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Predator-prey relationships between fish-eating birds and Atlantic salmon

(With a supplement on fundamentals of merganser control)

By
P. F. ELSON
Fisheries Research Board of Canada
Biological Station, St. Andrews, N.B.

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99729-6—1½

FOREWORD

MANAGING CANADA'S Atlantic salmon resource has to a large extent consisted of reducing the impact of civilization on the habitat. Conservation has been remedial. In a new approach Dr. Elson's Bulletin records work toward increasing the numbers of salmon produced in natural waters.

In the 1930's, Mr. Harley White of the then Biological Board of Canada recognized the possibility that fish-eating birds, if numerous enough, could limit salmon smolt production in rivers. His later studies mostly absolved the kingfisher which had hitherto received most of the blame but his studies also showed that mergansers could, with their voracious appetites for fish, reduce populations of young salmon down to low levels.

During the course of research as carried out over the past twenty-five years, Dr. Elson has studied the relationship between fish-eating birds and salmon persistently and objectively. His work, supported by colleagues in the Fisheries Research Board and the Department of Fisheries, has confirmed the hypothesis that mergansers can and do limit salmon production on some streams, and he has established the quantitative relations between salmon smolt production and bird activities. In his studies, Dr. Elson has gone beyond developing a schedule for managing Atlantic salmon stocks. He has actually documented and analysed an example of predator–prey relationship, and has thereby contributed substantially to our knowledge of population ecology. His analysis is accordingly, of general biological interest as well as of special interest in the field of fisheries biology.

The Bulletin presents a method for increasing production of salmon smolts. There is some evidence of a direct relationship between the size of smolt runs and the numbers of returning mature salmon. If this relationship is borne out a very real contribution to salmon management will have been made.

J. L. KASK,
Chairman,
Fisheries Research Board of Canada.

OTTAWA,
August 14, 1961

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ABSTRACT

Five annual (1942 to 1946) plantings of hatchery-reared Atlantic salmon underyearlings were made on a 10-mile stretch of the Pollett River, N.B. The plantings used from 16,000 to 250,000 fish and were distributed in various ways. Average production was 3,000 seaward-migrating smolts per year, best production 5,000 smolts. Depredations by mergansers (*Mergus merganser*) and kingfishers (*Megaceryle alcyon*) were suspected to be limiting smolt production. Control of these two species was applied and four annual (1947 to 1950) plantings of 250,000 fingerlings each were then made. Average smolt output increased to 20,000. Analysis is made of records of bird incidence, bird food, and fish populations in the river. This indicates that depredations by mergansers were the limiting factor for smolt production. Kingfishers were unimportant. Mergansers tended to be more abundant in years when parr were more abundant. In general the food requirement of visiting mergansers was in excess of the number of parr which the river could be expected to support. In order that a productive salmon stream like the Pollett give reasonably full smolt output, merganser incidence should not exceed a rate of 1 bird for each 15 miles (24 km) length and 10 yards (9 m) width of stream, or approximately 50 acres (20 hectares) of water. Control of kingfishers is warranted only when their incidence exceeds an average rate of 1 bird per ½ mile (0.8 km) of stream 10 yards wide, or about 1 bird for 2 acres (0.8 hectare) of water.

INTRODUCTION

General

In Canada, the supply of Atlantic salmon has for over a century been less than the demand. Public concern over supposedly declining stocks was noted by Perley (1852). The general situation does not appear to have changed much since then. During this time Canada has established one of the most extensive systems in the world for hatching, rearing and distributing young salmon. Artificial propagation of salmon, as developed by Samuel Wilmot (1869), was viewed with much optimism as a method of improving Canadian salmon fisheries (Wilmot, 1885). Increasingly severe legal restrictions on the taking of salmon were brought into practice in the hope of assuring greater numbers of spawners and hence more eggs and young salmon in the rearing grounds. But salmon catches continued to fluctuate over a wide range. Indeed, during the second quarter of the present century these fluctuations have taken the form of a rather steady decline, despite increased application of both the above methods of management (Elson, 1955). With recognition of the fact that such measures alone were not sufficient, more and more effort has been directed towards discovering factors which limit salmon stocks, so that appropriate new procedures for management could be developed.

