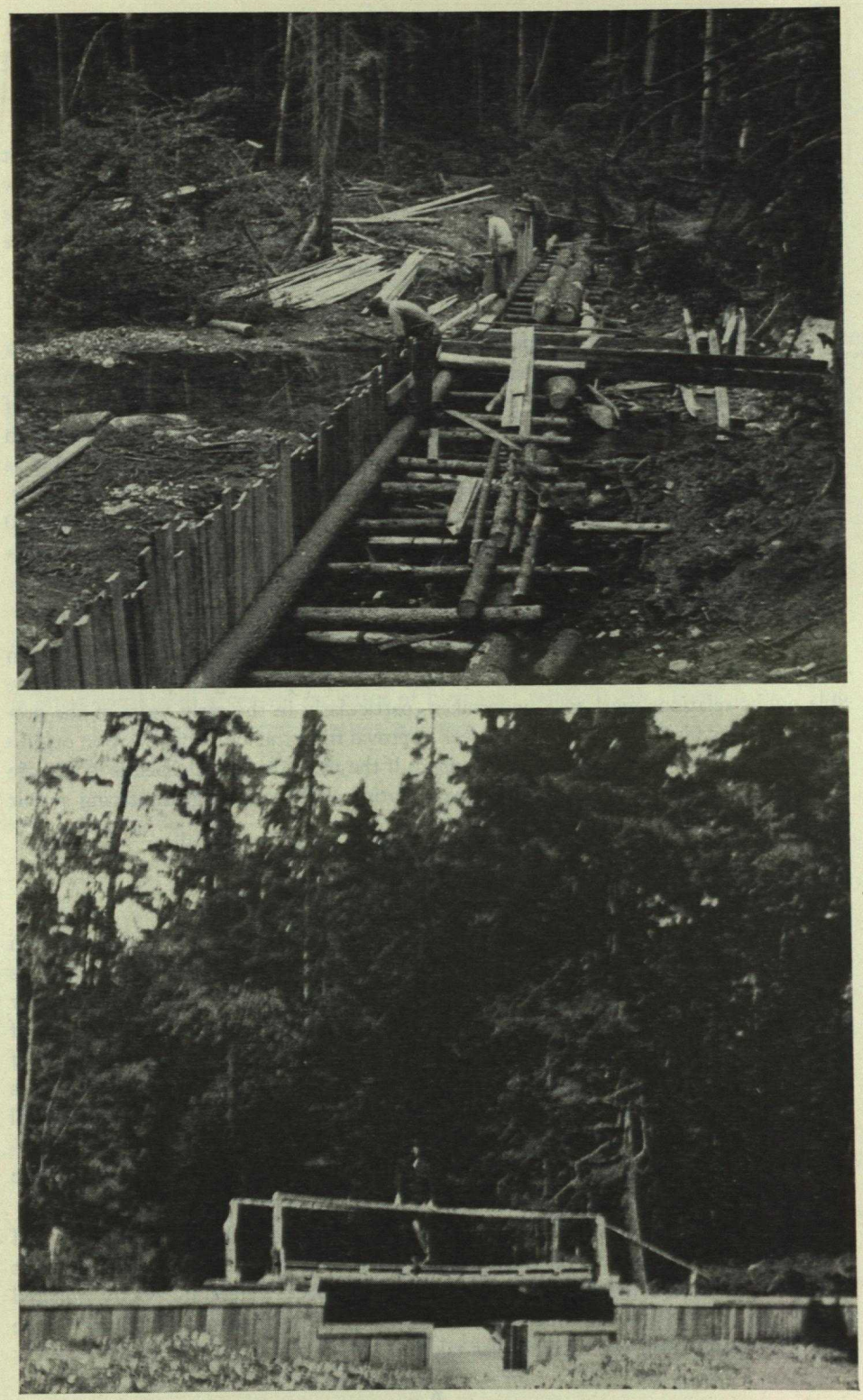

FIGURE 1.—*Barrier dam: (above) in process of construction; (below) completed, with trail cat-walk.*

Dams built in rock, rubble or gravel type streambeds have functioned perfectly. Those built in sand streambeds have undercut in three instances and cut around the sides in two instances. In two of these five malfunctionings yellow perch reinvaded the reclaimed pond.

Due to the inaccessible nature of the damsite locations, the use of concrete is not feasible in all cases. However, in the more accessible damsite locations, we are now considering the construction of concrete barrier dams. The initial cost of concrete barrier dams will be considerably more, but they can be expected to last longer, require less maintenance and function more effectively than log dams.

Special Legislation

A recognized method of introducing undesirable species of fish into New York waters has been via the minnow or bait bucket. Legislation enacted in 1951 (Section 268, subdivision 9, of the New York State Fish and Game Law) prohibits the use of fish as bait either dead or alive, in reclaimed and other natural brook trout waters in the Adirondack Region. A list of such waters, located by county and township is published annually, and in addition metal warning signs are posted about the ponds. To enhance the effectiveness of this legislation, it has been recommended for 1960 that the possession of bait fish on the shores or waters thereof, shall be considered a violation.

Public Relations

While there is no question concerning the biological justification of our reclamation programme, the use of fish toxicants may cause controversy among the public. Considerable public relations work was undertaken, particularly in the early years of the programme. We continue to contact and seek approval from the local conservation organization interested in the pond to be reclaimed. If the water to be reclaimed is in private ownership, written agreement is obtained, stating approval and guaranteeing public access to the water.

Discussion

Physical and Chemical Characteristics of Reclaimed Waters

Of 90 waters reclaimed between 1950-1958, 69 were less than 50 surface acres in size, averaging 18 acres; 13 were between 50 and 100 surface acres, averaging 62 acres and eight were over 100 surface acres, averaging 162 acres. The largest body of water reclaimed was 340 acres. The water of many of the deeper ponds shows depletion of oxygen in the depths. A typical 30-acre pond of this type having a maximum depth of 55 feet would demonstrate marginal oxygen values at 25 feet and zero oxygen values at 35 feet. Other waters in the 50-60 foot maximum depth range evidenced chemical conditions suitable for fishlife at all depths. The deepest water reclaimed had a maximum depth of 80 feet. Regardless of the depth or chemical conditions in the depths the data indicate the introduced species of fish were eliminated in all instances.

