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Artificial Freshets and Other Factors Controlling the Ascent and Population of Atlantic Salmon in the LaHave River, Nova Scotia

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INTRODUCTION

CONSERVATION practices designed to improve angling have been in operation for many years. They include in the first line, laws concerning seasons, bag limits, types of gear and the like, together with appropriate enforcement officials. In the second line stand the hatcheries, which rear and distribute young fish annually. Finally there is the problem of clearing out the streams so that the salmon can reach their spawning grounds. Progress here has been negative, which is to say that obstructions in the form of dams have been installed to a much greater extent than clearance has been attempted. The limitations and deficiencies of all the procedures have been under scrutiny in various parts of the world.

The experiment to be reported was an examination of a further conservation technique. Experiments had suggested that freshets similar to those caused by rainstorms would induce Atlantic salmon (*Salmo salar*) to run up from the salt water. It was further thought that improved angling would follow if, through storage, an adequate flow of water was maintained in a river during the summer months.

Preliminary discussions of the work were begun late in 1945. It was decided that a party should be placed in the field during the summer of 1946 to investigate several rivers, with a view to the selection of one suitable for setting up an experiment on the control of summer water volumes and the production of freshets. A suitable river would be one in which (*a*) good salmon angling had existed in rainy years, (*b*) headwater storage lakes were present and (*c*) the waters were not already taken over for electrical power. The most promising rivers appeared to be the LaHave, St. Mary's and Medway, and of these the LaHave was selected.

The research which led to the LaHave experiment was carried out in 1939-1943 by Dr. A. G. Huntsman and colleagues on the Moser River, 70 miles east of Halifax (see Huntsman, 1948). In the very dry summer of 1942 a dam was set up at Round Lake up the river, and the gates opened at intervals to produce freshets. Salmon were trapped for counting at three points as they ascended the river. It was found that short successive freshets in the latter part of July, brought up salmon. By the end of July the stock in the estuary was presumably almost used up and freshets in mid-August gave smaller returns. From the beginning of August the water level was kept up by partial opening of the gate; and on August 7 a kind of sub-freshet was produced in which the usual quantity of water was added over a period six times as long as before. In both cases the effect was negligible.

The general conclusion was that a changing rate of flow acts as a stimulus to movement in the river. The fact that fish leave the estuary for fresh water in response to a freshet may be either due to dilution of the salt in the water, or a direct effect of the current.

A repetition of the experiment in 1943, a wet summer with numerous natural freshets, gave less clear results than those of 1942. It was also observed that, despite the salmon that were induced to enter the river in 1942, angling was not improved, either because of low levels between freshets or because of high temperatures. In 1943 as well, although the water level was kept up, angling became unprofitable in July. The possibility also exists that the stock of salmon in an estuary might be used up before the summer is over, as apparently happened in 1942. For these reasons it was thought desirable to try out the technique on another river for several seasons.

Preliminary Standard

There were no initial data as to what water volume and what size freshets might be expected to ensure good fishing on the LaHave. However during the summer of 1946, a field party observed conditions on the St. Mary's River. The season was dry and angling was poor, except for the temporary good fishing resulting from one rainstorm. An analysis of the critical period, as shown in Figure 1, provided a basis for a rough estimate of minimum requirements. A plausible deduction from Figure 1 is that good salmon angling would have been provided if the general flow had been maintained at 200 cubic feet per second and an artificial freshet provided each week in which the volume was raised to 400 cubic feet per second for a 48-hour period. Since the St. Mary's

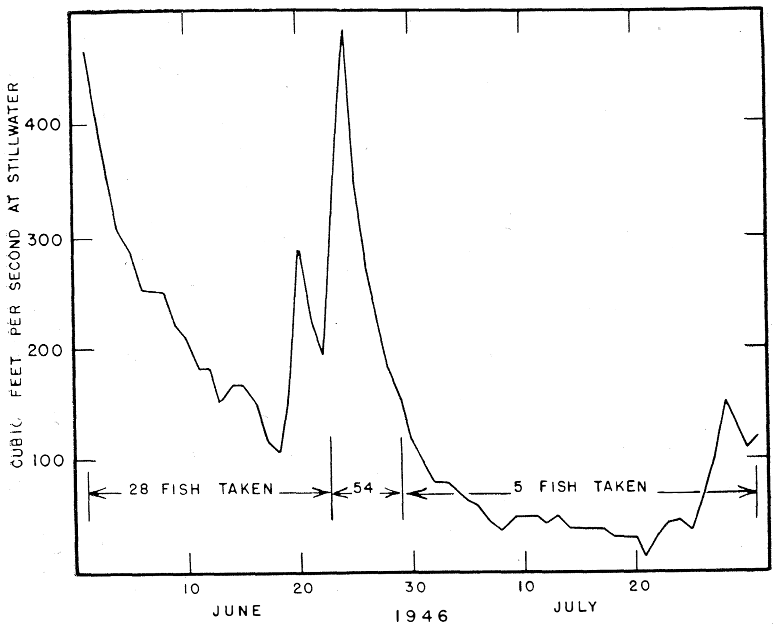

Figure 1. Relation of salmon angling to water volume. St. Mary's River, 1946.

River and the LaHave River are about the same size, the values were taken as a basis for the LaHave experiment.

In practice the freshets on the LaHave were of shorter duration than the foregoing paragraph would suggest, lasting usually for four hours. They were also of greater volume, up to 1,600 second-feet. The general aim was to keep the river volume at 400 second-feet as long as the supply lasted, except for periods of experimental lowering to 200 second-feet to see the effect on angling. Lowering of the river is not well received by guides and anglers, so that tests in this direction were curtailed. On the other hand, the maintenance of a good flow during the summer interfered with haying operations on intervale meadows. Thus the manipulation of water was not something that could be worked out in an office before the season started. It was more like a day-to-day resultant or vector of several forces, of which the force of public relations was not the least.

ACKNOWLEDGMENTS

This investigation was initiated and financed by the Nova Scotia Department of Trade and Industry. Its guiding spirit was Dr. D. L. Cooper, whose solid support freed the writer from many cares.

The staff of the Fisheries Research Board has been of unfailing help. To Dr. A. G. Huntsman the writer owes, not only the scientific debt apparent to any reader of this paper, but a personal obligation for advice and practical aid in getting started. Dr. A. W. H. Needler has always stood in closest consultation when our plans were being made. Several of the field workers were apprenticed to Dr. Paul Elson and Mr. Harley White, who showed them how to set up counting fences and seine streams.

The Federal Department of Fisheries made a contribution towards the cost of the dams, which were designed by Mr. Harry Lynch. The Department also participated in the tagging operations and provided angling records. Mr. Forrest Watson has helped out in many ways. On the river Mr. James Buchanan and Mr. Glendon Smith have assisted the work wherever possible.

The Dominion Water and Power Bureau made its records available and installed automatic recording equipment in the LaHave. Mr. K. G. Chisholm gave a great deal of personal help in matters of interpretation.

Weather records were provided by the Dominion Public Weather Office through the courtesy of Mr. R. A. Hornstein.

Dr. W. E. Ricker and Miss Jean A. Peabody have been kind enough to read critically the sections dealing with angling success as a standard for measuring river improvements.

About a dozen university students worked on the LaHave during one summer or another. All deserve thanks but especially those on whom responsibility fell. James Lewin surveyed the river and drew up the original recommendations for dams. Donald Rice and Reginald McColough set up the counting fences, and the latter conducted the first freshet experiments. Douglas MacDonald carried out the programme of freshets for two seasons. Donald Woodside was responsible for the population studies of young salmon and other fish.

DESIGN OF THE EXPERIMENT

The River and the Dams

The LaHave River (Figure 2) empties into the sea on the south coast of Nova Scotia, about 45 miles southwest of Halifax. The head of tide is at Bridgewater, below which is a navigable estuary 11 miles long. In summer the

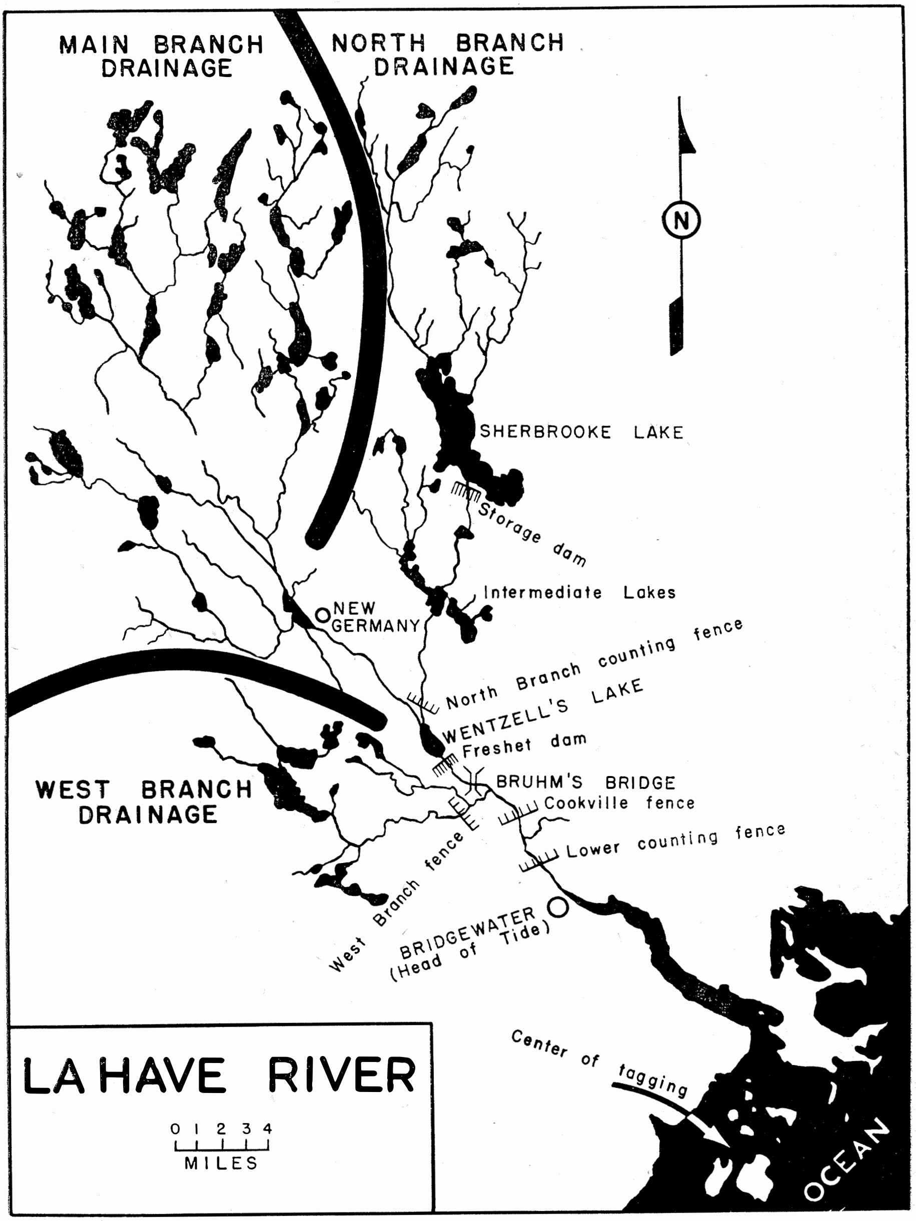

Figure 2. Map of the LaHave River showing location of places mentioned in the text.

river discharge forms a surface layer of virtually fresh water, which is about two feet thick at Bridgewater, and thins to the point of disappearance two or three miles downstream. Below this layer is sea water of some 3 per cent salt.

Most of the river lies in Lunenburg County, but the headwaters extend across the province into Annapolis and Kings counties. The drainage basin covers about 500 square miles and, as Figure 2 shows, there are three branches to the LaHave, which may be mentioned in turn. The West Branch drains about 15 per cent of the whole. Salmon ascend the branch part way and at its head there is a chain of lakes which could be used to store water. There is little salmon angling on the branch and few salmon move up during summer months. Beyond the operation of a counting fence for one season, no part of the experiment was carried out on the West Branch.

The main LaHave River flows through New Germany down to Wentzell's Lake. There is a small lake at New Germany blocked by two dams, neither of which has a fishway. The lower dam is connected with a pulp mill, the upper with a box mill—major industries for the area. Angling in the branch is poor below New Germany and nonexistent above. No analysis was made to see whether waste chemicals are discharged into the river. There are doubtless potential salmon spawning grounds above New Germany which would be used if obstructions were removed. No part of the experiment was conducted on the Main Branch.

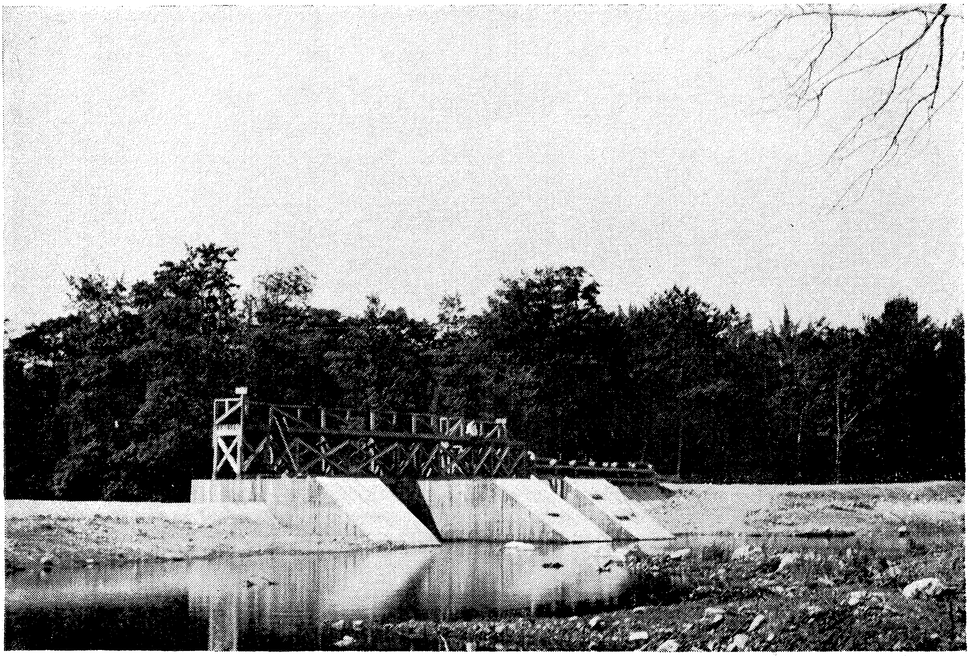

FIGURE 3. Sherbrooke Lake storage dam seen from above. There is a double gate at centre, raised and lowered by two gate hoists. The dam also contains a fishway, and there is a lumber-driving gate. A head of six feet of water over an area of seven square miles is maintained by the dam.

The North Branch has as its headwater Sherbrooke Lake (locally called Nine Mile Lake), which is nearly nine miles long and has an area of seven square miles. It was here that a storage dam was constructed, replacing an older broken down dam. The dam, which is illustrated in Figure 3, is 200 feet long and made to retain a six-foot head of water, which is about 1.2 billion cubic feet. The dam is pierced by two gates which can be raised by gate hoists, a driving gate blocked with stop-logs, and a fishway.

In the preliminary formulation of the experiment it was planned to keep the summer flow of the river above Bridgewater at 200 cubic feet per second during the angling season. It was also intended to produce an extra 200 second-feet for freshet purposes during 48 hours of each week. From an examination of 30 years of past summer water records, the expectation was that in 19 per cent of summers no control would be necessary, as rain would suffice. In 68 per cent of the seasons, the 1.2 billion cubic feet at our disposal would suffice to keep the water as desired. In the remaining 13 per cent of summers, stored water would be used up before the angling season closed. These expectations were not

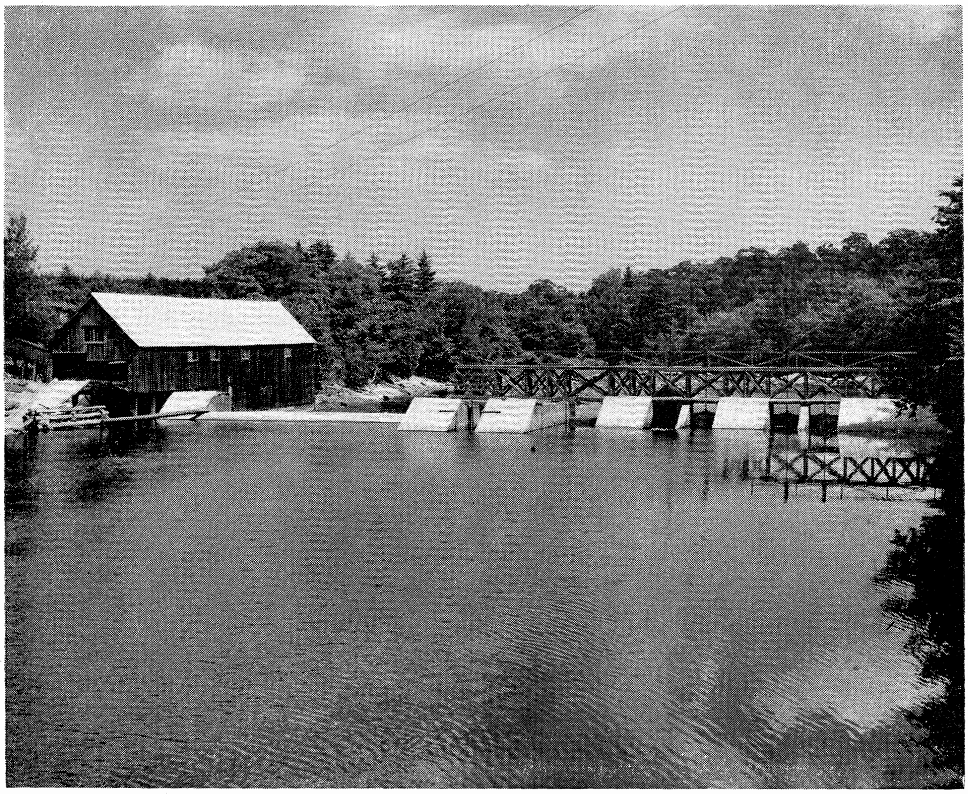

FIGURE 4. Freshet-production dam at Wentzell's Lake, seen from above. To the left is the mill which uses the stored water for power at certain times of year. The wide opening to the right of the mill is the spillway, and then a fishway, log driving gate and two double freshet gates. To produce a freshet the gates are raised by four hoists on top of the dam.

completely met, since protests from landowners about flooding of timber land around the lake made it necessary to discharge some of the stored water early in the season. However, something like three-quarters of the theoretical demand was met in practice.