Salmon of the Petitcodiac

The Petitcodiac River system in southeastern New Brunswick (Fig. 1A) is much the largest system of the Chignecto region. Its drainage basin above Hopewell Cape covers about 820 square miles (2114 sq km). About five-sixths of this area lie within relatively fertile (Smith, 1949) carboniferous formations. The remainder is in a band of hard Precambrian formations which form a divide between the Petitcodiac system and the shorter coastal streams flowing directly into the Bay of Fundy. The Petitcodiac system was selected as an area suitable for "practical experiments in planting young salmon" (Huntsman, MS, 1941). Although not now noted as a salmon river, the Petitcodiac once had a good supply of the fish and still has the physical attributes necessary for producing salmon. Perley (op. cit.) wrote of the great numbers of salmon once found in the Petitcodiac and their depletion, he presumed from overfishing. A generation later Venning (1870) described new conservation efforts, including the provision of fishways over dams on two of its tributaries, the Pollett and Coverdale Rivers, and the enforcement of protective measures.

In 1874 the commercial catch from the Chignecto region amounted to 150,000 pounds (Huntsman, 1931) or about 2% of the catch in the entire Maritime region south of Cape Gaspé. Within a few years the Chignecto catch dwindled to less than one-tenth of this proportion. Seven years later Venning (1881) advised that salmon in the Petitcodiac system were so few that conservation measures were scarcely warranted. The next 60 years saw sporadic attempts

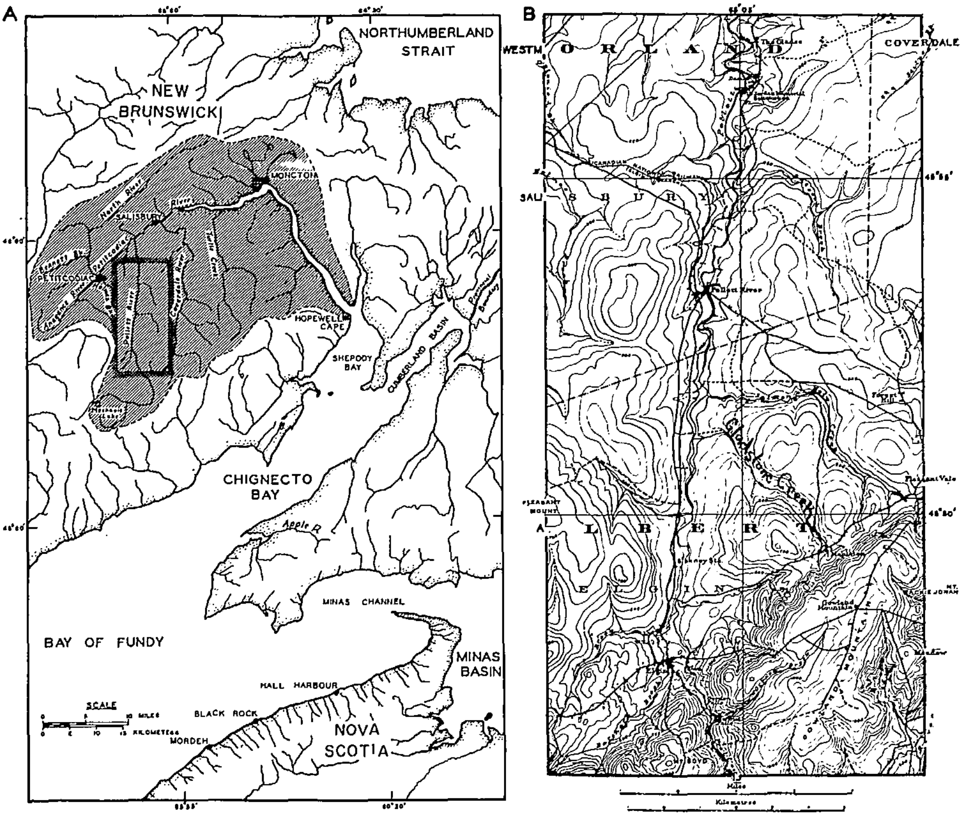

FIGURE 1. A—The Petitcodiac River basin (cross-hatched) in southeastern New Brunswick, showing location of the 10-mile section of the Pollett River (rectangular insert) used for intensive studies of salmon smolt production.