Thirty-two of these waters ranged in pH between 5.4 and 5.9; 53 ranged in pH between 6.0 and 6.9 and seven waters had surface readings of 7.0 or 7.1 with all but one of these seven being acid in the depths. Adirondack waters are poorly buffered and more acid readings could be expected for many of these waters, at a time of the year other than when the reading was taken.

Elevation of these waters ranged from 970 feet to 2065 feet above sea level, with an average elevation of 1620 feet.

Summarization of water temperature data pertaining to 45 waters reclaimed between 1950-1955 is given in Table 1.

TABLE 1

Summary of Water Temperatures for 45 Reclaimed Ponds

Month Reclaimed	Number of Ponds Reclaimed	Water Temperatures in degrees Fahrenheit	
		Surface (range)	Bottom (range)
July	7	70-73	47-62
August	14	68-74	46-72
September	20	60-75	40-67
October	4	53-62	45-60

All but four of the waters summarized in Table 1 were thermally stratified at time of reclamation. No relationship was found between water temperature at time of treatment and complete eradication of all species of fish. The general relationship of water temperature and chemistry to time for observed final kill is similar to that given by Zilliox and Pfeiffer (1956) for 14 Adirondack reclaimed waters.

Relative hardness of water (p.p.m. total alkalinity expressed as calcium carbonate) is often considered a general indicator of biological productivity. Table 2 shows the relative hardness for 27 representative waters reclaimed between 1950-1958 and classified according to Juday, (1942).

TABLE 2

Relative hardness for 27 waters reclaimed between 1950-1958

Total Number of Waters	Classification				
	0-5 p.p.m.	5-10 p.p.m.	10-20 p.p.m.	20-30 p.p.m.	over 30 p.p.m.
27	5	12	8	2	0

Total dissolved solids values are available for five reclaimed waters. These five waters are rather typical in chemical and physical characteristics to many waters reclaimed to date. The five waters include two ponds having no inlet or outlet:—26.1 and 16.9 p.p.m. total dissolved solids; one water with an inlet but no outlet:—26.2 p.p.m. total dissolved solids; one water with no inlet but having an intermittent outlet:—22.9 p.p.m. total dissolved solids; and one water with a permanent inlet and outlet:—26.3 p.p.m. total dissolved solids.

Approximately half of the waters treated had been subjected to varying degrees of beaver activity (Figure 2). Beaver dams on the pond outlet or tributary streams resulted in acre-feet of impounded, shallow, swampy water or floating bog type of

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FIGURE 2.—*Portion of drained beaver impoundment.*

environment. Considerable time and labour was expended in draining beaver impoundments. (Zilliox and Pfeiffer, 1956, p. 182).

Muskrat and beaver activity caused underground channels in flooded bog or floating bogs, and springs or spring seepage entered some of these passages. The possibility exists that fish or fish eggs could be harbored in such channels until water in portions of the pond proper became detoxified. Although the introduced non-native species of game and pan fish have been eliminated in heavily beavered waters, it has not been possible to eliminate all native species in any such waters.

Duration of Toxicity

Toxicity checks were made using live hatchery fingerling or yearling brook trout in wire cages suspended at various depths in 75 waters reclaimed between 1950-1957. Two cages of test fish placed at different locations and depths in the pond were used. A 48-hour suspension period was deemed sufficient to give a reliable index of toxicity. Care was observed in making the toxicity tests, so that the cages were neither suspended at a depth having unsatisfactory chemical conditions for brook trout, nor resting on pond bottom in possible rotenone residue.

In all cases where test fish indicated that waters had become detoxified, no losses of trout occurred when stocking ensued. Toxicity data from these waters indicate that in all but a few waters, ponds treated in the fall of the year can be expected to become

non-toxic to brook trout the following spring. Most waters became detoxified in less than 100 days following treatment. Occasional ponds will remain toxic to brook trout for longer periods of time. Ponds with little or no inlet or outlet flow remain toxic longer than ponds with such flowage. Five such waters remained toxic to brook trout over 150 days. One bog pond lacking an outlet and treated at a concentration of 2.0 p.p.m. remained toxic for at least 293 days.

When stocking a pond that has a flowing outlet the year following reclamation, it has been judged unnecessary to conduct a toxicity check. Toxicity checks are still conducted on waters having no outlet or an impermanent outlet.

Siegler and Pillsbury (1947) reporting for New Hampshire waters found that toxic conditions for brook trout endured from less than 35 days to more than 137 days following treatment. Waters were treated with derris (3.70-4.55 per cent rotenone) at concentrations varying between 0.5 p.p.m. and 2.0 p.p.m. Toxicity data for New Hampshire waters is also similar to Adirondack waters when emulsifiable rotenone five per cent is used at comparable concentrations (R. Knowlton, State of New Hampshire Fish and Game Department, personal communication).

Clemens and Martin (1953) reporting for two Oklahoma waters with a pH of 6.8 and 6.7, using emulsifiable rotenone at concentrations of 0.5 and 1.0 p.p.m. respectively, found detoxification occurring less than 94 hours following treatment. In clear alkaline ponds (pH 7.7-8.8) using emulsifiable rotenone at concentrations varying between 1.0 p.p.m. and 2.0 p.p.m., detoxification occurred in less than 56 hours. Surface temperatures varied between 78.2 and 91.6 degrees Fahrenheit and minnows were test fish used. The rapidity of loss of toxicity in such waters can be considered undesirable. It is possible detoxification can occur in certain areas of the lake or pond treated, prior to complete mixing in the pond proper.

Success of Programme

The yellow perch is the most prevalent introduced species of fish in Adirondack waters and the introduced fish most frequently encountered in waters to be reclaimed. The incidence of various introduced species in 90 waters prior to reclamation was as follows: yellow perch 75; smallmouth bass 14; northern pike 12; chain pickerel 6; largemouth bass 2; black crappie 2; rock bass 2; pikeperch 1; carp 1. Various combinations of the above named species were encountered in many of the individual ponds.

Our data to date indicate that in every water reclaimed with rotenone, the above listed species have been completely eradicated. Three native species, lake trout, brook trout, and common whitefish have been eradicated in all ponds when present.