In a general proposal to bring about an increase in summer water levels and also to produce periodic freshets in the estuary, an ideal river would be one in which the same storage lake could serve both purposes. It often happens, however, as in the LaHave, that intermediate lakes or deadwaters lie between the storage basin and the sea. Under such conditions freshets from the basin tend to be buffered into a steady flow as they go along; it is impossible to transmit the freshet to the estuary, for it raises this lake an inch or two and that lake an inch or two and so comes to an end. The solution is a storage dam at the headwater lake and a freshet dam as close as practicable to the estuary.

For reasons just mentioned, a freshet dam was constructed just below Wentzell's Lake, giving a direct flow to the estuary. The dam, which is shown in Figure 4, replaced a mill dam on the site. It was equipped with four gates furnished with hoists, a log-driving gate with stop-logs, a fishway and a spillway. Wentzell's Lake, which constituted the freshet basin, has an area of 0.55 square miles in which a two-foot head of water was retained. The arrangement proved adequate for production of freshets of any size desired. In later years, owing to protests about flooding of meadows above Wentzell's Lake, the head maintained was cut to one foot, so that maximal freshets could no longer be produced.

It should be remarked that Wentzell's Lake by itself would not serve for river management because its area is insufficient to store a season's supply of water. Also as noted, the lake could not be raised very much without flooding valuble land. Finally it would not help the large stretch of the North Branch lying inland, which provides good angling during the later part of the season. For these reasons Sherbrooke Lake had to be used as well.

Counting Fences

Counting fences were set up at several sites on the river. Figure 5 illustrates their general design, where the arrangement is for counting ascending fish only. In later fences there was a second trap to count descending smolts and other fish. This particular design is made to be installed and operated in a depth of six feet of water or less. It consists essentially of a picket fence across the river, placed at such an angle that the gaps between the pickets are equal to the cross section of the river, so that there is no backing up of the water. The trap proper forms a part of the fence in the river channel, and is entered by the fish through a funnel. From time to time the fish are counted and released through the upstream door. Once built, a trap can be removed in sections and set up again in any desired location; in general it is a temporary installation placed at any site where information is to be obtained. The pickets are nailed to racks. In the spring, racks are used in which the spaces are narrow enough to prevent smolts going through, so that a smolt count can be made. After the smolt season, more widely spaced racks are installed. Pickets are placed as far apart as possible (while still stopping salmon) in order to minimize loss of the fence from floods. When floods do occur, some of the racks may be lifted out for a day or two to save the fence. Nonetheless it is not unusual to lose a section or two of a fence during a storm.

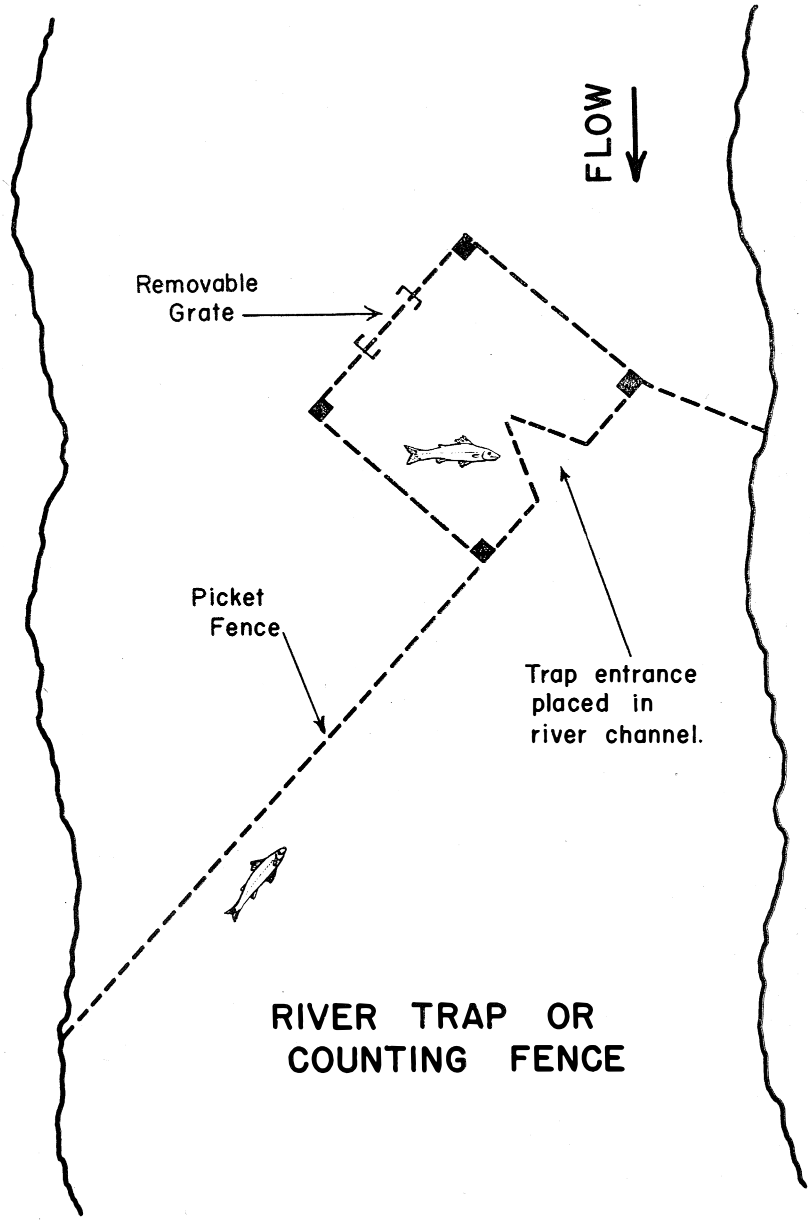

FIGURE 5. Type of counting fence used on the LaHave. This fence has only an upstream trap, but later models had a downstream trap as well.

One of the inconveniences of operating counting fences is in taking care of the heavy run of gaspereau (*Pomolobus pseudoharengus*) which moves upstream in the early part of the summer and downstream later on. Beaver also occasionally get into the trap and do considerable damage to the woodwork before they are released. Several muskrat were also caught, one of which had killed a salmon in the trap; another was attacking a salmon when found. They, too, chewed holes in the woodwork. Numerous turtles entered the trap but did no damage. They were the only animals exhibiting sufficient intelligence to make directly for the gate as soon as it was opened to release them.

Counting fences very often fail under high-water conditions. Leaves, or occasionally hay from intervale meadows, are washed down and block the racks,

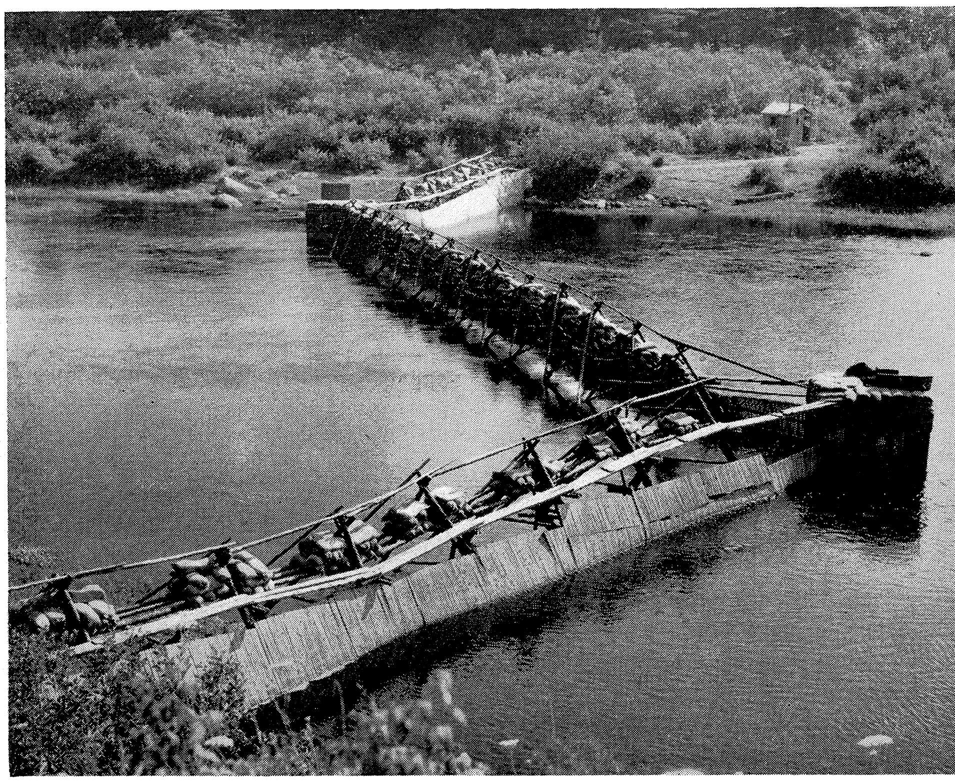

FIGURE 6. Main counting fence, located about a mile above the head of tide at Bridgewater. The river flows towards the left, so that the nearest trap is for ascending fish, and the more distant one, whose cover is open, is for descending fish. The watchman's cabin is on the far shore. In the spring the racks were narrow, to hold back descending smolts, but after the smolt run they were replaced with more widely spaced racks, which stop salmon while at the same time offering less chance of damage to the fence during freshets. The fence is Z-shaped and the limbs make a 45° angle with the river banks, which shape appears to provide maximum strength. When the angle with the shore is too great, approaching 90°, the fence acts as a dam and is likely to give way under high water. When the angle is too acute, say 20°, the water is funnelled into the trap instead of passing through the laths, so that the trap tends to break away when the river is high.

so that the water pressure breaks out a section of the fence. Perhaps a tree or a boat will pierce the structure. It may then be several days before the water goes down enough to permit repairs, and during this time salmon may be ascending uncounted in numbers which have to be guessed. However it is well to state clearly that the primary purpose of counting fences of the design used, was to test the effect on salmon migration of artificially produced freshets and small natural freshets which parallel the artificial ones in magnitude. This function the fences fulfil admirably. When failure of a fence occurs it is the seasonal total count which is interrupted, not the freshet experiments.

In 1947 a counting fence was set up at Cookville, over three miles above the head of tide. It was operated only for a month in mid-summer, when the weather was warm and the river was low. About one salmon passed through every two days.

In 1948 the fence was again installed, beginning operations on June 17, following which the first freshet trials were made.

In 1949, in addition to the Cookville fence (May 13), there was another established near the head of tide, within the town limits of Bridgewater (counting began June 6). This fence, which is shown in Figure 6, was 330 feet long and had counting chambers for ascending and descending fish. The structure probably approached the practical limits of size for a fence of this design.

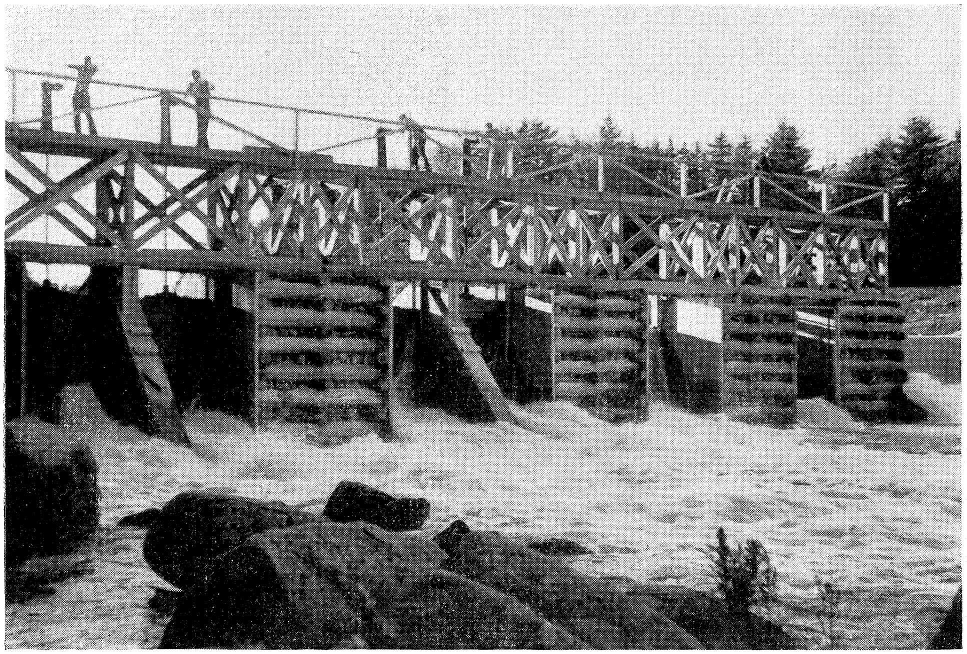

FIGURE 7. Wentzell's Lake dam seen from below during production of a freshet. Four men on top of the dam are raising the freshet gates by hoists. The fifth opening from the left is a log-driving gate, not used in the experiments. The opening at extreme right is a fishway and beyond it the spillway.

In 1950 the Cookville fence was not set up, having served its purpose. There was again a fence at the head of tide and two other fences to measure ascent of the West Branch and North Branch.

In 1951 only the head-of-tide fence was used.

Freshets

The course and production of freshets will be apparent from Figure 2, which is a map of the river, and Figure 7, a photograph of a freshet being turned on. Usually four gates of a size 6 feet x 4 feet each, at the Wentzell's Lake dam, were opened, the operation occupying four men for about half an hour.

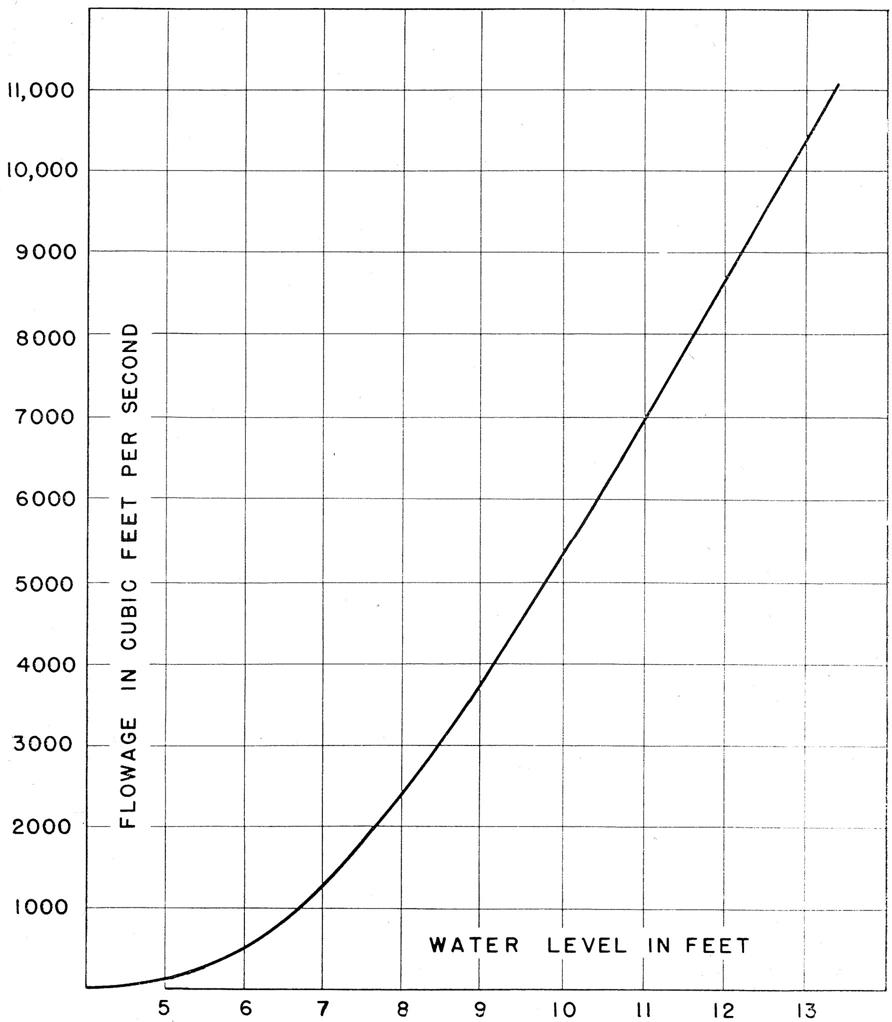

Figure 8. Graph for conversion of levels at Bruhm's Bridge to cubic feet of water per second. Courtesy of Dominion Water and Power Bureau.