B—Detailed map of this middle portion of the Pollett River (from Map 402A, Petitcodiac Sheet, East Half, Department of Mines and Resources, Canada).

at conservation, but the fishery never again approached its earlier magnitude. However, local inhabitants continued to get a few salmon by one means or another and in 1943 some native young salmon were found in all suitable reaches not barred by dams.

To discuss salmon production one must have a general grasp of the fish's life history. For Petitcodiac salmon, spawning occurs in October, November and occasionally into December. The *alevins*, or *fry* emerge from the *redds* in the spawning gravels from late May to early June, depending on spring warming of the water. Over 80% of these young fish spend 2 years as river-dwelling *parr*; practically all the rest spend 3 years. As a rule, parr which have reached or exceeded a total length of about 3.9 inches (10 cm) towards the end of August become *smolts* in the following spring (Elson, 1957a). As the water warms in the spring these fish commence their seasonal period of rapid growth, put on the silvery coat of guanin which characterizes salmon in the sea, and descend to the salt water in the latter half of May and early June. These smolts have an average total length of about 6.3 inches (16 cm) and weigh about 0.1 lb (0.045 kg).

Post-smolts marked in Petitcodiac tributaries have been taken in weirs operated for herring and salmon along the Nova Scotian shore of the Bay of Fundy from Hall Harbour to Morden (Fig. 1A) in July and August following descent as smolts. They had been feeding on young herring and other small fishes and had grown to about a foot (30 cm) in length and a pound (0.45 kg) in weight.

Mature salmon returning to the Petitcodiac for their first time do so mostly as grilse, a little more than a year after going to sea as smolts. They are then about 25 inches (65 cm) long and weigh approximately 4.7 lb (2.13 kg), just under the present legal 5-pound limit for the New Brunswick commercial fishery. A few exceed this limit and a few survive their first spawning to grow larger—up to 20 lb. There is still a small commercial fishery for salmon from the Petitcodiac and neighbouring streams, in Chignecto Bay and Shepody Bay (Fig. 1A). Planted fish, which were introduced from the Miramichi River in New Brunswick and River Philip in Nova Scotia and were marked in the Pollett as descending smolts, have actually contributed more to Gulf of St. Lawrence, eastern Newfoundland and Labrador fisheries (Kerswill, 1955) as 2-sea-year salmon than to local fisheries or local spawning stocks at any age, though this is not known to be true of the native stock.

While a few grilse and larger salmon enter the Petitcodiac and its tributaries from mid-June onward, most of them come into the fresh water during October and November, with falling water temperatures and the onset of autumn rains.

The Pollett River

The Pollett River is the largest tributary of the Petitcodiac system. Its abundant supply of salmon for food was reported to have been one of the attractions for early settlers. Heavy use of the fish and obstructing their access to spawning grounds were followed by a decline of the runs to very low numbers. At the time this study was started some salmon continued to enter the river each year, usually late in the season, but could ascend only 5 miles (8 km), as far as the first dam. Many of these fish were taken surreptitiously by the local inhabitants.

Geographical description. The drainage basin of the Pollett River includes about 120 square miles (310 sq km) (Fig. 1B). The river is 36 miles (58 km) long from its source in the Albert County highlands bordering the Bay of Fundy to its confluence with the Petitcodiac River, 4 miles (6.4 km) above the head of tide. It descends a little more than 1100 feet (335 m) in this distance.

The upper half of the stream flows through a steep valley in Paleozoic and Precambrian intrusives and sediments. This part of the drainage basin is largely covered with second growth mixed deciduous and coniferous forest. A few scattered farms were abandoned 30 to 50 years ago. The lower half flows through an area of Pennsylvanian sandstones and shales which has been used for agriculture during most of the last century and a half. Compared with most New Brunswick salmon streams, the watershed of the Pollett is relatively fertile (Smith, 1949).

The upper half of the river is separated from the lower half by a deep gorge nearly a mile long. In this section the river consists of a series of deep pools separated by short rapids and cascades. Midway in the gorge the Gordon Falls (Fig. 2A), a straight plunge of 15 to 20 feet (4.5 to 6m) depending on the amount of discharge, has apparently always been a barrier to upward movement of salmon.