The success of a reclamation programme should be measured in terms of quality of fishing produced rather than in terms of complete eradication of all fishlife. We have learned from past experience that the presence of yellow perch and other introduced species usually makes it impossible to sustain a successful brook trout fishery even with legal-sized stocking. Therefore, it is imperative that these species be completely eliminated. Emulsifiable rotenone five per cent used at 0.5 p.p.m. and emulsifiable synergized rotenone 2.5 per cent used at 0.25 p.p.m. will accomplish this in Adirondack waters.

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Our data also indicate that a typical brook trout pond will produce a greater poundage of brook trout if native species are eliminated and only brook trout are present. Unfortunately, we have not been able to successfully eliminate all native species of fish in these waters.

Zilliox and Pfeiffer (1956), gave the following criteria for a complete kill: "Failure of observation, angling and netting for two successive years following reclamation to indicate any species of fish present in a reclaimed pond, except stocked trout, would appear to be a reasonable indication of a complete kill". These criteria continue to hold true for the non-native species previously mentioned, but do not hold true for native species. For example, a water reclaimed in 1953 and judged to be a complete success in 1955 provided angling for the brown bullhead and pumpkinseed in 1959. Similarly 12 of 23 ponds reclaimed during 1950, 1951 and 1952 were judged to be complete successes in 1954; six of the 12 now contain either the brown bullhead, white sucker or a native species of minnow. Although we are aware that some reclaimed waters have been subjected to introductions by anglers, the data indicate that for most of the waters concerned the native species survived reclamation.

The synergized rotenone product has not proven superior to the non-synergized product in the matter of eliminating native species of fish.

Burdick, Dean and Harris (1955) showed that under laboratory conditions creek chubs were killed between 51-106 minutes using emulsifiable rotenone at a concentration of 0.5 p.p.m. The survival of this species in a number of reclaimed waters would indicate that concentrations of 0.5 p.p.m. are not penetrating to all portions of the water treated. These workers also show that the smallmouth bass has a greater resistance to rotenone than does the creek chub. As the smallmouth bass have been successfully eliminated in all 14 waters where present prior to treatment, it would appear the habits of a species of fish in its natural environment enable it to survive reclamation.

Five waters reclaimed between 1950-1954 had populations of brook trout infested with copepod parasites (*Salmincola* sp.). One of these waters was reclaimed with Fishtox, the remaining four with emulsifiable rotenone. To date the trout in these waters remain free from infestation. It is possible only brook trout have to be successfully eliminated to break the cycle of this ectoparasite, inasmuch as native species survived reclamation in three of the five waters concerned.

Management of Reclaimed Waters

All reclaimed waters in the Adirondacks are managed for salmonids and with few exceptions with brook trout. None have been managed for lake trout, although suitable conditions exist for this species in many of the waters. Primary reason for managing for brook trout are: 1) brook trout provide greater fishing opportunity to a larger number of anglers; 2) brook trout provide angling the year following reclamation; 3) brook trout require little in the line of management techniques other than annual stocking.

For variety to the angler and study purposes, the splake (M brook trout x Flake trout) and the rainbow trout are being stocked in nine waters.

Although rainbow trout do not grow or survive well in all Adirondack waters, they have been stocked in certain waters and have proved successful. The pH of the water is the only evident factor pointing towards success or failure of this species.

A water with a pH lower than 6.2 will generally not prove favourable for rainbow trout. Horseshoe Pond, a 90-acre, 30-foot maximum depth water with a pH of 6.9 will produce rainbow trout in the four- to five-pound class. Black Pond, a 25-acre, 50-foot maximum depth pond, with a varying pH between 4.8 and 5.4 has failed to produce any rainbow trout after three years of stocking, but maintains a fair brook trout population.

The splake has been stocked in several waters having varied environments. In a typical small brook trout pond of 10 acres, having a maximum depth of 22 feet, where all species of fish were eliminated, splake have not attained a length greater than 12-14 inches. In a larger, deeper water where minnows and suckers have survived reclamation, splake have attained a size of 17 inches. Splake in their fifth growing season have attained weights in excess of five pounds in a non-reclaimed Adirondack water containing forage fish. In one water where the splake has been stocked in combination with rainbow trout, adults of the alewife were introduced in 1958 and 1959. They spawned successfully in 1959 and a good crop of young of the year are present. It is thought that the alewife will provide forage for the splake, resulting in an increase in the growth rate of splake in this water.

Brook trout do well in reclaimed waters. Growth and survival studies in many of the reclaimed ponds and lakes indicate that the number of trout stocked per surface acre, the presence or absence of competitive species of fish and the chemical quality of the water are factors affecting growth and survival.

Growth data also indicate that rotenone products used at 0.5 p.p.m. do not have an adverse residual effect upon the food supply of brook trout in New York waters. The growth rate of brook trout fall fingerlings stocked the year following treatment is as good or better than trout stocked in comparable non-reclaimed waters. The growth rate for fall fingerling brook trout stocked the same year following treatment can be considered normal. Cushing and Olive (1957), using derris powder (five per cent rotenone) at a concentration of 1.0 p.p.m. in a Colorado Reservoir found only short-lived effects to the macroscopic bottom fauna.

Natural reproduction of brook trout is non-existent in many waters and where it does occur in the ponds and lakes studied, it is not sufficient to provide remunerative angling, hence stocking is undertaken. Most of the waters are stocked by airplane and stocking rates between 50-100 fall fingerlings per surface acre of water have been found suitable. Rates in excess of 100 fall fingerlings per surface acre will often result in slow growth and stunting.

Very few stocked fingerling hatchery brook trout older than three winters have been collected in the reclaimed pond studies. Since Adirondack ponds with wild stocks of brook trout will produce four or five winter trout, it appears that the hatchery product is relatively short-lived, even when stocked in reclaimed waters where reclamation has been complete.

We have not engaged in selective or partial reclamation in New York. When managing waters for trout species it seems advisable to try for the complete kill.

A factor affecting production of warm water game fish in New York's waters is competition from rock bass, sunfish, yellow perch and other species. We have not been able to selectively remove these competitive species of fish by use of rotenone. Hence with the exception of farm ponds, rotenone has not been widely employed in managing warm water species in New York.