The estimate of water volume was taken from an automatic recorder which the Dominion Water and Power Bureau installed in 1949 at Bruhm's Bridge. Levels were observed at the counting fence at Cookville and head of tide, and were calibrated with Bruhm's Bridge values. After the time relations of a few freshets had been worked out, it became possible to restrict observation of levels to Bruhm's Bridge alone. This meant in practice simply taking off a copy of the weekly chart at the Bruhm's Bridge recorder, from which the appropriate levels were read.

Results have been set down as second-feet (cubic feet of water flowing down the river per second). The advantage of this notation is that it permits easy comparison of Sherbrooke Lake storage with river flowages and enables one to forecast how long a storage basin may be expected to last. Measured levels were converted to second-feet by use of a table prepared by the Dominion Water and Power Bureau. The table, expressed in graphical form in Figure 8, was drawn up as a result of numerous measurements at Bruhm's Bridge by officials of the Bureau during the past 30 years. A second graph for low summer levels of the river also was supplied by the Bureau.

Figure 9 shows the time relations of a single freshet as it went down the river. The period marked "Gates open" goes from the mean time (gates halfway open). The time required to close the gates was generally under ten minutes. The diagram shows clearly that the freshet was transmitted with undiminished intensity from the point of origin to the head of tide. Thus from a technical point of view the installations at Wentzell's Lake were considered a

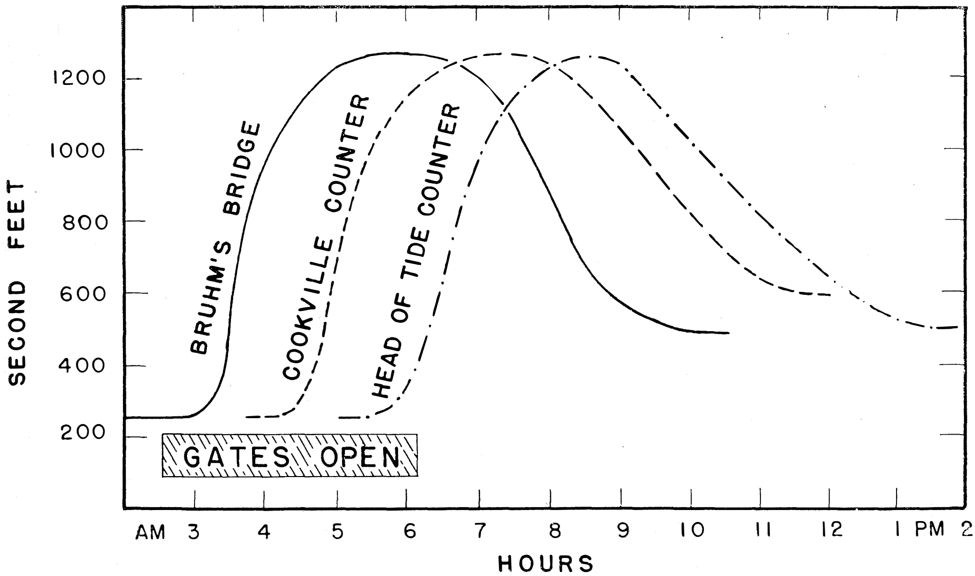

FIGURE 9. Effect of opening gates at Wentzell's Lake on water volume down the river. It is apparent that the freshet is transmitted undiminished to the head of tide. In this particular case levels were kept up after the freshet concluded by the operation of a mill which added water to the river.

success; that is, the dam did what it was set up to do. The time course of a freshet downstream, measured at the point of inflection of the ascending curves, is as follows: gates 0.0 hours, Bruhm's Bridge 1.25 hours, Cookville fence 2.5 hours, Head of Tide fence 4 hours. The particular freshet illustrated lasted four hours. At its conclusion the water at points lower down did not fall to the original volume because the mill at Wentzell's dam had opened up for its morning operations and was discharging some water down river.

In general the custom was to close the gates at the conclusion of a freshet to the point necessary to allow a designated water volume (usually 200 to 400 second-feet) to be maintained in the river.

CONDUCT OF THE EXPERIMENT

Production of Freshets

In 1949 the stored water gave out about the middle of July. In 1950 and 1951, aided by occasional rains, it held up throughout the season, although in the latter part of the summer there was not sufficient left to continue the full-scale freshet programme. In 1949, nine artificial freshets were produced; in 1950 there were ten; and in 1951, seven positive freshets, as well as three "negative freshets" formed by cutting down the flowage for an interval and then restoring the river to its former level.

In Figure 10 there is presented the detailed effect of a freshet on salmon passage through the lower counter. The selected freshet cannot be called a "typical" one. Actually no particular "type" emerged from the freshets produced.

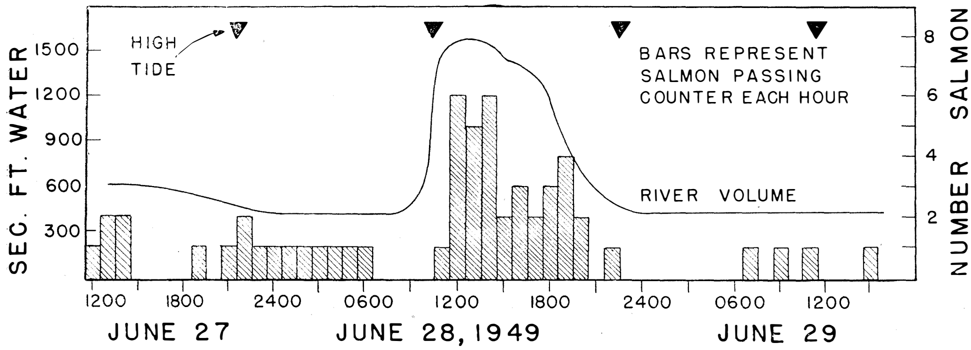

Figure 10. Detail of a freshet effect. All observations were made at the lower counting fence at head of tide.

The one shown in Figure 10 yielded a moderate number of salmon; it was the second best of the 1949 series. As the freshets went, this one was high in volume and long in duration. Figure 10 deals with effects at the lower counting fence, at the head of tide. The freshet was timed to reach the estuary when the tide was at flood so that the added river water would be carried out as far as possible towards the sea. The river flowage was raised by the freshet from some 400 second-feet to nearly 1,600 second-feet, the spate lasting for eight hours. Prior to the onset of the spate, salmon had been entering the counter at the rate of about one per hour. The stimulating effect was almost immediately felt, so that during the course of the freshet 35 salmon were counted. Following the return of the river to its previous level there was an abrupt drop in the salmon count, followed eight hours later by resumption of the pre-freshet pattern. This freshet used up about 3 x 10^7 cubic feet of water, which was one-fortieth of the total initial storage in Sherbrooke Lake. However, in a dry summer more than half of the stored water is required to maintain the river level between freshets, so that only about a dozen freshets of the size illustrated in Figure 10 could be produced in such a season.

As a modification of the experiment in 1950, it was decided to produce two six-hour freshets of maximal size on successive nights. This was because the results with single, short, sharp freshets, of four hours or less, had not been very successful. As an example of procedure, a pair of freshets produced in June 16 and 17 is illustrated in Figure 11. It is seen that prior to the first freshet, and following it, the number of fish going through was quite small. It is thought that this freshet brought fish some distance up the estuary towards the head of tide, but not into the fresh water. A second freshet was produced 24 hours after the first, and was followed by a run of over 100 salmon through the fence.

Operations in 1950

The general activities of the 1950 season can be conveniently considered with reference to Figure 12 which summarizes the principal observations. As regards the artificial freshets (top line), in general they produced an increase in the numbers of salmon going through the counter. However, the increase was in most cases small, a notable exception being when a pair of freshets initiated the major run of the season on June 17, as shown in detail in Figure 11. Following these freshets there was a very small rain, during which the run was continued. The run appears to have depleted the offshore stock of salmon, because a subsequent freshet on June 30, followed by a heavy rain, apparently failed to bring up any numbers corresponding to the previous run. Evidence on this point is, however, incomplete, because the fence was not continuously in operation.

Angling was not very successful until the main run entered the river. It then reached a peak and continued well beyond the usual period of successful fishing, attributable to the fact that stored water kept the river at a satisfactory level. It is likely that the decline in the angling catch during the end of July and August, would not have occurred had the fishing effort been maintained. In most previous years there had not been water enough for successful fishing in August, and fishermen had got out of the habit of trying at this time.

An interesting feature of Figure 12 is the absence of any record of a fall run of salmon. They came in steadily, from nil to half a dozen every day. Records were continued right up to the normal spawning time, which is usually the first week in November. Whether salmon which may have entered with the high water after that date, would be able to spawn, is a question. It must, however,

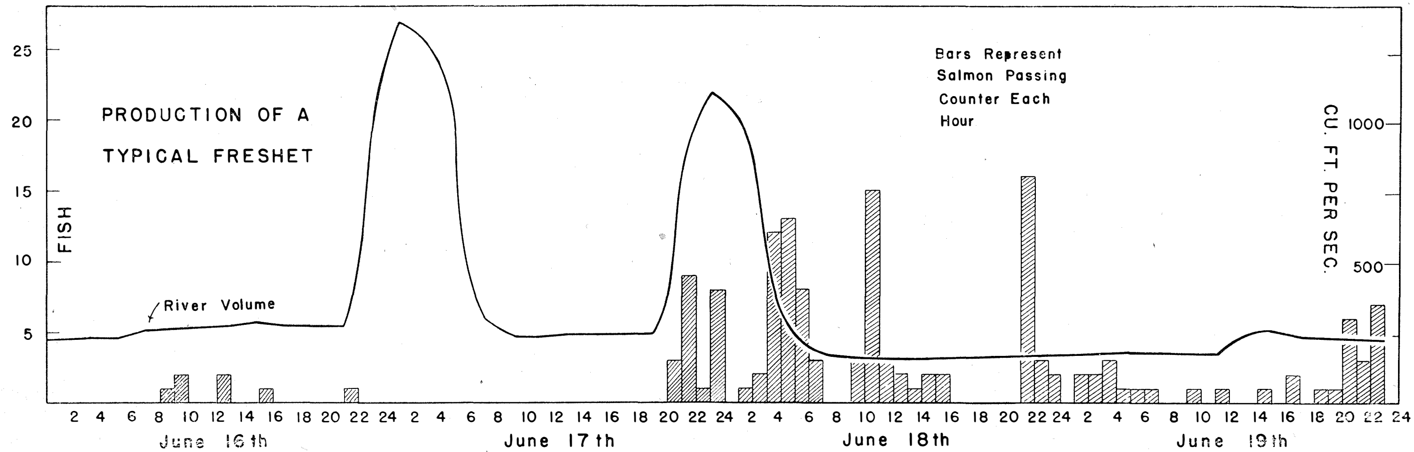

FIGURE 11. Example of the type of freshet production which appeared to be most successful in 1950. Two freshets were produced on successive days. Apparently the first one brought salmon some distance up into the estuary, and the second one took them into the fresh water. Observations were made at the head-of-tide fence.

be noted as a reservation that the fence was put out of operation by high water from August 22 to September 1, during which time there may have been a small run. If a run did occur then, it could scarcely have been a major one, or some traces of its conclusion would have been evident after the taking of records was resumed, in the form of increased daily counts. Figure 12 shows no high counts in early September.

Operations in 1951

The final season of 1951 will be described in some detail, and illustrated in Figure 13. Natural freshets of interest are marked on the large chart by inverted triangles.

No. 1 occurring in May and June was believed to be responsible for a large run of salmon up the river as is indicated by the angling record. This freshet coincides with the strongest onshore winds of the season as well as a minor peak in the tidal cycle.

No. 2 was the result of a small rainstorm on July 18 and was responsible for a run of 65 salmon. This run also coincides with a peak in the tidal cycle as well as strong onshore winds, and is a good example of what a small change in water level can accomplish when all the conditions are right and there are salmon in the vicinity.

No. 3 was the result of heavy rain beginning August 12. The water rose and then levelled off at its new height for six days before any run of fish began. The tidal cycle was at its peak, but there were no strong onshore winds. On the day following strong onshore winds of 20 miles per hour, a run of 39 salmon went through the counter. In all, a total of 186 fish came up when the run had been completed. The first sharp increase in water level during four days brought up only 21 fish. Evidently these were present in the river. It was not until the strong onshore winds came that the large run started. The probable mode of action was the concentration of a large amount of fresh water at the estuary mouth through the action of freshet and tides, while onshore winds concentrated the fish here. They then moved up the river.

No. 4. The largest natural freshet of the summer (2,200 cubic feet per second) was added to No. 3. It failed to bring up any appreciable number of fish. Four days after it started, nine fish moved up the river and in the succeeding days a total of 26 fish moved. The tide cycle was at its lowest point and there were only medium onshore winds for one day. Evidently the supply of salmon in the estuary had been exhausted by the previous freshet and the factors were not now operating to concentrate a new supply in the estuary, if such a supply existed.

Artificial freshets of interest and periods of water control are indicated on Figure 13 by the letters A, B, C, D, E, F. In general it can be said that in 1951 artificial freshets moved some fish, but were not responsible for any major run of fish.

"A" represents one six-hour freshet added to a natural freshet which together moved a peak of 15 fish in one day, but did not start a major run. Tides and winds were unfavourable.

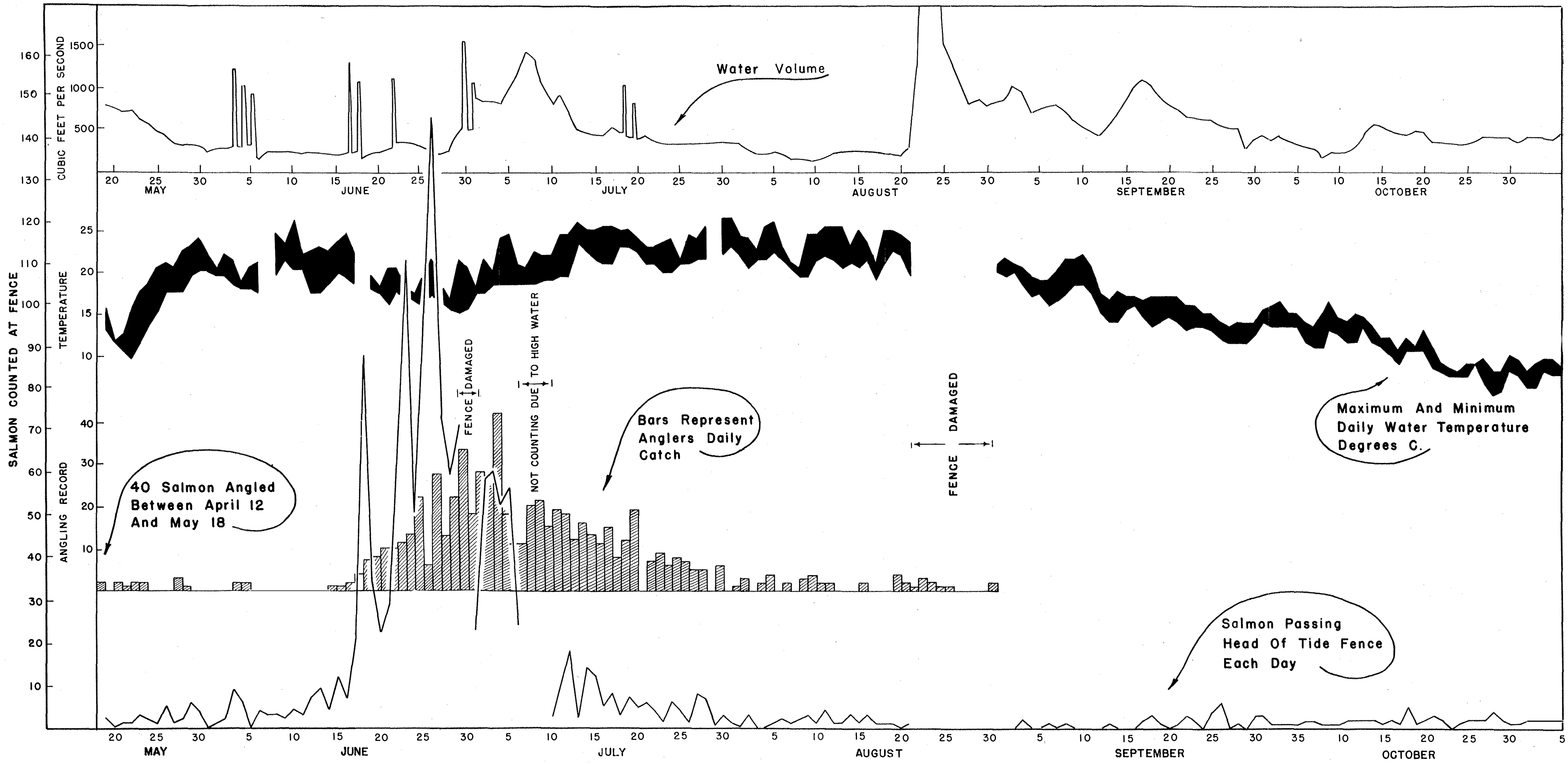

FIGURE 12. An assembly of several types of record taken on the LaHave River during 1950 and discussed in the text. Maximum and minimum temperatures for each day at the head-of-tide fence are shown. Where the temperature lines are close together, making a narrow black area, an overcast or rainy day is indicated; where they are far apart it indicates bright sunshine. In general the summer was cool.