From the falls to its mouth the river is fairly uniform in character. It is a series of rather shallow pools alternating with long, gentle rapids. The stream bed is about 75 feet (23 m) wide. Its gradient is fairly uniform with about 16

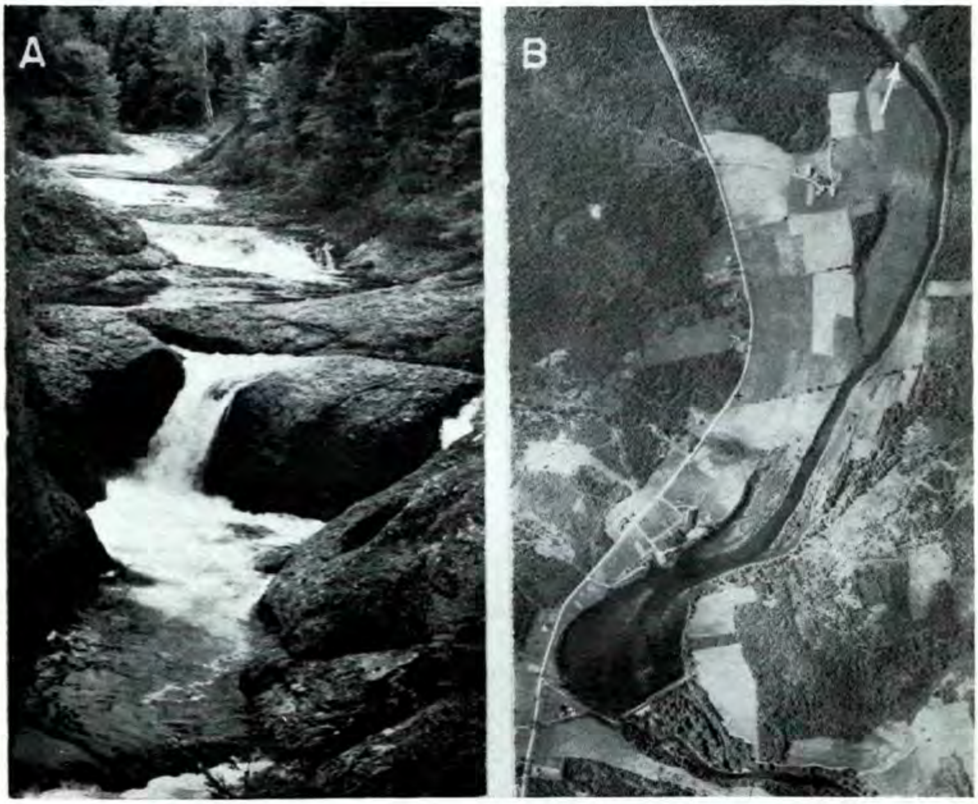

FIGURE 2. Barriers to upstream movement of salmon bounding the study area of the middle Pollett. A—Gordon Falls, located near Elgin, is a straight plunge of 15 to 20 feet, depending on amount of discharge, and has always been a barrier. B—A dam at the Jordan Memorial Sanatorium, 11 miles below Elgin, was a barrier after the associated fish pass was destroyed in the middle 1930's. In 1947 and earlier the smolt-counting weir (thin white "V") was located just downstream from the spillway showing near the lower left-hand corner of the picture. In 1948 the weir was relocated at the demarcation between fields and woods on the right bank of the river (white arrow) showing in the upper right corner of the picture. (Photograph taken in 1947.)

feet of drop per mile of length (3 m per km). Forest and farm land occur along the river in about equal proportions. The farm lands, largely hay and pasture field, occupy the more gently sloping banks and the flat intervale or bottom land.

The water is normally clear, but when in freshet carries enough sediment to be turbid and is also stained brown. Rises of 3 feet (1 m) in water level are not unusual during spring and fall; occasional rises of 6 to 8 feet may occur within 12 hours. Under low water conditions the discharge is about 50 cubic feet per second (1.4 m^3/sec); in heavy floods it may exceed 3000 cfs (85 m^3/sec).