Comparisons

Many factors could be listed when describing an ideal fish toxicant. If rotenone could consistently eliminate native species of fish and was less costly it could be considered the ideal fish toxicant for New York waters. Because of these limitations it is imperative to experiment with fish toxicants other than rotenone as they become available. In 1958 and 1959 emulsifiable Toxaphene has been utilized in the reclamation of eight ponds. Toxaphene has been used in waters where rotenone has failed to give a complete kill and in waters where we would not expect rotenone to eliminate native species. Toxaphene is less costly than rotenone. It will be several years before we know the capabilities or limitations of Toxaphene. Emulsifiable DDT and emulsifiable Thiodan were also used during 1958 in three ponds.

Conclusion

Rotenone products have been used in the reclamation of many New York waters at a concentration of approximately 0.5 p.p.m. Prior to reclamation, due to the presence of introduced non-native species of fish, these waters provided little if any angling. Annual stocking, with fingerling trout, following treatment, provides remunerative trout fishing in most instances. Complete eradication of the introduced species of fish described, in natural lakes and ponds of New York, is almost a certainty by use of emulsifiable rotenone at a concentration of 0.5 p.p.m. The complete eradication of certain native species of fish is not a certainty. Although it is desirable to eliminate all species of fish, the eradication of the introduced species can be considered sound fisheries management.

Due to the relatively rapid loss of toxicity, the knowledge of its capabilities, its acceptance by the general public, health authorities and fishery administrators, the use of rotenone as a fish toxicant can be expected to continue even as other more efficient and less costly products become available. Certain waters in New York will probably continue to be treated with rotenone products in the near future due to their location, conflicts with riparian rights and possible involvement with human water supply sources.

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Use of Fish Toxicants in the Province of Quebec

by

Gustave Prevost

Director, Quebec Biological Bureau, Department of Fish and Game, Province of Quebec

Abstract

Rotenone is a fish toxicant used since 1934 but Toxaphene, Endrin and Thiodan, relative newcomers in the field, are the ones mainly studied, first in the laboratory and then in the lakes. A standard method for laboratory work is stressed. Source and ontogenesis of the fish, temperature and volume of the water have a definite effect on the results obtained. In treating natural waters, many factors have to be cared for, e.g. thermocline, weed beds, floating islands, springs, temperature, turbidity, alkalinity of the water, source of the stream. Rotenone has very little effect on food organisms, while Toxaphene has a very prejudicial one, though some species of plankton are more resistant than fish. Toxicity of the water can be checked in the laboratory or in the lake, but no practical method of accelerating detoxification has been worked out yet, although bentonite gives hope. Health hazards are very small. Stocking with speckled trout gives spectacular results in lakes poisoned with Rotenone, but with the other toxicants, delay in the fishing can be long and no definite fishing results have been found or published. Rotenone is still the best product to use but it is very costly, compared with the others.

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Introduction

It has been demonstrated on many occasions, scientifically and simply by plain observation, that undesirable fish in too great abundance in a lake are disastrous for the development of, for instance, speckled trout, and therefore should be destroyed.

In our waters we have, by descending order of nuisance: perch, sunfish, carp, catfish, suckers, ling, many species of minnows and even black bass and pike, when they are too small. As a matter of fact, in general, in our type of lakes at least, speckled trout thrive when they are the only species present.

Attempts to remove coarse fish with fishing gears or by other physical methods have generally been unsuccessful; even the drainage of a farm pond, unless there is complete drying-out, generally fails to remove all the fish. Partial removal of coarse fish could sometimes bring improvement, but the results are usually only temporary since most of these coarse fish are very prolific and the lake will resume its maximum capacity with them in a very short time. Thus, unless there is a complete removal of the fish, the coarse fish continue to be troublesome.

Until good results are well established with fishing gear, partial or selective poisoning or any other method in our type of waters, we shall continue to aim in practice at a complete kill of all the fish and at restocking the lakes thereafter with speckled trout.

To date, this has proved the only reliable way, and the only one which has given really good results. Some biologists such as Miller (1950), Solman (1950), Tompkins and Mullan (1958) have expressed doubts about the complete kill of fish with Rotenone which has been claimed by other biologists. In the Province of Quebec, we have treated 105 lakes, and we must admit that at the beginning we had some difficulty in securing a complete kill, especially in small muddy ponds with floating islands containing catfish or killifish, but since then, we have improved our methods of application, and we have been able to kill all the fish in any type of lake. Lakes on private properties have been free of coarse fish for more than 10 years. However, many public lakes have been reinfested with coarse fish brought by fishermen, and people are inclined to state that the operation was unsuccessful when in fact there was no failure of the operation itself.

It is not our intention to present in detail the history of fish-toxicants and the methods of their application as well as the results obtained, since exactly ten years ago, in this same room, a symposium on the same subject was held and some excellent papers were presented. One has only to refer to the Canadian Fish Culturist, Number 8, October 1950, to find: "The History and Use of Fish Poisons in the United States" by V. E. F. Solman; "The Use of Poisons to Control Undesirable Fish in Canadian Fresh Waters" by M. W. Smith, and "A Critique of the Need and Use of Poisons in Fisheries Research and Management" by R. Miller. Since our basic methods are quite similar to those already described by these authors, we do not intend to repeat them here. We shall therefore give a description of our methods, as briefly as possible, and give a more extended treatment only to new or controversial aspects, which are numerous in laboratory work and in the field.

Toxicants Used

First, let us give a brief description of the four toxicants used, their composition and a short history of their use as fish toxicants: Rotenone, Toxaphene, Endrin and Thiodan.

1. *Rotenone.* Rotenone is an organic compound, $C_{23}H_{22}O_6$, found in the roots of various Leguminosae, marketed under the name of Derris or Cube Root, and used by Indians in South America for catching fish from time immemorial. It was obtained in a crystalline form by Greshoff (1898). Gersdorff (1930) used Rotenone for testing goldfish, using these as biological test animals for determining the concentration of chemical products. According to Krumholz (1948), Carl Hubbs was the first to suggest the use of Rotenone for the rehabilitation of two small lakes in Michigan in 1934, done under the supervision of Milton B. Trautman. Since then, hundreds of lakes have been treated with it in the United States and Canada. In Nova Scotia, M'Gonigle and Smith (1938) cleaned out 25 miles of stream and a small lake. Leonard (1938) and Vestal (1942) published an extensive paper on the use of Rotenone. In 1942 we started to use Rotenone in the Province of Quebec. Most of our supply of Rotenone comes directly from South America. It is supplied in the form of a powder, Cube or Derris Root, whose concentration in Rotenone may vary from 5% to 8%. We generally use a product with a concentration of 7.1%. We also use Rotenone in liquid form with an emulsifier, the concentration of that product being usually 5%. The concentrations generally used in our waters vary from 0.5 p.p.m. to 3 p.p.m. of Derris Root at 5% Rotenone, and are as follows for the different species concerned: 0.5 to 0.7 p.p.m. for perch, sunfish and minnows; 0.7 p.p.m. to 1 p.p.m. for suckers, ling and pike; 1 p.p.m. to 3 p.p.m. for catfish and killifish. A shallow and muddy lake demands a higher concentration than a clear and deep lake, especially when catfish or killifish are present.