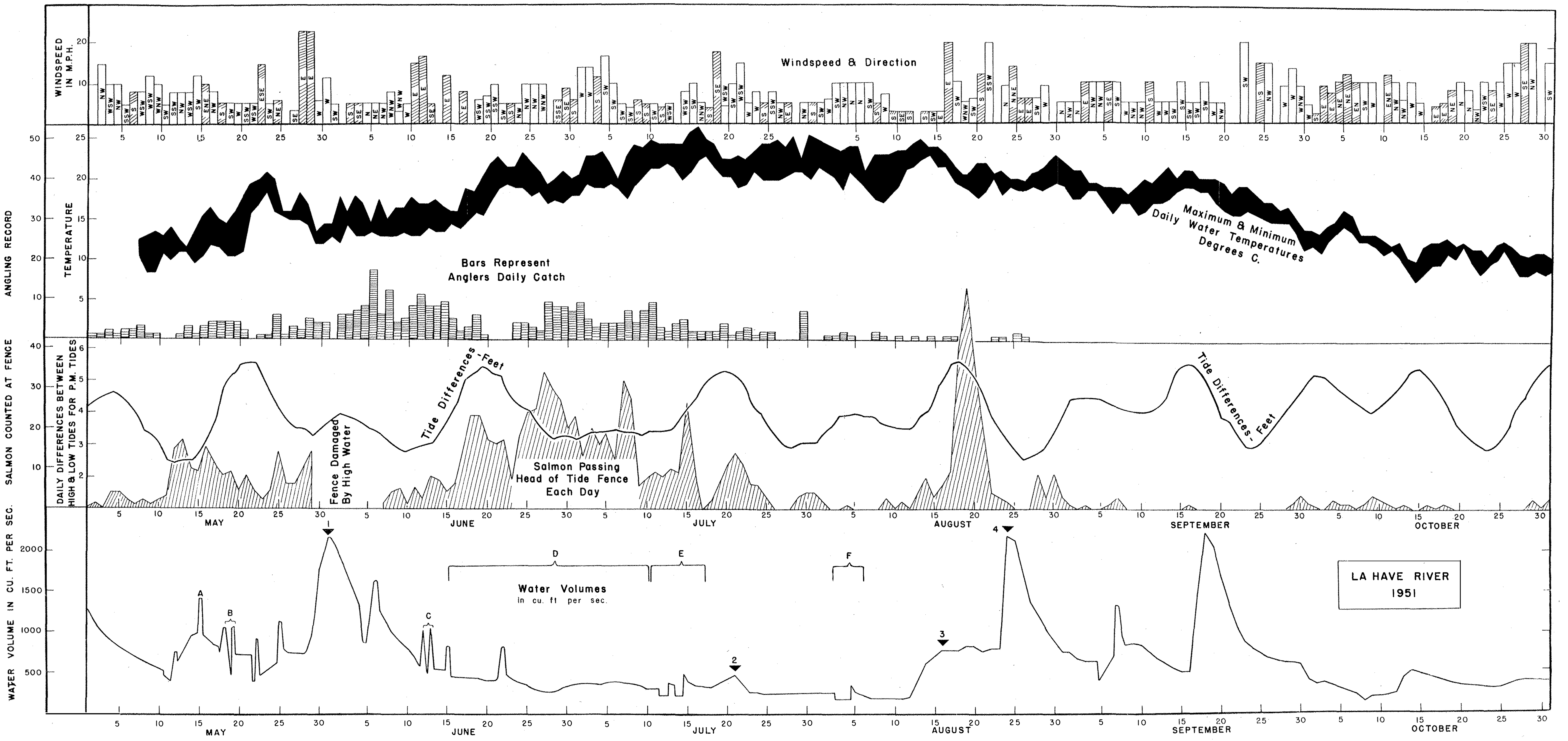

FIGURE 13. An assembly of data taken from the LaHave River in 1951 and discussed in the text. Wind speed and direction at the mouth of the river are shown, and onshore winds are shaded. Other records are as described under Figure 12 for 1950. The diagram is terminated as of October 31, but the fence was operated for an additional week in order to go over spawning time. There was no last minute run, for only two fish ascended on November 1 and none later.

"B" represents a pair of six-hour freshets of medium size run on successive nights. They were totally unsuccessful in moving fish, in contrast to the success of the two large six-hour freshets in 1950.

"C" represents two medium-sized four-hour freshets which were also unsuccessful in initiating a run of fish.

"D" represents a period of 24 days in which the major number of fish ascended the river. The run was not initiated by any freshet since only a single small artificial freshet was produced three days before the run started. The river had been held at a level of 400 cubic feet per second for three days when a combination of a peak in the tidal cycle plus strong onshore winds for five days apparently caused the run. There have been many arguments concerning the effectiveness of freshet production versus controlled steady flow of water in moving salmon. It was decided that this was a good time to test controlled water, since freshet production had been a failure for the year. The water was hence maintained at 400 cubic feet per second until the run died out. The run lasted 24 days. (Just once it was necessary to produce a freshet to prevent flooding lands at the head of Wentzell's Lake. This had no effect on moving fish.) Fish kept moving through at an average of about 20 per day and then dropped off quite sharply. Here was a run of fish initiated by tides and winds and maintained for 24 days by a steady flow of water. It speaks strongly for a programme of water control, especially where the need is to conserve water as was explained above.

"E". In an effort to find some way to stimulate fish to move upstream and at the same time conserve water, a new method of "freshet" production was evolved, which in effect was the reverse of a freshet. The preliminary success would warrant further investigation. The theory behind the method was as follows. Freshet production obviously involves a change of stimulus to the fish—whether a rheotaxis or chemotaxis. Presumably there would be a stimulus if the river were maintained at a constant level for a long period, then cut down very low by means of the gates at the Wentzell's Lake Dam for 24 hours, and then restored to its original level during the night. The restored water level reached the head of tide at dusk. No extra fish moved. This was repeated the next day and night and was followed by a run of 26 fish in that one night. In all 61 fish moved during the experimental period.

"F". The same experiment was repeated except the river level was cut for two days and restored at the end of the period. No fish moved.

Conclusions about Water Control

The angling effort throughout the 1949 season yielded uniformly low returns. Such success as the water-control programme had in bringing fish into the river was not passed on to the fishermen. The catch was reported as 137 salmon, surely one of the lowest in history. (It was, incidentally, the first year of an expanded warden service, and the officials were ardent to report only records personally verified. Hence any errors are of omission, and there is no basis for comparison with previous years.) In 1950 there were 705 salmon reported caught and in 1951 there were 379. The annual divergences are so great that they make it impossible to say whether the programme produced an increase in the catch. As discussed in the appendix to this paper, angling success generally is subject to such great natural variation from year to year that only a spectacular improvement would be mathematically significant.

It is possible that the maintenance of good fishing levels during what is normally the low-water season in midsummer has contributed to angling success. One of the difficulties in assessing the question is that the angling effort virtually dies away in July. This is because there has been traditionally very little hope of success. The 1950 and 1951 records show a July decline in angling despite the maintenance of river levels. Figures on catch per unit of effort, furnished by the Federal Department of Fisheries for 1950, show that in the five spring weeks before the main run, the catch per rod day was 0.13 salmon; during five weeks of the main run it was 1.44; and for the final five weeks of the season to the end of August it was 0.43 per rod-day. Stated otherwise, this means that during August almost every second fisherman caught a salmon every day he went fishing. The chances were a good deal better in August than they were in May and the first half of June.

It is the writer's opinion that the maintenance of satisfactory water levels in the river can prolong the season for successful angling into late July and August, subject always to a power of veto exercised by the sun. Temperatures are always likely to be too high for fishing during fine afternoons. The difference between maximum and minimum temperatures on fine days often reaches 5°C. and occasionally 6°. The minimum is reached about dawn, and several hours after dawn the water begins to warm up. Probably that is why summer angling, as is well known, is only likely to be profitable in the early morning. In 1950 the daily minima were 18° at the height of the fishing season; in 1951, 13°. From an examination of Figures 12 and 13, it may be concluded that salmon will still take a fly when early morning temperatures are as high as 22°. If supplied with proper water levels, the angler may expect, when fishing in the early morning during hot weather, to have about one-third the success he would have during the main run.

There has been some discussion about the ideal size of a freshet, and whether large freshets were better than small ones. The LaHave work suggests that, compared with natural rains, any freshet produced, or likely to be produced by storage dams, should be reckoned as small. There is no reason to believe that it will be possible to produce a flow large enough to inhibit salmon ascent. The problem is to discover the smallest volume of water that can bring up fish. So far it would appear that almost the full resources are necessary to have any effect.

Another question is whether an artificial freshet can bring the salmon all the way up from the sea. Experience indicates that there is not enough water available to do this. Salmon have to be in the estuary before the opening of flood gates can move them up into the fresh water. The variations in the number of salmon going through the fence following freshet production appear to be related to the number of fish which happen to be in the estuary at the time.

If the salmon are in the lower estuary, the first of a pair of six-hour freshets may move them up some distance, and the second take them through the fence. If a natural rainstorm brings a run of salmon into the estuary, artificial freshets at later dates can keep them moving into fresh water.

A third question is whether high water alone can move the salmon up the river. As far as heavy natural rainstorms are concerned, the answer may be yes. As far as water volumes under storage are concerned, the answer is no. In order to approximate a heavy rain, it would be necessary to throw away all the season's stored water in a few days. It is quite beyond the resources to "raise the water a little and keep it there" every time the angling seems to be falling off.

Future Water Control

On the basis of the findings here presented, a plan for future water control may be suggested. To some it will seem a negative approach, but it should be kept in mind that it is designed both to conserve water and to meet the practical limitations of the Wentzell's Lake dam, the level of which has been lowered so that freshets of the size described above can no longer be produced. Were unlimited water supplies at hand the plan might differ.

The river should be maintained at a steady, constant-flowing level, which of course will be higher in the spring than later on in the summer. Water levels during the summer should not be allowed to drop below 400 cubic feet per second as long as water lasts. Nature should be allowed to take her own course in initiating the run of fish up the river, but the run should be maintained with the controlled water level.

The time to apply the stimulus is when the run shows signs of dying out. Water should not be wasted haphazardly on numerous early artificial freshets. Positive freshets, when used, should ideally be timed to reach the head of tide at dusk. However this means that they would have to originate at Wentzell's Lake four hours before dusk, with the consequence that they would pass through the main salmon-angling zone during the height of evening fishing and cause some inconvenience. Hence it is recommended that freshets be originated at dusk, so that they actually reach the tide water a little after midnight. Alternatively freshets might be started a little after midnight, to reach the estuary at dawn. Freshets are most likely to be successful when related to peaks in the tidal cycle and strong onshore winds (see below). Inverse or negative artificial freshets should be tried on two successive nights, timed to reach the head of tide at dusk or dawn, and related to favourable winds and tides. Negative freshets will be indicated when the supply of water is low. By these means, correct application of the stimulus combined with natural forces may prolong the run and concentrate more fish in the estuary. It would seem that since the wind and the tide are important, one can never be independent of nature but must wait until she is ready.

Water Control on the Medway

On the Medway River, close to the LaHave, dams were constructed in 1950 for water storage. In 1951 and 1952 officials of the Department of Fisheries kept up summer water levels with the object of improving salmon fishing. There was no production of freshets.

In an appendix to this bulletin, the results of the Medway experiment are examined, with the conclusion that there is as yet no indication of angling improvement as a result of water control. Of course the experiment up to the present has been dealing with existing stocks in the hope of making them more available for angling. It might be that higher summer water levels would increase smolt production and eventually improve angling in that way. Any increase in smolt production could hardly affect angling until 1953 or later.

GENERAL OBSERVATIONS ON SALMON

Size of the Run and Angling Success

Observations prior to 1950 cover too short a season to attempt an estimate of the annual run. However in 1950 and 1951 the head-of-tide fence was installed

TABLE I. Total number of salmon entering the river in 1950 and 1951 and the number taken by anglers. The "estimated additional" values for the counting-fence records are based on inspection of day to day records both of angling success and of the fence operations before and after non-counting periods.

1950	Salmon	Grilse	Total	Average per day	Taken by anglers
Up to May 18 (before fence operations)					41
May 19 to June 16 (prior to main run)	57	47	104	3.6	22
June 17 to July 6 (main run)	211	930	1,141	57.1	325
July 7 to Aug. 31 (post main run to end of angling season)	38	120	158	2.8	317
Sept. 1 to Nov. 5 (post angling season to spawning time)	86	8	94	1.4	
Observed Total	392	1,105	1,497		705
Estimated additional when counting fence not in operation			600		
Estimated Total for Year			2,097		
1951					
Up to April 30 (before fence operations)					11
May 1—June 16 (prior to main run)	206	23	229	4.9	192
June 17—July 26 (main run)	155	445	600	15.0	151
July 27—Aug. 31 (post main run to end of angling season)	105	126	231	6.4	25
Sept. 1—Nov. 8 (post angling season to spawning time)	30	1	31	0.5	
Observed Total	496	595	1,091		379
Estimated additional when counting fence not in operation			200		
Estimated Total for Year			1,291		

fairly early and maintained, except for a few days during damage by floods, until spawning time. It is noteworthy that in neither year did a marked autumn run take place. In both years just about half the annual total entered during the main run, which lasted 20 days in 1950 and 40 days in 1951. The values are given in Table I, which includes an estimate for those parts of the year when the fence was not in use or was damaged. In 1950 nearly 2,100 salmon entered the river, of which 34 per cent were taken by anglers. In 1951 nearly 1,300 salmon entered, of which the angling take amounted to 29 per cent.

If the drainage area of the LaHave supporting spawning streams is 65 square miles (Table III), the number of salmon occupying each square mile to spawn would be from 14 to 21. The egg production per pair of fish might be 4,300 Hayes, MS) so that the eggs per sqare mile of used drainage basin would be 30 to 45 thousand. The total stock for the river would be 2 to 3 million eggs. The annual smolt production is observed to be about 10,000 (see below) which represents a yield of 0.51 to 0.34 per cent of smolts from eggs. Hayes (MS), on theoretical grounds, gives a smolt yield from eggs of 0.23 per cent, which is not far from the observed LaHave values.

Ascent of North Branch

The daily numbers of salmon ascending the North Branch of the river in 1950 are shown in Figure 14. Excellent water for angling was maintained in the North Branch at all times (except for a five-day interval in August). It is seen that the ascent in the Branch hardly reflects, in size, the main run at the head of tide, the daily average figure of 57 for the latter never having been approached. It appears that many salmon rest in the lower reaches of the river and in Wentzell's Lake for some time before ascending the North Branch. The general experience of anglers is that good fishing is later on the North Branch than in the main river, which confirms the counting-fence results. The total number of fish counted during the angling season was 130.

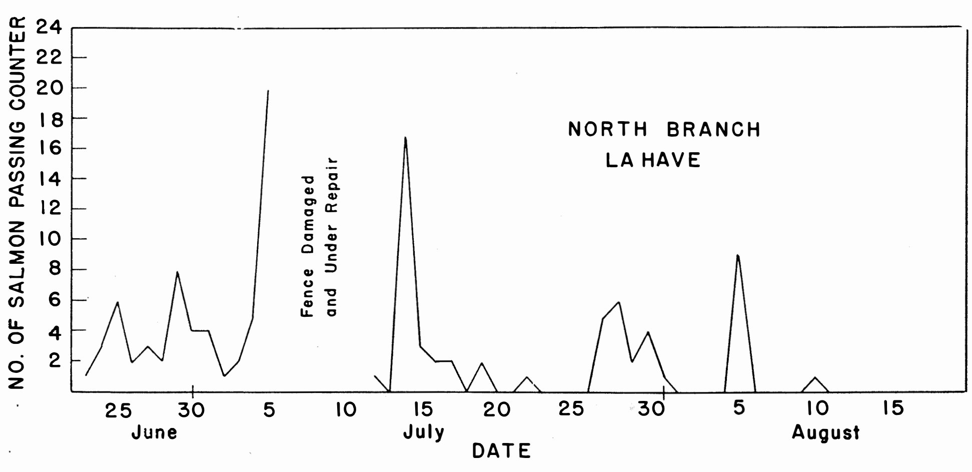

Figure 14. Daily ascent of salmon in the North Branch in 1950, as recorded at the counting fence near Pinehurst.

The conclusions are made somewhat uncertain by the fact that the fence was damaged by a freshet and put out of operation for seven days. Examination of Figure 14 shows what might have been the beginning of a run of salmon when the damage occurred. Such a suggestion is made plausible by anglers' reports that salmon were more plentiful in the North Branch than the counting-fence records would suggest.

Ascent of the West Branch

This question can be dealt with in a few words. Up to August 31, 1950, only two salmon and one grilse passed the counting fence. The West Branch therefore appears to be negligible as an angling stream, although there is now no obstruction blocking the ascent. One reason the fish do not ascend in summer is because the water is so low. It is said locally that there is a fall run, and, as noted below, young salmon were found distributed generally in the area.

Tagging Operations

Between June 5 and July 27, 1950, 192 salmon were tagged in Green Bay, midway between the Medway and LaHave Rivers. They were obtained alive from four trap nets operated by commercial fishermen. The object of the experiment was to discover whether there was any appreciable migration of salmon along the coast in either direction. The numbers tagged in each day are shown in Figure 15. It is noted that after July 6 the numbers available for tagging dropped sharply. This date coincides with the conclusion of the main river run, and suggests that the offshore waters might be temporarily depleted.