THE EXPERIMENTAL AREA. In common with other streams of the region, encroaching settlement early in the last century brought dams to the Pollett River. These were built to provide power for grist mills and saw mills. There has been such a dam near the village of Pollett River, locally called Forest Glen, 10 miles (16 km) above the mouth of the river, for at least 150 years. During much of this time it had no fishway and constituted a barrier to salmon. A dam at Elgin, 17½ miles (28 km) above the mouth and a half mile below the Gordon Falls, barred salmon from holding pools in the lower half mile of the gorge for many years. An earth and concrete dam 6 miles (10 km) above the mouth of the Pollett at what is now the Jordan Memorial Sanatorium, was built about 1910 (Fig. 2B); there was no provision for fish to pass it after the mid 1930's.

Thus there was an 11-mile (18 km) section of the river between Elgin and the Jordan Memorial Sanatorium which was a former salmon rearing area but was no longer accessible to salmon. Even after the Elgin dam was destroyed by floods in January 1948, the section remained discrete since the Gordon Falls a half mile above still formed a natural barrier to salmon and a smaller 6-foot (2 m) falls only a quarter mile above the site of the Elgin dam constitutes a natural barrier to upstream movement of immature salmon. At the lower end of this section the concrete Sanatorium dam was a barrier until a Denil-type fish pass was installed in 1950. This pass incorporated a trap to control upward movement of salmon. The slow water behind this dam extends about a mile upstream. The actual productive part of the experimental area for salmon is about 10 miles (16 km) long. The area of the stream bed in this section, under ordinary summer water conditions, has been computed, by measuring on aerial photographs with a planimeter, as about 435,600 square yards (plus or minus a standard error of 6% or 26,100 square yards), i.e., about 90 acres (36 hectares). For the purpose of computing total fish production the area has been considered as 435,000 square yards (363,700 m^2). In the experimental area, as throughout most of the rest of the stream, the deepest part of the channel, at low water, is commonly less than 2 feet deep. There are only 5 pools more than 5 feet deep.

This part of the stream is accessible by truck at 2-mile (3 km) or closer intervals, a decided advantage for its use as a study area.

Part I. Production of Salmon Smolts with Birds Undisturbed

Experiments in planting young salmon were begun on the experimental part of the Pollett, described above, in 1942. The object was "to obtain the highest smolt production for the costs of stocking, in fish and effort" (Huntsman, MS, 1942). As a starting point, it was estimated after detailed inspection of the territory that the experimental area could accommodate about 16,000 yearling and older parr. Initial plantings used about 16,000 underyearlings in order to permit maximum survival rates without waste due to overstocking. Later, heavier plantings were used to measure total capacity of the area to produce smolts. Procedures of planting were varied to take advantage of information gained about local survival. The results were judged primarily on the smolt yield from each planting. Interim observations on surviving parr contributed additional information.

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METHODS

Five successive experiments were set up, with a planting each year from 1942 to 1946. Measurements of the resulting runs of 2-year-old smolts were made from 1944 to 1948 and of 3-year smolts from 1945 to 1949.

PLANTINGS. Underyearling salmon for all plantings were provided by the Canadian Department of Fisheries. Most stock was of River Philip, Nova Scotia, origin but this was augmented with Miramichi River stock as necessary. Plantings were made during the latter half of August in each year. The young fish were brought 100 to 150 miles by truck from the hatcheries and usually transferred to live-cars placed in the river near their assigned water. They were then distributed in buckets from the live-cars within 24 hours of arrival. From 1942 to 1944 all fingerlings were counted as liberated. In 1945 and 1946 a sample of one-fifth, by weight, of the fish from each truck load of 25,000 to 40,000 fingerlings was set aside for counting in order to arrive at an overall figure for the number planted.

ASSESSMENT OF FISH POPULATIONS. The year after each planting, a search for resulting parr as well as fish of other species was made at least once during the summer. From 1943 to 1945 this was done by visual observation and a limited use of one-man hand seines (Fig. 3A). A general idea was obtained of year-to-year changes in abundance of parr and other fishes.

In 1946 development of more effective techniques for determining the numbers of parr in short, representative areas was begun. Seines 15 feet (4.5 m) long with ½-inch (13 mm) stretched mesh were used by a 4-man crew. The method was tested for efficiency on parr in a neighbouring stream.