2. *Toxaphene.* Toxaphene is the trade name for chlorinated camphene, and its formula is: Octochlorocamphene $C_{10}H_{10}Cl_8$. Its chemical structure is uncertain; it is a mixture of isomers. It was synthesised by Hercules Powder Co. in 1945 and patented (Anonymous 1951). It is used in liquid form with an emulsifier, the concentration in active product being 61 per cent. It was used for the first time in the laboratory as a fish killer by Surber (1948) who found that a concentration of 0.02 p.p.m. was lethal to golden shiner. Since then, Toxaphene has been tested in the laboratory by Lawrence (1950) and in a lake, August 1951, by Hemphill (1954). In Canada, since 1956, Stringer and McMynn (1958) of British Columbia have used Toxaphene in many lakes. In Quebec, we also began in 1956, after discussion of the question with Hooper and McMynn, who gave us very valuable information. The concentration we have used in our lakes is around 15 p.p.b., but we presume, under some conditions, that we could use a much weaker concentration, if there was duplication in a lake of the conditions we have in a laboratory, where we know we can kill one of the hardiest fish, *Ictalurus nebulosus*, at a concentration of 2 p.p.b. However, the concentration to be used may depend on many factors and the concentrations recommended by Cooper Tox (Anonymous, 1959) seem quite correct according to our own observations. Since the concentration may vary so much—from 5 to 30 p.p.b.—with the type of lake or stream, a close examination of the local conditions is necessary. Concentrations of 17 p.p.b. and 2. p.p.b. of Toxaphene on *Ictalurus nebulosus* give practically the same pattern of curve in time-mortality, (Prevost and Grenier, 1960b) except at the beginning, and thus the impression is that there is an optimum concentration and that the use of a strong concentration does not yield better results for extermination. We may here point out that Toxaphene is, or was, contained in a commercial product called Fish-Tox, although this was not disclosed by the Company, but was discovered by McMynn and

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Stringer (1958). The result of its use was that lakes remained toxic a very long time. It was found that the Toxaphene incorporated in this product was about 10 times stronger than necessary to kill fish.

3. *Endrin.* Endrin is an organic product having the formula: 1,2,3,4,10,10-hexachloro-6,7-epox-1,4,4a,5,6,7,8,8a-octahydro-1,3-endo-5,8-dimethanonaphthalene. It was discovered by Shell Oil Company (Anonymous, 1948) and tested on fish in a laboratory for the first time by James H. Stevenson (1952). We have not found anyone who has used it as a means for reclaiming lakes. However, we poisoned our first lake with Endrin in 1958, and since then a few lakes have been treated with it. The product used comes from the Shell Oil Co. Ltd, and contains 20 per cent of active material. It has been found by Henderson *et al.*, (1959) in the laboratory, to be the most toxic product for killing fish as compared with Toxaphene and other products. It is used in liquid form with an emulsifier. The concentration of the Endrin, after it is spread in the lake, is around 2 p.p.b. In the laboratory we have been able to kill catfish, 6" long, with a concentration of 0.5 p.p.b. after 48 days.

4. *Thiodan.* Thiodan is an organic product having the following formula: hexa chloro-hexahydromethano-2,4,3-benzodioxathiepin oxide, as described by Niagara Chemical Division (1958). It was synthesised by Frensch, Goebel, Finkenbrink and Staudermann (1954). The first tests with fish were performed by Prof. Lendle, (1956) Institute of Pharmacology, University of Goettingen, and a report of 29 pages was presented on July 16, 1956, to Hoechst Co. It is unfortunate that this work has not been published so that better credit could be given to Prof. Lendle. The first published paper is from Prof. Adlung *et al.* (1957). Another paper was published by Adlung (1957) on the influence of temperature. According to Les Veaux (1959) the Plant Pest Control in the U.S.A., in 1958, performed some small scale tests in the Adirondacks in a small pond. But this was simply to test this insecticide for agricultural purposes by observing its effect on fish. Also, Cole Wilde reported verbally that in 1959 he treated Mohawk Pond for rehabilitation purposes, and killed all the fish, even killifish, with a concentration of 46 p.p.b. Last October, we treated a lake with Thiodan, using a concentration of 2 p.p.b. and we shall know the results next spring. In the meantime, we are conducting laboratory experiments and we have been able to kill *Ictalurus nebulosus*, six inches long, with a concentration of 0.5 p.p.b. after 84 days (Prévost et Grenier, 1960b).

Laboratory Experiments

General procedure. It is normal to try any poison in the laboratory before trying it in a lake. This does not mean, however, that the results in the laboratory will duplicate those found in a lake, and very often results, even of experiments in the laboratory, do not repeat exactly, because there are so many variables which workers sometimes overlook or which they cannot overcome.

In the field of aquatic pollution, fish is the most frequently employed test organism. Standard methods for bioassay and accurate statistical interpretation have also been worked out and the excellent contribution of Doudoroff *et al.* (1951) is the bible on which we may rely for bioassay work, especially with industrial pollutants of generally high concentration of toxic material. However, these authors point out that "details of methods for the detection and study of chronic toxicity are not within the scope of

the present recommendations" and the results obtained by their method, therefore, "do not represent concentrations which may be harmless in fish habitats subject to pollution".

We must therefore consider the use of this method with a very critical eye and try to improve it. While obtaining very interesting knowledge on the effect of Toxaphene on fish, we hope also, by our experimental methods, to help to improve the bioassay methods actually in use and contribute to a standardization of them. The great necessity of this has been pointed out by many workers.