Rewards were offered for the return of tags and 53 salmon were reported, which is 28 per cent of those tagged. The places where the tagged salmon were caught are shown in the map, Figure 16. The conclusion to be drawn is that there was no evidence of a marked migration. In so far as the fish moved

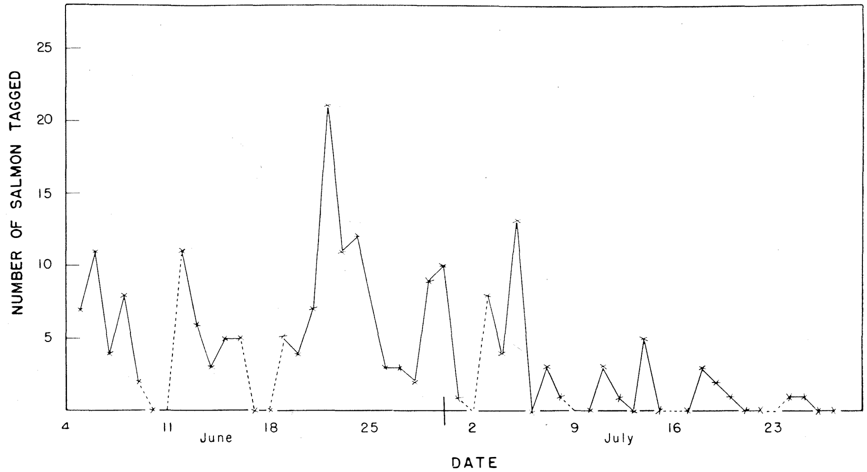

Figure 15. Numbers of salmon tagged each day off the LaHave Islands, season of 1950.

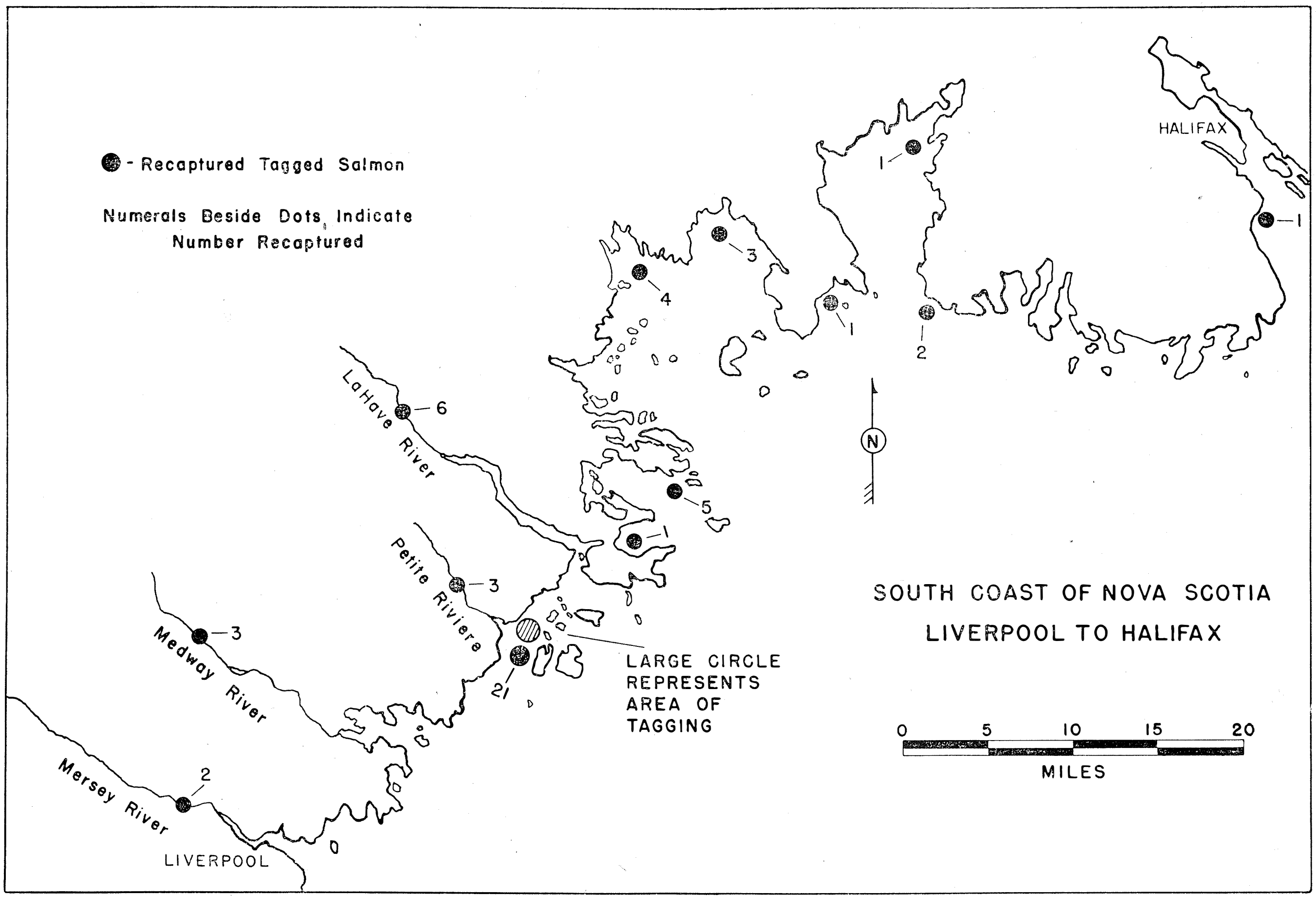

FIGURE 16. Migration of salmon from the LaHave area in 1950, as shown by the return of tags. The number tagged was 192 and the number of recaptures was 53.

out of the area they moved in a northeasterly direction. Only two tags have been returned from west of the general area, as against 18 from eastward. The return may be broken down as follows:

Returned by anglers from LaHave River	6
Returned by anglers from Medway River	3
Returned by anglers from Petite Rivière	3
Returned by anglers from Mersey River	2
Returned by commercial fishermen from the same nets in which tagged	4

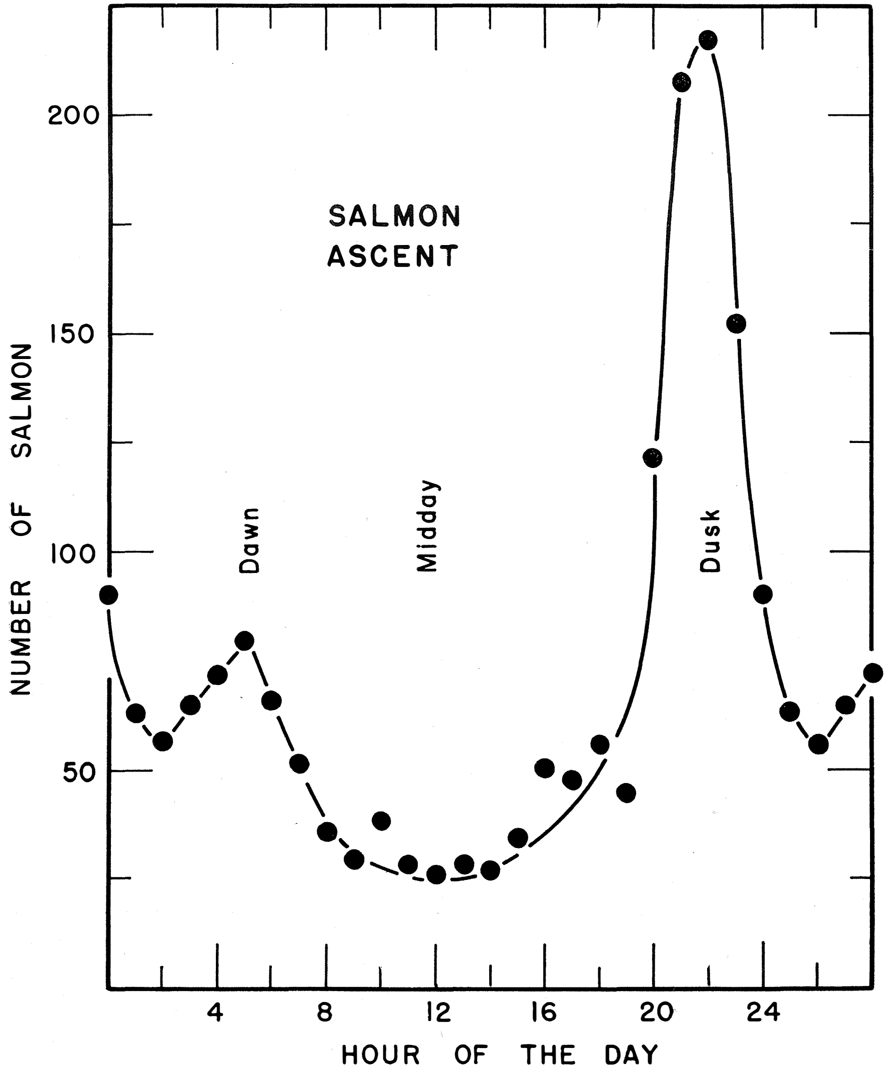

FIGURE 17. Total salmon passing the counting fence at head of tide, arranged by hours (standard time) and covering the main runs of 1950 and 1951. The interval in the latter part of June and early July spanned the longest day of the year. In all, 1,685 salmon and grilse were counted. Notice the strong tendency to ascend at dusk and a less well-marked habit of ascent at dawn. The controlling factor seems to be the rate of change in light intensity.

Returned by other commercial fishermen in the area of tagging	17
Returned by commercial fishermen, northeast of the area (up to Halifax)	18
Returned by commercial fishermen, southwest of the area	nil

As far as the tagging experiments go (remembering that the work does not provide information on possible spring migrations), it would appear that most of the summer salmon are stationary in the general area.

Hour of River Ascent

Salmon were released at each counting fence every hour, and from the records it may be determined when the main daily run occurred. Several years of such observations on the LaHave, as well as records from the Margaree River, show substantial agreement. Figure 17 covers the main LaHave run during June-July in 1950 and 1951, arranged by hours, and dealing with a total of 1,685 salmon. The interval chosen spans the longest day of the year so that light conditions should be approximately uniform. It is seen that the main run occurs at dusk, which is 9 or 10 p.m. at this season (standard time). There is a secondary, less well-marked run centring at dawn about 5 a.m. The minimum ascent is at midday, with a secondary decline centring at about 2 a.m. The stimulating factor for ascent would appear to be the rate of change of light intensity.

Season of Salmon and Grilse Ascent

Data on the relative proportions of salmon and grilse throughout the 1951 season are presented in Figure 18. Evidently the grilse run is a midsummer phenomenon with salmon preceding and following it.

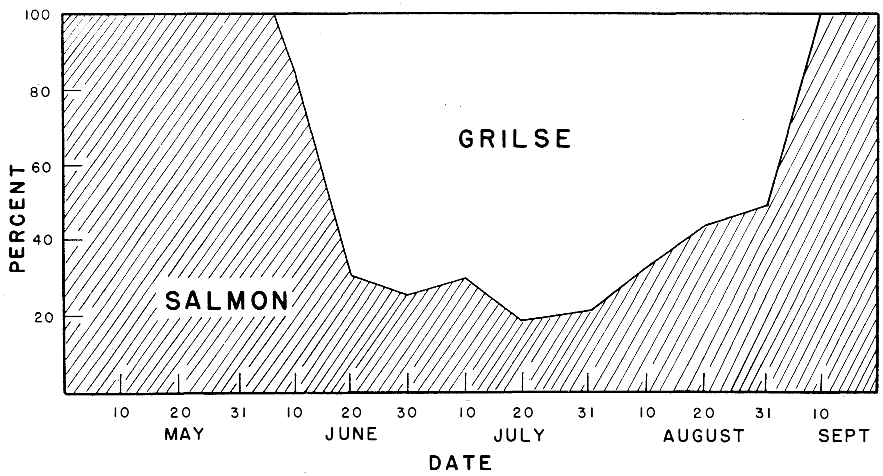

FIGURE 18. A comparison of the proportions of salmon and grilse ascending the LaHave in 1951. The total fish per week have been called 100 per cent and the distribution between salmon and grilse is plotted against time. The figure confirms findings of previous years and supplements them by carrying the analysis farther into the autumn months, by which time the grilse had again stopped entering the river so that only salmon were observed. The fall replacement of grilse by salmon occurs after the angling season is over and is not as well known to anglers as the midsummer grilse run.

Effect of Wind

Huntsman (1939) discusses the effect of wind on the entry of salmon into the Margaree River and suggests that "winds which blow directly into the estuary mouth from the sea, hold the issuing water close to the mouth and

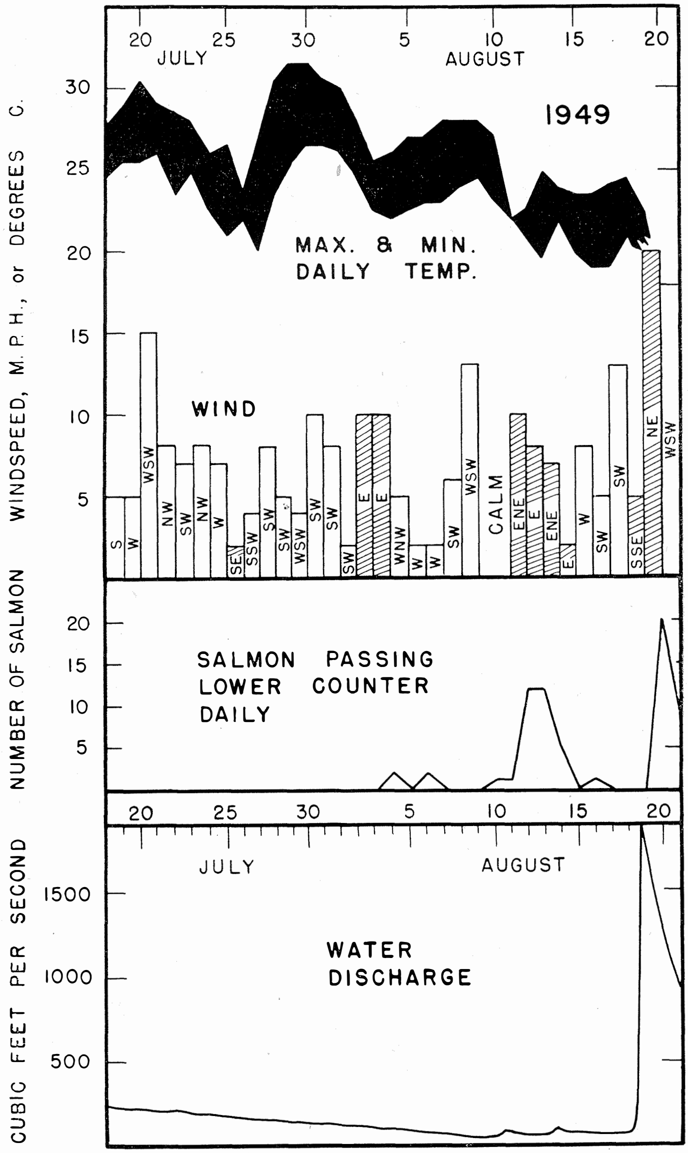

Figure 19. A portion of the records for 1949, showing how onshore winds, apparently unaided by other causes, coincide with a run of salmon on August 4 and again on August 12. Onshore winds are cross-hatched. Maximum and minimum daily water temperatures are also shown. Water discharge records are from the meter at Bruhm's Bridge.

facilitate the entrance of salmon in that way as well as by causing a surface current with which the salmon will go to the estuary mouth". It happens in the Margaree, however, as well as in the LaHave that these onshore winds are nearly always accompanied by rain, so that isolation of the wind effect is seldom possible.

One fairly clear example of the wind effect alone did turn up on the LaHave in August, 1949, and is shown in Figure 19. It is seen that during the latter part of July the water discharge was low and falling steadily, and no salmon at all passed the counter. The winds were also westerly in direction, which is offshore. The weather was quite fine as indicated by the width of the temperature band. Falling water temperatures from July 20-29 brought in no salmon. On August 2 and 3 there was a shift of direction to an east, or onshore, wind of 10 m.p.h. velocity. At the same time a few salmon passed the fence. The wind then shifted to offshore again and salmon stopped coming up. On August 11-14 there were onshore winds again and a run of salmon took place at the same time. Inspection of the discharge curve shows that there was a very small rain at this time. The run ceased with the shift to offshore winds again on August 15. Finally on August 19 the usual effect is seen, namely a strong onshore wind, accompanied by rain, which raised the volume and produced a run of salmon.

In the next section evidence will be presented to suggest that runs often accompany maximal daily differences between high and low tide. It may be noted here that the August, 1949, runs did not coincide with such peaks. The intervals August 4-6 and August 12-13 when runs occurred, were intermediate tidal times, neither spring nor neap. During the first interval the daily tidal difference was increasing, during the second declining. Thus Figure 19 appears to show an isolated wind effect at work.

Some further evidence about wind is given in the general illustration for 1951, Figure 13, in which onshore winds from easterly and southerly directions are shaded. From May 23-28 the prevailing winds were onshore and reached 22.5 m.p.h. on May 27-28. This coupled with rising water in the river on May 30 was believed to have started a large run of salmon up the river in the following days, as is suggested by the angling record in early June.