We must remember that the bioassay methods have been worked out with a view to preventing pollution, not to killing all the fish in a lake, as we have to do. On the other hand we must also, in some cases, prevent the killing of fish in effluents of the lake. Our methods will therefore necessarily be different. Nevertheless, we shall occasionnally use Doudoroff methods simply to show that in general they do not work for the type of information we need, and thereby caution other workers.

Our methods will vary with the type of information we seek and in our case this information may be three-fold.

1. Information concerning the effect of pure organic compounds or other compounds, on fish placed in well-defined laboratory conditions. This we would call *fundamental information*. The experiments have thus to be conducted in such a way that they can be comparable anywhere they are performed. This is the most difficult task we have to undertake, but it is what we should aim at, if we want good comparable results.

2. Information concerning the influence of pure organic compounds or other compounds, on fish of a precise locality. Although there are many factors to keep in account, we can obtain this information rather more easily than information of the preceding category.

3. Information concerning the disappearance of toxicity in a body of water. This information is the easiest to obtain, though some important factors have to be taken into account in our procedure.

It is not our purpose here to describe the standard method which, in our opinion, should be used for each kind of information desired, since this is published in another paper (Prévost, 1960b), but the experiments performed with these toxicants and the results obtained will stress the importance of a standard method and of all the numerous factors we have to take into account.

Here are some examples of these:

Source of the Fish. Speckled trout of same strain, same weight, but of different length and from two different hatcheries, and fed differently, one with mostly a meat diet, the other with dry food, show a great difference in resistance to Toxaphene (Leduc and Prévost, 1959b). Both groups were submitted to a concentration of 0.00296 p.p.m. of Toxaphene at five degrees Centigrade. With the group from Baldwin's Hatchery where a diet poor in meat was given, the fish start to die after 4 days, while the fish from the St. Faustin group, with a richer diet in meat, start to die only 14 days later when 60 per cent of the other group have already died. The interval between the two curves is sufficiently great to remove all doubt. The experiment shows also that the bioassay technique such as recommended by Doudoroff *et al.* would not show any

mortality and so would be inappropriate. We must mention that we had comparable results on using Toxaphene at higher concentrations, say 0.0048 and 0.0148 p.p.m. The interval was, of course, narrower in this case. Thus, an experimenter is only deceiving himself if he thinks that by using specimens of a species of fish, of a certain size, from one source, his results could be compared to those of another experimenter of another district who used the same species of fish, of the same size, but from a different source. But keeping a record of the whole history of the fish would help him to understand the difference between the results. He might then be able to explain some divergence, as we think we are able to do in this case. Although Toxaphene metabolism in fat tissues is not yet established, fat content of the body seems to be a limiting factor of intoxication as a result of its liposolubility (Anonymous 1952, Metcalf 1955). The greater resistance of the St. Faustin trout to Toxaphene could be explained by a weight relatively higher for their length than those of Baldwin Mills, probably owing to a larger fat deposit caused by a meat diet as compared to a dry diet.

Size and Ontogenesis. It has been demonstrated many times that a big fish would resist toxicants better than a small fish of same species. We should consequently suspect that a young vesiculated fry should be less resistant than a 6-inch fish. But Steinmann (1927) showed that trout fry prior to the resorption of the yolk sac are less sensitive than the adult animals. Fujiya (1955) showed that the fertilized egg of carp is more resistant to Endrin than the fry at five days, three weeks, six weeks and three months after hatching, and Iyatomi Kisabu *et al.* (1958) have shown that the median tolerance limit for a carp of one day after hatching is 180 times greater than after six days at a temperature of 20°C. In using Toxaphene at a concentration of 0.740 p.p.m. on speckled trout, we found (Leduc et Prévost, 1959b) that sensitivity rises following the embryological development. At four and five weeks old, mortality is nil after 170 hours, but reaches 100 per cent at 10 weeks old, after 20 hours. The increasing sensitivity following the development is understandable when we look to the fat content as a limiting factor of intoxication with Toxaphene; a brief round-up of the literature concerned with biochemical changes during ontogenesis shows that fat is mainly utilized at the end of the sac-fry stage (Phillips and Dumas, 1959). Metabolism of fat could then explain the difference of sensitivity to Toxaphene in our experiments. This shows that if we require sensitive fish, we should use specimens not less than 10 weeks old, and since the one-year trout is fairly close to the 10-week fry, as far as sensitivity is concerned, it would seem a desirable fish for long-term experiments.

Duration of the Experiment and Symptoms. In the bioassay methods described by Doudoroff *et al.* (1951) for checking the toxicity for mortality tolerance limit, time was established at 24, 48 and 96 hours, and occasionally eight days, but later on Doudoroff, Katz and Tarzwell (1953) revised these methods and suggested 10 days. They state also that "very pronounced distress and persistent loss of equilibrium (turning over)" would be a sufficient criterion. But we do not agree on these points, as fish can begin to exhibit symptoms after a much longer time than 10 days. For example, a catfish died only after 84 days' exposure to a concentration of 0.2 p.p.b. of Thiodan, and *Semotilus atromoculatus*, exposed to one p.p.b. of Thiodan, turned over after 8 days and remained like that for six days. When put back in fresh water, it regained its equilibrium within 24 hours. It follows from this that death must be the criterion used in our experiments, if we do not wish to be led astray in actual poisoning of natural waters.

Volume of Solution. These results alone show that we have to be very careful in our assumptions, especially when we wish to know the concentration which will kill all the fish, not only 50 per cent of them.

It is, therefore, very important to determine the volume of solution to be used when we operate in still water. According to Doudoroff *et al.* (1951), we should use not less than one liter per gram of fish and not less than one liter per fish. However, Doudoroff, Katz and Tarzwell (1953) modified their method, in the light of our work (Prévost, Lanouette and Grenier, 1948) showing that decrease of toxicity in a small volume of water might impair the results of the experiment. They found that with Toxaphene one liter per gram of fish was insufficient and they suggested five liters. This apparently was decided empirically since no experiment is mentioned to show that it was the correct amount of solution to be used. No doubt they thought this quantity was great enough to produce any effect that was due to appear. For the concentration used, they had the expected results, but for the kind of information we need in our work it would not be satisfactory, as demonstrated by the following experiments (Leduc and Prévost, 1959a):

Speckled trout (*Salvelinus fontinalis*) placed in a concentration of 0.0285 p.p.m. of Toxaphene show different results: if they are placed in a volume of 0.83 liter for each gram of fish no mortality occurs, but if they are placed in a volume of 1.66 liter per gram, 50 per cent die, and in five liters, mortality is still higher, say 85 per cent.