Also from June 10-18 the prevailing winds were onshore, with speeds varying from 18.5 to 5 m.p.h. On June 18 a large run of grilse and salmon started which lasted until the middle of July. The period was one of falling water, interrupted only by a small artificial freshet, produced two days before the run began. It would appear that winds provided the important stimulus on this occasion.

Again on July 17-18 and August 15-16, Figure 13 shows onshore winds of considerable speed coupled with natural freshets to produce, a day or so later, large runs of fish up the river. Summing up the 1951 observations, it can be said that in no instance did a new run of fish begin which was not preceded several days before by onshore winds approaching 20 m.p.h. Most of these winds were accompanied by natural freshets and hence it is difficult to dissociate the effects of wind and water except on June 18, when a large run began without the presence of a natural freshet.

Effect of Tide

It is local opinion that salmon move back and forth on the tides, entering the river at each flood. This may well be so once a run has begun, but a point of more interest is the effect of tides in initiating a run. Plotting daily tide differences between high and low tides for 1951 (Figure 13), gives a series of peaks where the differences rise from minimum to maximum and then drop again, the whole cycle taking about 15 days. Only p.m. tides were plotted, since, as shown elsewhere in this paper, the hour of salmon migration is usually at dusk. When the tide records are superimposed upon the daily salmon count in Figure 13, the peaks correspond quite well with new salmon runs. In every case the onset of a new run coincides either with increasing daily differences between high and low tides, or else with the peaks of these cycles. Notable examples are the runs of June 18, July 15, July 17-25, and especially August 15 to 22.

Again this picture is complicated by natural freshets, except in the case of June 18 where only wind and tide appear to be operating. It must also be noted that the highest tides of the lunar cycle generally occur at dusk, which is the peak time of ascent. Thus an unusually high tide might reinforce the light effect to produce an ascent at dusk.

Effect of Fences and Counting Chambers on Behaviour

Anglers are not usually very enthusiastic about counting fences and sometimes suggest that salmon are delayed by the fence and postpone their progress upstream, or that their catchability is reduced, or that they are injured while in the counting chamber before release.

Considering the possibility of injury first, our observation was that salmon are extremely quiet and "sensible" fish in a counter. They do not swim around vgiorously as shad, for instance do, but retain a calm that has reminded attendants and visitors of cows at a gate. The angler is familiar with this behaviour from his observation of salmon when they rest quietly in pools, indifferent to all his efforts to excite them.

As to fish not liking a fly after passing a counter, two instances may be cited. One angler, who had been fishing unsuccessfully for two hours at a spot 100 yards above Cookville counter, hooked and landed a salmon three minutes after four salmon had been released. On another occasion a local fisherman hooked and landed a grilse 50 yards above the same fence. Less than a minute previous to this, three grilse had been released to continue up the river.

At no time has there been evidence of salmon being delayed below the fence. For instance on July 24-27, 1948, 25 salmon passed the Cookville counter, although the previous eight days had averaged less than two salmon per day. Now on July 21, anglers had reported a considerable amount of "jumping" and "rising" of salmon in a pool two miles below the counter. On July 23, these salmon had apparently moved up to a pool some 500 yards below the fence, for anglers reported a great number of fish seen and caught there. Two days later they could find no fish in this pool.

Angling Success as a Standard of Measurement for River Improvements

A question frequently asked of field workers is why they do not simply take angling returns as a measure of the success or failure of river improvements, without bothering with counting fences. One answer is that there must be for comparison a good record of angling in the years before the treatment, and such records are not available, for instance, in the LaHave. Moreover, angling success is an insensitive and slow standard by which to measure changes in a river. This is because the natural fluctuations due to weather are so great that they obscure the results of experiments, just as the flavour of garlic covers up more delicate aromas. Nonetheless, river improvements, if they are conferring any benefit to angling, should be visible in the form of an increased catch.

In order to set up standards for detection of the minimum measurable improvement to angling the first requirement is to know something of the fluctuations from year to year under ordinary conditions. Angling statistics on Nova Scotia rivers have varied considerably in accuracy. Fishery officers were few in number and, where there was a commercial fishery, most of their time had to go there. Thus in the LaHave region the great Lunenburg sea fishery left little time for inspectors to visit guides and others to obtain daily angling records. Within the last five years there has been an increase in the number of officers and a separation of marine and fresh-water services. There are now good records for several years past.

There are two rivers on the same coast as the LaHave for which good records exist for the past quarter of a century, namely the Medway and St. Mary's. These records can be used to set up standards, probably of general applicability, on which to test supposed river improvement in the Maritime Provinces generally. In an appendix to this paper an attempt is made to set up such standards.

YOUNG SALMON

Survey of Present and Potential Spawning Grounds

In 1950 a survey was made to determine the salmon production of the river both actual and potential, and at the same time to count the coarse fish which lived side by side with the salmonids. It was hoped that the investigation would yield information about the extent of the spawning grounds available and actually used by adult salmon, and also a rough quantitative assessment of the level of salmon and coarse-fish population in different parts of the river. Such results would permit recommendations for improving production.

For the purpose of census taking, a test section of river or brook was blocked off with barrier nets, and the fish cleared out with one-man seines (for small brooks) or two-man seines. Areas were selected which included a pool at the downstream end and a ripple at the upstream end. Thus, by taking habitat preferences into consideration, an attempt was made to secure a fair representation of all species.

The effectiveness of the method may be illustrated by an example of a census taken 21 miles above the head of tide, on the Main Branch of the river (Table II). Barrier nets were stretched across to block out an area of 946 square yards, and the bottoms of the nets made fast with rock and gravel. Floats and forked sticks kept the tops of the nets above water. The area was then seined by a four-man crew. Two men held a net while the others drove the fish from ten feet in front down into it. This was repeated until the whole area had been systematically covered. Long sweeps were then made in the channels and deeper areas. All the fish collected were identified and counted, and were listed as the "first haul". In all, three hauls were made to get "total fish in the area".

TABLE II. Results of three successive seine hauls in a portion of a brook on the Main Branch LaHave. After seining, the area was poisoned with derris root and additional fish counted. Additional fish recovered by poisoning are listed in the bottom column. The seines evidently caught about 95 per cent of the fish present. Results for eels are not considered reliable because eels tend to remain under rocks and so are often overlooked.

Haul	*Catostomus commersoni* (sucker)	*Couesius plumbeus* (chub)	*Fundulus diaphanus* (killifish or fresh-water minnow)	*Anguilla rostrata* (eel)	*Perca flavescens* (perch)	Total fish
1	27	1	154	0	25	207
2	23	0	29	1	4	57
3	6	1	8	0	0	15
Total	56	2	191	1	29	279
Poison	12	3	0	0	0	15

The accuracy of the method was checked at this site by poisoning the area with derris root after the third haul. Derris root was used in general only after thorough seining had failed to yield any salmon fingerlings or parr, being regarded as a final check.

From Table II it is clear that the seining method can take a large proportion of the fish in an area, and it was found that by using a standardized technique results were quantitatively reproducible. Eels, however, cannot be taken effectively either by seining or poisoning, for they remain under the rocks at the stream bottom. Our data are of little value as regards the abundance of eels.

The finding of parr and especially salmon fingerlings in a given area was taken as evidence that the area was actually being reached by spawning salmon. Presence of parr indicated that salmon had reached the area two years previously, whereas fingerlings indicated that it was open the previous season. The fact that parr had been planted in several streams in the spring was taken into consideration. Thus if parr only were found where plantings had been carried out, it was assumed that adult salmon had not been using the stream. Complete absence of parr and especially fingerlings beyond some recognizable point such as dam or fall, was taken to indicate an obstacle to the ascent of salmon.

The area of the LaHave drainage basin which was found to be open or closed to salmon ascent is presented in the form of a map (Figure 20), and in Table III. The shaded portion of the map shows the actual spawning grounds available and being used at the present time in which parr and fingerlings were observed. Any increase brought about by opening other parts of the river to salmon would certainly increase the number of smolt descending to the ocean annually, and presumably the later stock of salmon to the river.

TABLE III. Extent of the various areas in the LaHave River as illustrated in the map, Figure 20.

LaHave drainage basin	Square miles	Percentage of total river drainage
Below head of tide. No young salmon found in brooks	77	11.5
Area above Bridgewater, which appears open to salmon but is evidently not used for spawning. No young salmon found.	244	36.5
Area blocked out by New Germany dams. No young salmon found.	283	42.3
Area actually used for spawning, where young salmon were found.	65	9.7

Areas open to salmon but not used are represented by those portions outside the heavy black line but not included in the shaded area of Figure 20. This represents river in which no salmon were found. Any programme designed to increase smolt production would have to include an attempt to establish salmon in these streams, for which purpose an initial stocking policy might be advisable. Within this "open" area there are, of course, a few barriers to salmon ascent on individual streams, which have been indicated on the map. Where dams are present they have been marked on the map. Three falls in this area should also be noted as obstructions, being found on Wiles Lake Brook (West Branch), Solomon Brook (North Branch) and Indian Brook (Main Branch). Of the three, only Indian Brook Falls could be opened at moderate expense by blasting rock pools in the ascent.

The area on Figure 20 within the heavy black line shows potential spawning and rearing grounds now blocked to salmon. In a careful search of this region not a single parr or fingerling was found. Evidently the presence of two mill dams at New Germany is completely blocking the Main Branch and drastically reducing the possible smolt run of which the river could be capable.

One of the New Germany dams is located at the LaHave Pulp Co. Ltd. This mill operates from the time of the fall rains (usually in September) until the end of the water supply in the spring, usually the middle of May but sometimes until August. The mill runs solely on water power and hence is closed down during the summer months, when repairs are made. The other dam is at Zwicker's Box Factory, a mile farther upstream. It operates by water power for only a few

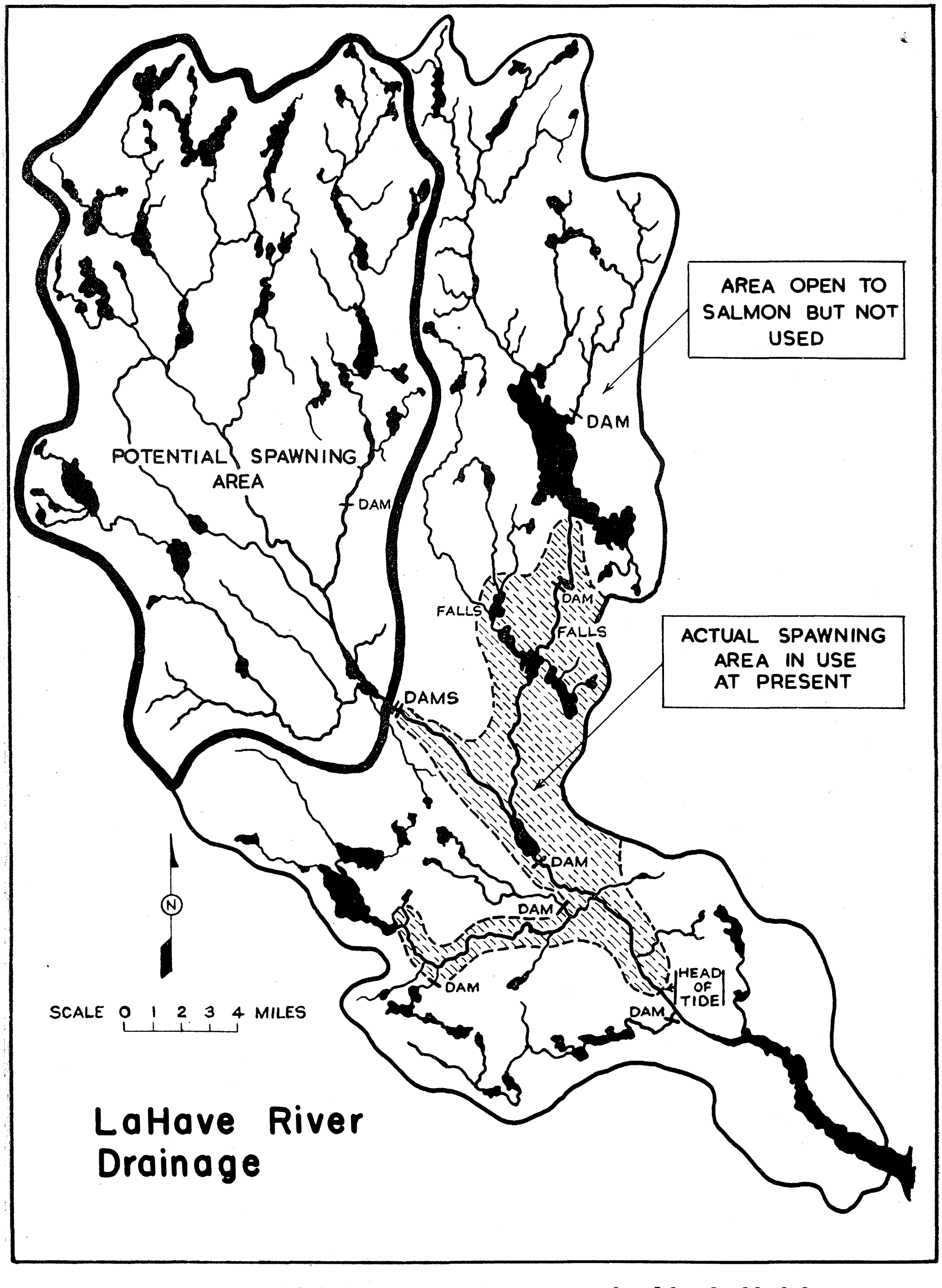

FIGURE 20. Drainage area of the LaHave River. Portion enclosed by the black line represents potential salmon-spawning grounds which are now blocked by dams at New Germany. Shaded area is actually being used by spawning salmon. Remaining areas are for the most part open to salmon but not used at present.

months of the year, especially during the month of May if the water is high enough at this time. The rest of the year it is run by diesel engines and can switch to these at any time. Any steps to improve conditions for ascent and descent of salmon on the Main Branch LaHave must obviously include fishways at both sites. At the same time a programme of stocking the river above these dams might assist in inducing salmon to re-enter the area above New Germany which they presumably once occupied. The destruction of descending smolt as they go past the turbines of the mills at New Germany would also have to be considered. Some arrangement might be made under which the mills would operate by diesel power or abstain from operations during the three or four weeks of smolt descent. Alternatively, installations might be set up by which smolt would be prevented from drifting into the turbines as they move down the river.

Something may now be said about the quantitative aspects of the fish census. For comparison of results, a population index was set up, which is the average number of fish of all species occupying 10 square yards of sampling area. Typical results dealing with the Main Branch are shown in Figure 21. It is seen that in the lower parts of the river there are only one or two fish in 10 square yards

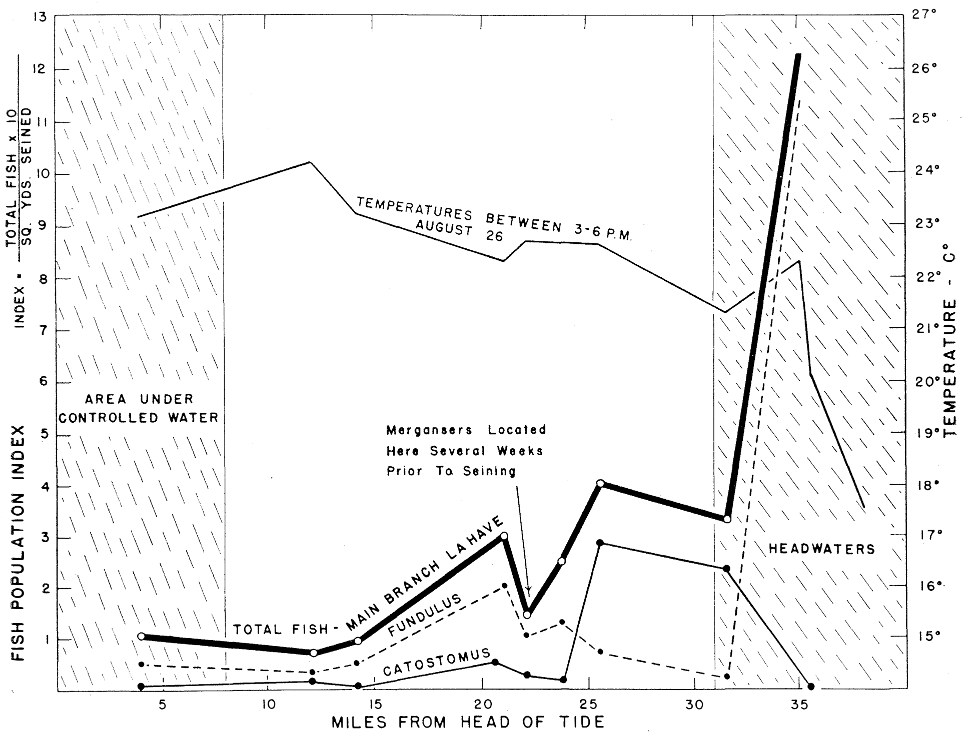

FIGURE 21. Results of a series of consecutive seinings on the Main Branch LaHave. Only the two most common species of fish and the total are shown. The population index is the average number of fish in 10 square yards.

while up at the headwaters the number rises to a dozen. Similar results to these were found on the North Branch and to some extent on the West Branch.