This shows very clearly that one liter per gram of fish, which is the general standard admitted for testing poison, would not be acceptable for the kind of knowledge we wish to have, since what we have in view is to find the minimum concentration of a poison which would kill all the fish. It follows that if we had used a weaker concentration, it would have been still more obvious that the ordinary recommended volume of one liter per gram of fish is insufficient. Even five liters do not suffice.

However, if we have to operate in a restricted volume of water, we must first test it in different volumes, taking account of the species of fish, its size, and other factors such as temperature, etc., and establish the minimum volume necessary. Although this method is the only scientific one for determining the correct volume of solution to use, we can rely on another one which consists of using what we estimate to be an excess of solution, and repeating the test in the same solution (Hooper *et al.*, 1955). If the results are not the same or nearly the same as in the first test, we increase the volume of the solution and start all over again. Waste products from the fish might affect the fish themselves and might then act similarly to the poison of the solution, and on the other hand, a diminution of the toxicity could result from the absorption of the poison and its elimination by its breakdown in the organism. Again, if the fish survives a longer time in the already used solution, this does not necessarily mean that the concentration of the poison has decreased accordingly but that the secretions of the fish may have produced a better habitat. In fact, it has been demonstrated by Allee *et al.*, (1934) that there is an optimum habitat for fish, which is not necessarily represented by pure water. It has been proved, in general, that fish thrive in water containing a certain quantity of substances produced by the fish themselves, this water being then called conditioned water. Thus, under some circumstances, chemical analysis of the water might be desirable to give a better evaluation of the effect of the poison used.

Instead of using a great volume of water, we can change it as often as necessary, and wherever possible, it is better to have a constant flowing solution in quantity

great enough that similar results would be given by using two aquaria in succession, the second one receiving the solution from the first. Some mechanical devices for dispersing the product in water can be found on the market, but there is a very simple device developed by Grenier of the Quebec Biological Bureau (1960) using the principle of the Mariotte Bottle. This system delivers a constant flow of a constant concentration. The temperature of the water is kept constant through a cold unit system and an automagnetic valve to supply warmer water if desired. The temperature is constantly recorded on a micromax and the variation is less than 0.2 degrees Centigrade. This arrangement allows us to pursue experiments month after month, and would be very valuable for bioassays in pollution work also, if we wished to detect a chronic pollution caused by minute amounts of a toxic material.

Temperature of the Water. Since metabolism increases with temperature, experiments in flowing water at 5°, 10°, 15° and 20°C were set up, using *Salvelinus fontinalis.* Leduc, Grenier and Prévost (1959) found a marked difference between 5° and 10°C, which stresses the sensitivity of the trout in that range of temperature. The threshold of sensitivity of the trout of 20 gr. has been found for a 30-day period at 5° and 10°C to be 0.00148 p.p.m. of Toxaphene. However, this is no longer valid at 15° and 20°C, where mortality reaches 40 per cent and 88 per cent respectively after 28 days.

Short periods of 96 hours as used by Henderson *et al.*, (1959) are not sufficient to define toxicity of insecticides such as Toxaphene, when used chiefly at low temperatures. In our case, observations confined to 96 hours would not indicate any effect of Toxaphene below 0.0029 p.p.m., while 100 per cent mortality is obtained when the experiments are pursued a longer time.

Natural Waters

Recalling what we said about the failure of netting or other mechanical procedures, or partial poisoning, to remove enough fish in our type of waters, we must try to kill all the undesirable fish and prevent their introduction. With the poisons mentioned, we kill trout also, since they are the most sensitive of all the fish we have to deal with. These poisons have not been found selective enough to save them, and the usual conformation of our lakes does not permit successful spot poisoning, as can be performed in other regions. Consequently trout will be killed, and will sink to the bottom of the lake like most individuals of the other species. Thus, unless the lake is very shallow and permits the viewing of the bottom, or a thorough search with "Scuba" equipment, one is unable to establish the fish population of the lake in this way as some people think, being under the impression that most, if not all of the fish, float to the surface.

Prerequisite

First we must establish that but for the coarse fish, trout would live well in a given lake and second, that coarse fish cannot reintroduce themselves naturally. We must therefore consider the upper waters and the outlet.

(1) *Upper Waters.* If there are other lakes flowing into the one we wish to poison, we have to be sure that no coarse fish are present in them. If there are any, poisoning of those lakes also should be performed. Some people think that a screen could efficiently be placed to stop fish from coming down. Although it is theoretically possible, it has rarely been efficient, since such screens are liable to break at any time, expecially in

winter. They would have to be made of very small mesh to prevent small fish passing through and, in most cases, would require a great area to allow the water to flow through. But, if there is no other way, we would recommend three screens in succession, 10 feet apart, so that if one breaks it can be repaired without danger of contamination. The only sure way, however, of keeping out coarse fish from higher up, is to poison all the lakes containing them.

Outlet. It is important to know the course of the outlet. If it passes through somebody else's property or if it flows into another lake, we have to make arrangements with the owners, since toxicant will be carried downstream, and could kill fish, unless some successful means are provided to prevent this, means which at the moment are under study. This being done, we must check very carefully to find if there are any straight waterfalls of at least four feet high, anywhere in the outlet, to prevent the ascension of undesirable fish from downstream. In addition, if adjoining streams flow into the outlet before we find such a waterfall, these have to be poisoned also, or screened, as described above, and if they lead to lakes where there are coarse fish, these lakes also have to be poisoned, unless efficient screens can be installed. If there is no such waterfall, perhaps some spots can be dynamited, with a view to creating the required four-foot waterfall, or else a concrete dam can be built. A wooden dam is usually very precarious; it may deteriorate very quickly and so we do not recommend it. A beaver dam is not reliable either. Too many failures have resulted from such dams. Of course, screens are very liable to break, as mentioned for the upper waters. If a four-foot dam cannot be built, but only a two-foot one, fish can still be prevented from going up a stream by placing two rows of horizontal screens below the dam over the level of the water (Prévost, 1960). If a fish tries to jump, it will hit the iron bars; it cannot go through two rows and even one row might be enough. If it is demonstrated that many fish, after restocking, come downstream, this can be prevented by building a horizontal screen on the front of the dam (Prévost, 1960). This kind of screen does not block very easily with leaves, branches, etc., and the area can be enlarged as much as is necessary.