Temperature observations during seining suggested that the headwaters were cooler than the lower parts of the river. The notion was checked by simultaneous observations at all major seining places. It was known that the daily temperature is most nearly constant and maximal from 3 p.m. to 6 p.m. Hence between these hours on August 26, 1950, flying trips were made by men in two jeeps to seining sites and water temperatures were recorded. As Figure 21 shows, the temperatures on August 26 fell steadily as one proceeded upstream, so that the headwater temperatures were almost 6°C. cooler than those recorded farther down the main river.

It was also of interest to note that no trout were found in any seining on the main river until the headwaters were reached, although the tributary brooks all contain trout fingerlings. This would indicate that trout prefer and are better able to survive in cooler waters. It was apparent that the lower these tributary brooks became during the dry season, the colder they were, which may be due to the fact that, as the lakes go down during dry intervals, any water in the brooks comes from cold springs in their beds. This would not apply to the river proper.

The particular species responsible for the great increase in population index as one goes upstream varies from stream to stream, being the banded killifish (*Fundulus diaphanus*) in the Main Branch and the northern chub (*Couesius plumbeus*) in the North Branch. Evidently the population increase is not restricted to one particular species, and salmon populations in the headwater regions appear to be similarly affected. Thus in the upper part of the North Branch the salmon index is approximately 12 times that of the lower part of the North Branch.

It is not the intention to suggest that lower temperature in the headwater region is the sole reason for the increase in fish population there, but rather that the same factors which make the temperature lower also provide a stable environment in these streams, in contrast to the lack of stability of the river as one approaches the head of tide. The headwaters are located in forest land, which probably provides optimum constancy of temperature, water volume and food supply. The lower part of the river on the other hand is subject to wide fluctuations in these factors and thus represents a relatively unstable environment.

Young salmon were found on the West Branch LaHave in approximately the same numbers as in the lower reaches of the North Branch and Main Branch. At the West Branch fence only three adult salmon were counted in 1950. There is no reason to believe from local reports that this number is excessively small, although there may be a fall run of fish up the Branch. It is also noteworthy that, although comparatively few salmon manage to get through the sluice at Milbuary's mill on the North Branch, the river above has a population index 12 times that of the lower reaches. Thus it appears that comparatively few adult salmon are required to populate a given area of river provided they can reach that area at all.

The most serious predators of young salmon on the LaHave appear to be merganser ducks, as investigators for the Fisheries Research Board have found on other rivers (see for example White, 1939). An example of their action is shown in Figure 21 at the station 22 miles from head of tide. Even more striking examples of fish destruction by mergansers were observed on the North Branch. The birds are usually found in lonely stretches of river away from human dwellings.

Kingfishers do not seem to be as important as mergansers in so far as fish destruction is concerned, but they are active on the LaHave system. Blackspot parasitism was found on a few fish, although not common. Since the kingfisher is a part of the life cycle of this parasite, its presence would indicate kingfisher action. Probably kingfishers should be included in any programme of bird control undertaken on the LaHave, since blackspot might become prevalent with larger fish populations.

The position of the eel is equivocal. That it is a predator is certain, but to what extent is not certain. Eels are major targets of criticism because, owing to their snakelike appearance, they arouse irrational dislike. No rigorous proof that they are major destroyers of fish is known to the writer. It is known that where there is a high concentration of young salmon, as in hatcheries, eels are very destructive. It is also known that where large numbers of hatchery stock are put into a stream, the eels in the neighbourhood eat them up. Whether, however, the eels destroy large numbers of native salmon is not clear.

The variety and abundance of coarse fish in salmon-rearing grounds is of general interest. Table IV gives such values. In considering the list it should be remembered that the seinings were not intended to be a random sampling

TABLE IV. Variety and abundance of coarse fish found in salmon-rearing grounds. Composite results from the 1950 seining programme. The waters seined were not random but selected as looking suitable for young salmon. The column to the right is therefore probably indicative of the relative abundance of species in salmon-rearing grounds. *Couesius* and *Fundulus* show marked dominance.

Species	Average number per 10 sq. yds. in stations where found	Number of stations where found (out of a total of 21)	General abundance. Previous columns multiplied together
Salmon fingerlings	0.31	11	3.4
Salmon parr	0.11	10	1.1
Salvelinus fontinalis (trout)	0.57	5	2.9
Catostomus commersoni (sucker)	0.49	18	8.8
Couesius plumbeus (chub)	0.99	18	17.8
Fundulus diaphanus (killifish or fresh-water minnow)	1.36	14	19.1
Pungitius pungitius (ninespine stickleback)	0.57	7	4.0
Gasterosteus aculeatus (threespine stickleback)	0.13	1	0.1
Ameiurus nebulosus (bullhead or catfish)	0.03	2	0.1
Perca flavescens (yellow perch)	0.33	2	0.7
Anguilla rostrata (eel)	?	?	...

of the river basin as a whole, but a specific examination of those waters which appeared suitable for young salmon. Thus the table approximates a habitat group of which salmon is, for present purposes, the centre. Suckers and chubs are nearly always present where salmon are found (or would be found save for obstructions), and *Fundulus* is present more often than not. Suckers and chubs would appear to be indicators of good salmon water. The preference of the brook trout for colder water is shown by its absence from most of the habitats studied. The column on the right indicates the total abundance of coarse-fish species over the salmon area, and shows that *Fundulus*, chubs and suckers predominate, with the ninespine stickleback as the only other fish present in any numbers. As to eels, which are widely distributed, the methods used do not indicate their level of abundance.

In a stable population the ratio in Table IV of 1.1 salmon parr to 3.4 fingerlings might be taken to indicate a survival of 32 per cent during this part of the salmon life history.

Descent of Smolt

The numbers of smolt descending to the ocean were counted in 1950 and 1951 at the head-of-tide fence. Owing to practical difficulties neither year provides a complete record, so they will be taken together. In 1950 counting operations began on May 21 and continued until the run ended on June 18. In 1951 counts began on May 1 and ended on May 29, when the fence was put out of operation for eight days by high water. The descent being by that time on the decline, it was decided to replace the narrower smolt racks with more widely spaced salmon racks, which back up less water and so contribute to the safety of the fence.

The counts of smolt, in convenient periods, are given in Table V. So far as the values go, they suggest that 10,000 smolt is a good figure to think about for the LaHave. On evidence and assumptions made elsewhere (Hayes, MS), 10,000 smolt would correspond to a general river stock of 3,100 salmon and grilse. The observed annual ascent of the river in the same two years (with allowance for periodic non-operation of fence) is somewhat less, being 2,100 and 1,300 adult fish. In neither year was there any appreciable fall run, such as is often reported.

Figure 22 shows the smolt run for both years, arranged by days. It conforms to the expected pattern and requires no particular comment. In 1950 there was

Table V. Smolt counts during two years.

Interval	Count 1950	Count 1951
May 1—20		7,874
May 21—29	1,802	2,019
May 30—June 18	472	
Total counted	2,274	9,893
Add from alternate year	7,874	472
Estimated real total	10,148	10,365

a possible secondary run after June 5, perhaps from brooks at the head of the river. The curve as drawn ignores this small peak.

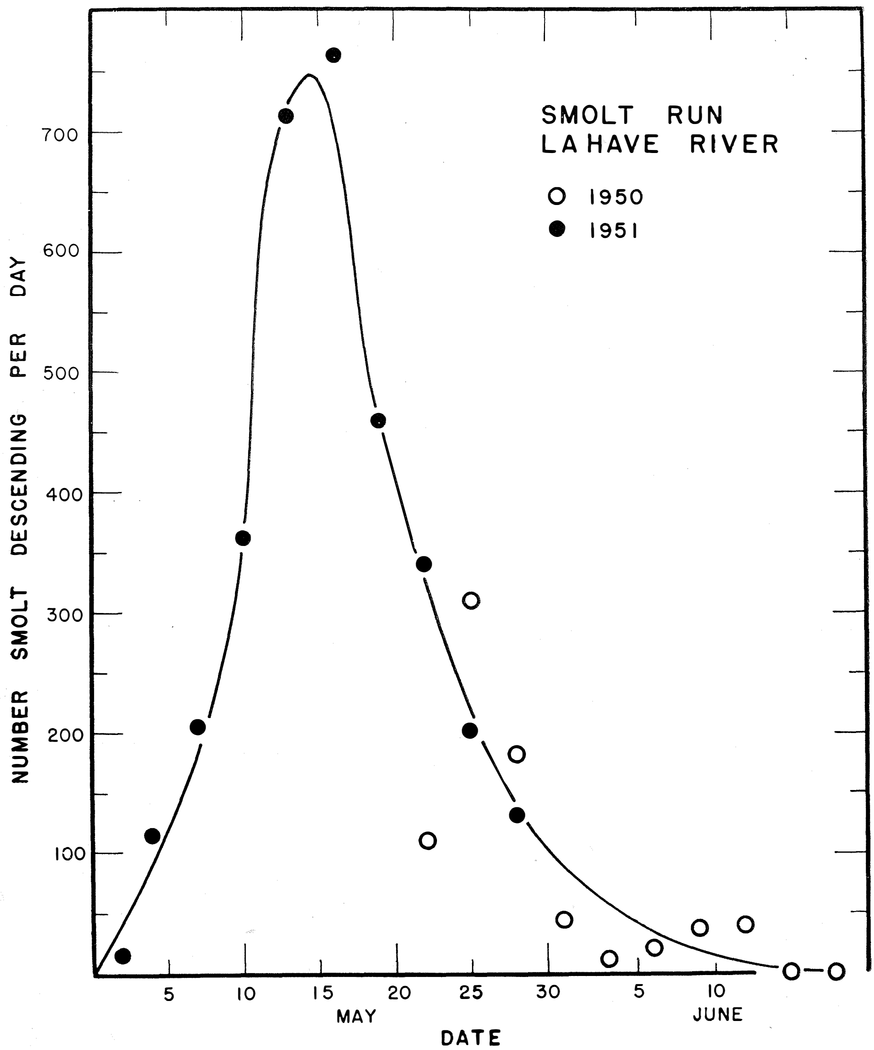

FIGURE 22. Smolt descending through head-of-tide fence each day. In 1950 observations began on May 21, following which 2,274 smolts were counted. In 1951 the count began on May 1 and there were 9,893 smolts observed. However the 1951 observations were interrupted by high water and discontinued on May 30. Allowing for this, the 1951 run was probably over 10,000. In order to reduce the number of points on the graph, each period of three days has been averaged at its central date. Thus, for example, the May 7 point at 207 is the average of 192, 240 and 189 which were for May 6, 7 and 8.

HOUR OF SMOLT DESCENT

Records of smolt passing the lower fence were taken hourly, and are shown in Figure 23. There is a general similarity to the pattern of salmon ascent, with peak movements at dawn and dusk. The dawn peak however is relatively more prominent than with ascending salmon and appears to exceed that of dusk. Another smolt characteristic is increasing activity during the afternoon, which is not noticeable with adults moving upstream. The dawn and dusk behaviour is presumably a response to changing light. The afternoon behaviour would seem to be related to the increase in water temperatures which occurs on fine

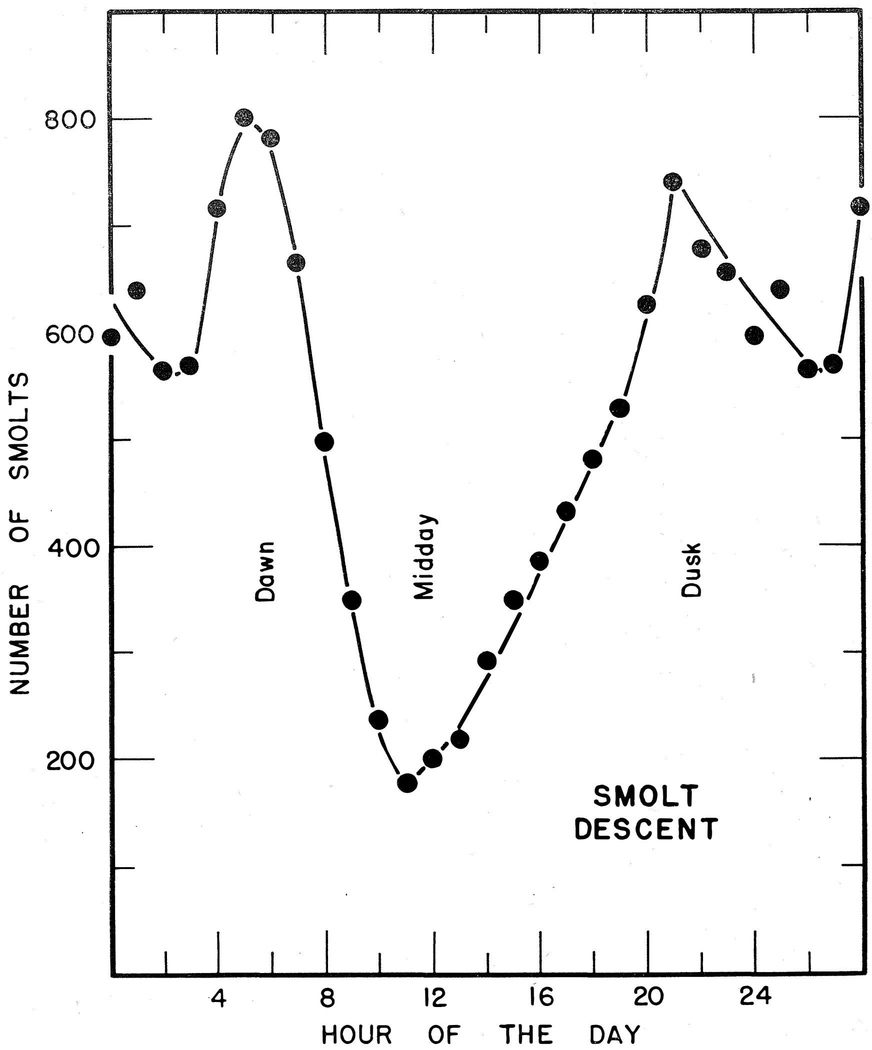

FIGURE 23. Smolt observed at lower counting fence in 1950 and 1951, arranged by hours (standard time). There are two maxima of movement, at dawn and dusk, with a minimum just before noon and a steady rise in the afternoon. The hourly values are running averages; for example, the point of 800 smolts at 5 o'clock is the average of 689, 923 and 787 being observed totals at 4, 5 and 6 o'clock. The method of running averages smooths the curve but depresses maximum peaks and troughs.

days. Thus there may be two factors controlling smolt descent, light and temperature.

A question of general interest, though of no present significance in the LaHave, is the destruction of smolt in the turbines of mills. If Figure 23 is indicative of conditions in the upper part of the stream, the number of smolt that pass a point during working hours (from 8 to 5, with an hour off for lunch) is about one-quarter of the total run. The value is little changed whether calculated on standard or daylight saving time. If smolt descended evenly at all hours, the figure would, of course, be one-third. Hence the fluctuations in their time of activity give smolt some slight advantage in opposing destruction by machinery.

SUMMARY

Counting fences for salmon ascent and smolt descent were set up at four places on the LaHave River. A storage dam at a headwater lake was constructed and also a freshet dam to deliver the equivalent of a small rainstorm directly into the estuary. Freshets of various types were tried of which the most successful appeared to be a pair on successive nights. The first would bring fish up the estuary some distance, and the second would bring them into fresh water.

Small natural freshets are capable of moving large numbers of fish when other factors are favourable. Major runs of fish can occur without the aid of natural or artificial freshets and can be maintained by a steady flow of water during the run season (June-July). Artificial freshets can move fish which happen to be at the head of tide into the fresh water, but are unable by themselves to move fish into the estuary. Timed with winds and tides they would probably be successful. The reverse of a freshet, that is, cutting river level down, may also act as an effective stimulus in moving fish and might be as successful as an artificial freshet if correctly timed.

Temperature appears to have little effect in initiating runs of fish.

Fish move out of tidal waters into fresh water at dusk and light change may be the operating factor. There is also evidence that fairly strong onshore winds approaching 20 m.p.h., induce salmon to concentrate in the river estuary and eventually ascend. Peaks in the tidal cycles representing daily increasing differences between high and low tides seem to be effective in concentrating salmon in the estuary and initiating a run into the fresh water. Large natural freshets can initiate a major run of fish into the river provided the winds and tides are favourable. In cases where these other two factors were not favourable, no run occurred.

From the middle of June to the end of August the river run is mainly composed of grilse. In the spring and fall, older salmon predominate.

In 1950, 192 salmon were tagged at commercial nets off the LaHave River. There were 53 returns, largely from near the site of tagging or from eastward, towards Halifax, which appeared to be the direction of migration.

A survey was made, by selective seining, of the young salmon and coarse fish in the river. Of the total drainage area of some 500 square miles, about 10 per cent is actually used for spawning, that is, contains young salmon.

As one ascends the river from the mouth, the water becomes cooler and the density of small fishes in the stream increases. In good salmon waters the dominant forms which accompany salmon are *Couesius* and *Fundulus*.

Descending smolts were counted during two seasons, neither complete. The estimated annual number is 10,000, compared to a run of some 1,700 adult fish.

As to their hour of downstream migration, smolts resembled adults in being most active at dawn and dusk. The dawn movement is more pronounced than the dusk, smolts being in this way different from adults.

A table of confidence limits is set up, to show the manner in which angling returns might serve as a measure of success or otherwise, of river improvements. Such returns are considerably less sensitive measures than direct counts of salmon at fences.

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APPENDIX

SUGGESTED STANDARDS IF ANGLING SUCCESS IS TO BE USED AS A MEASURE OF RIVER IMPROVEMENT

As already mentioned there are two rivers on the Atlantic Coast of Nova Scotia for which good angling records have been kept for some years, namely the Medway and St. Mary's. The records since 1928 were examined and are set down in Figure 24. The St. Mary's has about the same drainage basin as the LaHave and Medway and lies on the same coast about 150 miles northeast. Its angling records have been carefully taken, and they show that since 1928, the four worst years and two of the three best years are the same as for the Medway.

For the Medway, the 1928 to 1934 records are derived from the log book of Freeman's Hotel, where there is supposed to be a record of every salmon caught by guests. The hotel having been maintained at the same size and level of prosperity for a good many years, it may be supposed that the fluctuations in catch parallel those of the river as a whole and also of the LaHave. The regression of the whole Medway (official figures) on Freeman's Hotel, was calculated from 1935 to 1950, and found to be

$$y = 23 + 2.99\,x \qquad (1)$$

where y is the whole river and x Freeman's Hotel annual salmon catch. The correlation coefficient, r, is 0.929 (minimum r which must be exceeded is 0.50). From the equation the 1928-34 values for the whole river were derived as shown in Figure 24.

These two rivers can be used to illustrate the possibilities and requirements of assessing improvements on the basis of angling success.

Single-River Method

The Medway angling success over the years, as shown in Figure 24, should enable an observer to assess whether some supposed improvement, in this instance water control, was producing a measurable effect. This would be a relatively insensitive method, to be applied if nothing but the catch records were on hand, so that no allowance could be made for the effect of good and bad fishing years. Consider the lower line of Figure 24 whose equation is

$$y = -24340 + 12.83\,x, \qquad (2)$$

where y is the catch and x is the year it was taken. The slope of the line, indicating an increase in catch of 12.83 fish per year, taken by itself is not significant.

However (a) the Medway slope differs less from the St. Mary's slope than it does from zero, (b) the St. Mary's slope *is* significant and (c) the *a priori* expectation would probably be that the catch would change in more or less the same way in both rivers. For these reasons the regression line instead of the mean is used to compute most probable catches for years of controlled flow on the Medway, in order to see if any measurable improvement has occurred.

Consider a value, MMI or minimum measurable improvement, being the

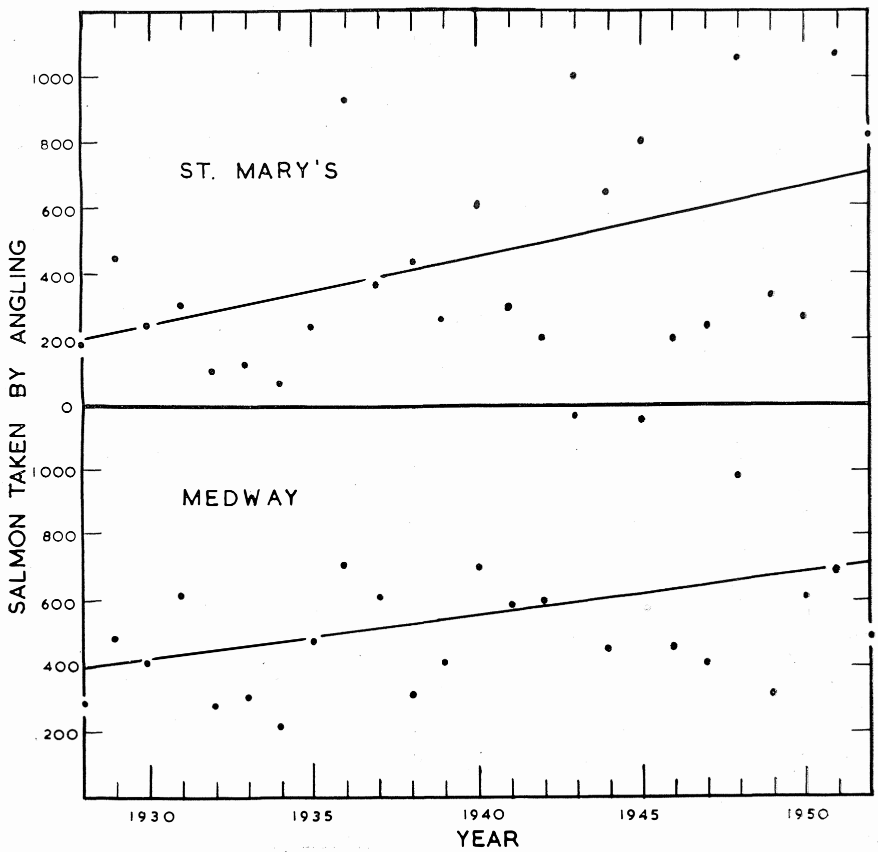

FIGURE 24. Illustration of the general variability of salmon angling in South Shore rivers.

Upper graph, St. Mary's River, where there is a trend towards improved fishing, the annual catch being described by the equation

$$y = -40423 + 21.07\ x$$

with y as the annual catch and x the year.

Lower graph, catch records on the Medway River, the line being drawn according to the calculated equation

$$y = -24340 + 12.83\ x.$$

Medway figures from 1935 on are official records; from 1928 to 1934 they are derived from Freeman's Hotel records, factored to total river values by the 1935–50 regression.

smallest average increase over expectation that could be taken as an indication of better fishing. This is equal to:

$$\text{MMI} = \frac{1.7 \text{ S.D.} \times \sqrt{c + e}}{\sqrt{ce}} \tag{3}$$

For the Medway River,

$$\text{MMI} = \frac{1.7 \times 231 \times \sqrt{23 + 2}}{\sqrt{23 \times 2}}$$
$$= 290 \text{ salmon}$$

S.D. = standard deviation of the series from the regression line (231 salmon). By convention, a measurement is said to be significantly different if it lies at least 2 S.D. above or below the expected. (Only one chance in 20 of occurrence by accident). However in the present work one is not interested in the zone below expectation, and for 2 S.D. the chances of wrong interpretation *above* expectation would be 1 to 40, which represents an unconventionally rigid demand. Therefore the value 1.7 S.D. has been used, in which the chances of a mistaken conclusion *above* the most probable value are 1 in 20 (chances plus or minus 1 in 10).

$c + e$ = number of years for which data exist, being 25. The precision of S.D. will be in proportion to the square root of the number of years. By multiplying by $\sqrt{c + e}$ the precision of S.D. is reduced to unit value, i.e. to what it would be if one year of observation followed one year of control.

c = number of control or normal years of observation before the improvement under consideration was put in. This is 1928 to 1949, or 23 years. The precision of S.D. improves in proportion to $\sqrt{c}$, by which one therefore divides.

e = number of years of observation following the improvement, or 2 in this case. The accuracy of S.D. also improves in proportion to $\sqrt{e}$ which has also been placed in the lower line of the equation.

TABLE VI. Required improvement needed in average two-year catch on the Medway for a significant demonstration of improvement in angling due to water control (column 5), compared with actual difference from expectation (column 4). Since the average catch is less than expectation, no success to date is demonstrated from water control.

1 Year	2 Observed catch	3 Expected catch from regression equation (2)	4 Difference (improvement, positive; decrease, negative)	5 Minimum difference which would indicate improvement (MMI) (see text)
1951	697	691	+6	...
1952	487	704	—217	...
Average	...	...	—106	+290

The analysis of the Medway experiment is shown in Table VI. In column 3 are shown calculated values from the equation describing the lower line of Figure 24. Differences between observed and expected are shown in column 4, and their average can be compared with the MMI shown in column 5. Column 4 is lower than column 5, so that no improvement is evident.

Two-River Method

Another method of assessing the Medway experiment is to compare that river with a "brother" river along the coast with which there is variation in common between good and bad years. On the basis of several years' experience

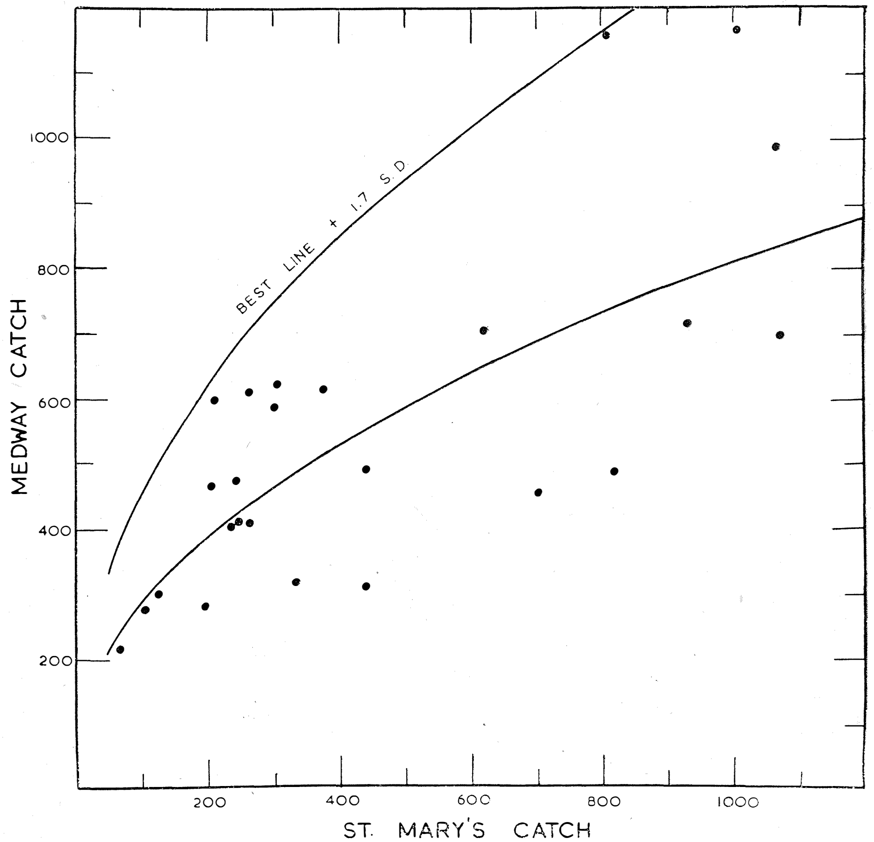

FIGURE 25. Comparison of the annual angling catch on the St. Mary's River and on the Medway River. Lower line is the "best line" fitted by the method of least squares on the logarithms of the catch numbers, being

$$\log y = 1.5546 + 0.450 \log x$$

where x is the St. Mary's annual catch and y the Medway catch. The upper line is 1.7 S.D. above the best line. For a demonstrated improvement in angling in any given year the Medway figure, corresponding to the appropriate St. Mary's value on the base line, would have to fall above the upper line.

in comparing the two rivers before the experimental time, the observer is able to forecast, within limits, how good the fishing should have been in the test river, had no improvement been introduced. This theoretical value is then compared with the real angling return, which, if the experiment was successful, should be higher. If it is sufficiently higher, the treatment may be said to be a success.

The control river selected was the St. Mary's, whose angling data are shown in Figure 24. In Figure 25 there is a comparison of the two rivers. The best line has been calculated on the basis of the logarithm of the catches and is described by the equation

$$\log y = 1.5546 + 0.450 \log x \tag{4}$$

where x is the St. Mary's catch and y the Medway catch. The r value is 0.772 (it must exceed 0.40) and the standard deviation from the line is 0.119.

The reason for using logarithms is that it takes care of the tendency on both rivers for catch to be more variable as it increases in size—a common phenomenon. The use of logarithms, as the lines on Figure 25 show, makes the assessment of improvement more sensitive in poor angling years, which are the years in which water control might be expected to exhibit its greatest benefit.

Columns 3 and 4 of Table VII show that the actual Medway catches for 1951 and 1952 are both less than the most probable catch computed from (4), so there is no question of any improvement having been shown to date. However it is the method of testing which is of interest here, so the procedure is outlined below.

TABLE VII. Actual salmon catch on the St. Mary's and Medway Rivers in 1951 and 1952, the expected or most probable catch on the Medway, and a comparison of the difference between actual and expected with a minimum measurable improvement (MMI). Column 7 is calculated from 5 and 6 using equation (4), and column 4 is the antilogarithm of 7. Column 8 is the difference of 6 and 7, the average value being compared in column 9 with the MMI calculated from equation (5).

1	2	3	4	5	6	7	8	9
	Catch (number of salmon)			Logarithms of catches				
Year	St. Mary's	Medway (actual)	Medway (expected)	St. Mary's	Medway (actual)	Medway (expected)	Difference	MMI
1951	1,070	697	828	3.029	2.843	2.918	—0.075	. . .
1952	820	487	734	2.914	2.688	2.866	—0.178	. . .
Average	. . .	. . .	. . .	. . .	. . .	. . .	—0.126	+0.149

A possible formula for computing MMI (as defined above) is the same as the one used earlier:

$$\text{MMI} = \frac{1.7 \text{ S.D.} \times \sqrt{c+e}}{\sqrt{ce}}; \tag{5}$$

where c is the number of control years, e the number of treatment years, and S.D. the standard deviation from the regression line relating the catches of the two rivers. (Used in the present context, this expression ignores a small component of error which would make MMI actually somewhat larger than (5) in most years, but to include the missing element would result in considerable complexity that is scarcely necessary.)

If only a single treatment year were available on the Medway, the MMI from (5) would be close to 1.7 times the standard deviation from the regression line as shown in Figure 25, or more exactly it is $1.7 \times 0.119 \times \sqrt{24/23} = 0.207$ log units. The antilogarithm, 1.611, shows that 61 per cent improvement over expectation would be necessary in order to have 95 per cent confidence in the result of a single year's catch.

When two or more years of treatment are available it is necessary to compute the *average* increase in catch over expectation (in log units) and compare it with MMI calculated from (5). The latter is, for two years,

$$\text{MMI} = \frac{1.7 \times 0.119 \times \sqrt{25}}{\sqrt{23 \times 2}}$$
$$= 0.149$$

Columns 8 and 9 of Table VII show that the average difference between actual and most probable Medway catch is —0.126 log units, whereas the minimum measurable improvement would be +0.149. The difference is —0.275, or in other words the observed catches were 53 per cent below the level required to demonstrate improvement (since antilog —0.275 = 0.531).

However, as noted above, water control is most likely to be effective in

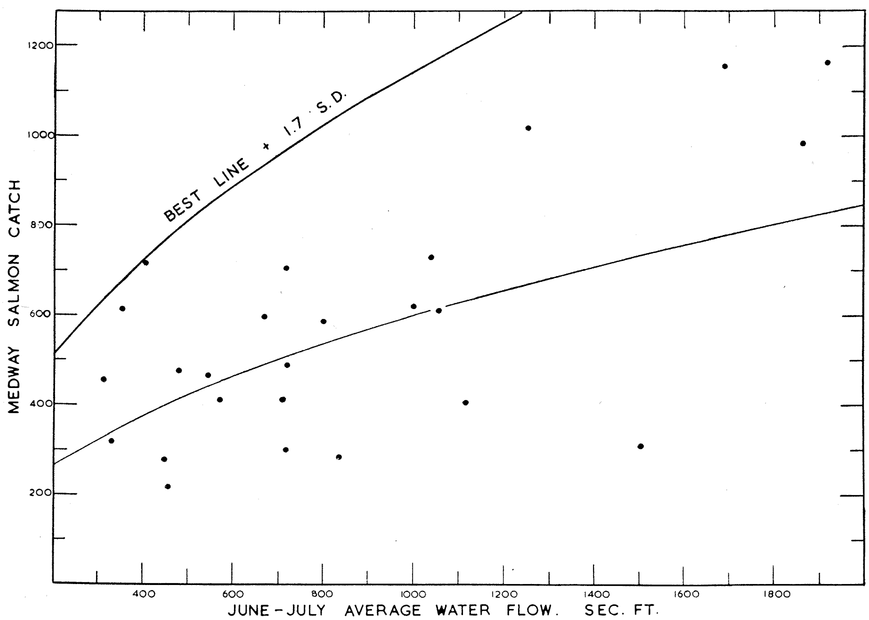

FIGURE 26. Comparison of the annual angling catch on the Medway River with the water flowage at the Charleston gauge near the mouth of the river.

years of low water and poor catch, whereas in the two years tested to date the St. Mary's catch has been above the trend line for that river (Figure 24).

Method Using Environmental Data

The method just described, of relating the catch in the experimental river to a control river, would not always be possible. For instance there are some improvements contemplated on the St. Mary's which may make it unsuitable to use as a control for the Medway in future years. An alternative standard might be set up by relating the catch over a period of years to the weather conditions. It is a general experience of anglers that fishing is good when the water is high and poor during dry summers.

The water flow of the Medway has been recorded for a good many years at the Charleston gauge near head of tide. The June-July average water flow in cubic feet per second was found to be related to the annual salmon catch according to the equation

$$\log y = 1.2617 + 0.505 \log x \qquad (6)$$

where x is the flowage and y the catch (Figure 26). This was for 25 years prior to the present experiment, 1926-1950. The correlation coefficient, r, is 0.535 and the standard deviation of the observations from the line is 0.166.

This equation is not as sensitive an indicator of improvement as the previous one (relating to St. Mary's catch) and when applied to the experiment in the same manner as Table VII, also fails to show any benefit which may have occurred as a result of water control. A theoretical defect in the method is that the Charleston water gauge is itself affected by the stored water during experimental years. However this effect is in practice quite small.

It is possible that a close study of weather conditions, including perhaps daily rainfall, could yield a closer correlation with catch than is provided by the flowage data used.