It has been written quite often that birds transport fish or eggs from one lake to another, and some people assume from this that a lake will be reinfested. Though this may happen in the tropical countries, it does not appear to happen here, since we have many virgin lakes, i.e., lakes without a single fish, and there is one particular lake, poisoned 14 years ago, which has had no re-introduction of coarse fish. These observations, I think, prove better than anything else that in our area at least, birds count, I would say, for very little, if at all, in the dissemination of fish. Thus, the only other possible reintroduction of coarse fish is by man, and this unfortunately happens too often. We had to poison a lake three times, because after the treatment perch was introduced by fishermen. It was particularly sad in one case, because some fishermen said that the biologists were simply crazy to kill all the minnows. Trout need minnows to grow (they said) and so they reintroduced them. But this of course was 15 years ago. Now, the rehabilitation programme is well understood, and we do not expect anyone to have such backward ideas. This does not mean that minnows will not be reintroduced accidentally by people fishing with them, even though in some districts there is a complete ban on the use of minnows.

Application of the toxicant in natural waters

(A) *In still waters, such as lakes, ponds*

(a) *General Procedure*

(1) *Open drum + Gasoline pump + Outboard motor.* This is the most common type of equipment we use, because it can ensure good dissemination of all kinds of products, such as Rotenone in powder or liquid form, Toxaphene, Endrin and Thiodan. In principle, it consists of a 40-gallon drum resting on a platform, which is laid on two row boats. At the bottom of the drum, a two-inch opening is provided, and on the outside there is a valve to regulate the flow we require. On each side of this valve two pipes, about five feet long, convey the solution to each side of the boats. Although perforated pipes are not absolutely necessary, they provide faster diffusion. To have continuous operation, a pump, pouring about 30 gallons of water per minute, mixes the toxicant in the drum. The toxicant itself, if it is in powder form, is placed from time to time in the drum by the operator, at the concentration judged sufficient for the conditions we have to encounter, and is mixed with a paddle or a stick. If it is in liquid form, it can be poured continuously at a speed calculated so that good dissemination of the product will be ensured all over the lake.

(2) *Loose knitted bag.* Rotenone in powder form is placed in a coarse knitted bag such as the ordinary potato bag, which is towed behind a boat, so that the powder escapes slowly. It may need to be tapped from time to time with a paddle to help the escaping of the powder. This method, although slow, is very practical in small remote lakes when minimum equipment is desirable.

(3) *Direct from the original container.* Some materials such as Endrin and Thiodan, and liquid Rotenone, can be spread directly over the lake without having to be pre mixed with water. Toxaphene cannot be applied with efficiency in this way, because it will sink, unless it is dropped in the wake of an outboard motor. Rotenone in powder form, less miscible except with a wetting agent, will float, and mixes very little with water. These procedures are the basic ones but very often we have to use supplementary methods, which vary with the conditions we encounter in the treatment of a lake. Thus, we look to see if any of the following conditions are present and use the appropriate methods.

(b) *Factors to be considered in poisoning a lake*

(1) *Thermocline.* It has been demonstrated that the thermocline stops the descent of many kinds of material, and so if we perform poisoning in summertime we have to be sure that there is no thermocline, or if there is we must take steps to cross through it. But since most of the lakes have a thermocline, we perform our poisoning in the fall when the thermocline has disappeared, and in this way we are sure that poison will spread all through the lake. Although poisoning could be done in the spring with presumably the same good results, we have not tried it yet.

(2) *Weed beds* which cannot be easily reached by boat have to be thoroughly sprayed with a concentration at least three times as strong, because much of the material can stay on the emergent weeds, and not reach the water. A thorough coverage is therefore necessary. Plane-spraying does not give good results in such areas, as could

be expected, because the fine drops of liquid stay on the emergent weeds and there is also some evaporation on the way down. The liquid has to be forced through the weeds if good results are to be expected.

(3) *Floating Islands.* Poison has to be forced under these. A gasoline pump is very useful for this. Holes can be made through the floating ground at about 50-foot intervals, and a hose inserted. Sometimes dynamite placed under the islands will help to mix the poison with the water and distribute it into all the corners.

(4) *Springs at the bottom.* If these springs are of considerable size, it is advisable to locate them with "Scuba" equipment, because we have to place the poison there in good quantity, and in a continuous flow for a time, since it will be driven away very quickly. Rotenone is still the best product to use under such circumstances, since it has a very rapid action; the others might not be effective unless they are poured a long time. Such a conformation, however, is not found very often in our lakes, and is bound to arise mostly when small artificial lakes are dammed up and the source of the spring is then covered by the water of the lake. To reach a spring of this kind the best method is to lower the level of the lake, when possible.

(5) *Mud bottom.* It has been observed, in some instances, that toxicants have a diminished action in shallow muddy lakes, and in such a case, if catfish are present, we usually put (at least for Rotenone) a concentration three times as strong, say three p.p.m. of five per cent Rotenone of Cube Root. For the other toxicants we have had no experience yet of this factor, but we presume that the same procedure should be followed.

(6) *Temperature of the water.* Although a low temperature delays the action of these toxicants, a complete kill can be achieved if the proper concentration is used, even at 33°F.

(7) *Turbidity.* As our lakes are quite clear (Secchi disk readings from 7 feet to 20 feet) we have not had to consider this factor with Rotenone, although we might have to take turbidity into account with the other products.

(8) *Alkalinity of the water.* In general, alkalinity of our water is low, generally not more than 10, and so this cannot contribute to lowering the efficiency of these products (Hemphill, 1954; Hooper, 1955) as has happened in other regions, where alkalinity can be 200 and more, making it very difficult to poison lakes, especially with Rotenone.

(9) *Other factors.* As we go along, it is quite possible that we shall find more factors affecting the toxicity of these products; for example: light, chemical composition of the water, etc.

(B) *Application of toxicants in streams*

The streams are the most difficult areas to treat, on account of their running water. The poison will not stay very long in them, and so we have to use different methods. If lower down there are lakes which we wish to poison also, they must be treated first, because if we begin with the streams, they will clear very quickly, and thereafter when the lake is treated, fish could find refuge in the now clear water of the stream.

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