In 1947 a systematic study was made of all species of fish in the experimental 10 miles, using 7 representative sampling areas. Each of these areas was selected as a more or less discrete unit of habitat within which the fish were expected to remain fairly well despite the seining activities. The criteria for such units were based on previous observations of the habits of the species involved. Upper or lower ends of rapids or pools were common boundaries. Most of the sampling areas included a pool and adjacent rapids and were 50 to 60 yards long (46–55 m). No barrier nets were used. A 4-man crew participated in the seining (Fig. 3B). As in 1946 two men operated the 15-foot seine and two others assisted by splashing around and disturbing the bottom so as to scare and hold fish within reach of the seiners. Fish were removed to live-cars (Fig. 3D) as caught. Seining was repeated at a given point until no more fish were taken. The whole sample area was covered systematically in this way. Such an operation sometimes required 1 to 2 hours for a 50-yard long section. This operation was repeated once or twice more, until relatively few fish were taken the last time. Each of the 2 or 3 complete coverages of an area involved about the same total amount of effort to catch fish. To facilitate study of the changing abundance of fish a "population index" has been calculated as the average number per 100 square yards[1] of stream bottom. Such an area is large enough that indices can be considered to only one decimal point without getting any grossly wrong impression, unless fish are very sparse indeed.

ASSESSMENT OF MIGRATING SMOLTS. In the spring young Atlantic salmon smolts gather and move quickly down to the sea. Sometimes they appear to move as individuals, but more often they have been observed in increasingly larger schools as they move downstream. These schools are often not particularly close-formed but nevertheless do appear to involve a degree of mutual attraction between individuals. In the Maritime Provinces these smolt "runs" occur principally during the last half of May and the first half of June. Consequently the annual smolt production of a stream can be measured by counting the migrants as they pass out at the lower end during this season. In practice, there may be difficulty in erecting and maintaining a sufficiently fine screen

[1]100 sq yd = 83.6 sq m; or 1 are = 100 sq m = 119.6 sq yd.

FIGURE 3. Methods used in assessing fish populations. A—1-man hand seine. B—2-man seine with two beaters, at the Barchard Station of the seven selected sample series. C—2-man seine used in conjunction with DC electrofishing, at Number 2 station of the 10-sample series. D—Fish taken by seining being held in live car until coverage of area is completed.

to guide the smolts to where they can be counted. Salmon streams, during the period of the smolt run, are often in freshet and the smolts run in largest numbers while these freshets are rampaging. The first weir used for counting smolts on the Pollett was a modification of that described by White (1939) but was built more sturdily and had a 6-foot rather than 4-foot high screen. It was located immediately below the Sanatorium dam just below the experimental area (Fig. 2B). All smolts checked through the trap were marked by removal of their adipose and right pelvic fins. The first and fourth smolt runs were trapped fairly successfully; but the second, third and fifth runs less so because of extremely difficult stream conditions at times of smolt descent. During the course of the experiments smolt counting apparatus was improved as experience accumulated. Similar smolt counts were made on other streams in this region. The pattern for the runs from these streams has been compared with the pattern for Pollett runs in years when good counts were obtained. Also the general history of Pollett runs for years of good counts has been examined. A more useful figure for Pollett production than the actual counts of descending smolts, for the poor years, has been estimated by applying corrections to the counted numbers. These corrections are based on comparison of the patterns of poorly-counted Pollett runs with the patterns of well-counted runs in other streams, or with well-counted Pollett runs in years with similar water conditions.

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RESULTS

Production of smolts in the Pollett is summarized and discussed on page 20 *et seq.* The details are given below.

Plantings

Numbers and distribution. Numbers of underyearling salmon planted varied from about 16,000 per year to 250,000 per year. They were given different degrees of dispersal at planting, being liberated at densities as low as 12 per 100 square yards and as high as 120 per 100 square yards for the actual ground covered at the planting. The plantings are plotted on maps of the experimental area in Fig. 4 and 5. Stretches between planted areas were usually from ¾ to 1½ miles long and never exceeded 2 miles. Details of planting operations have been recorded by Elson (MS, 1942–1946). Planting data are included in Table IV, below.

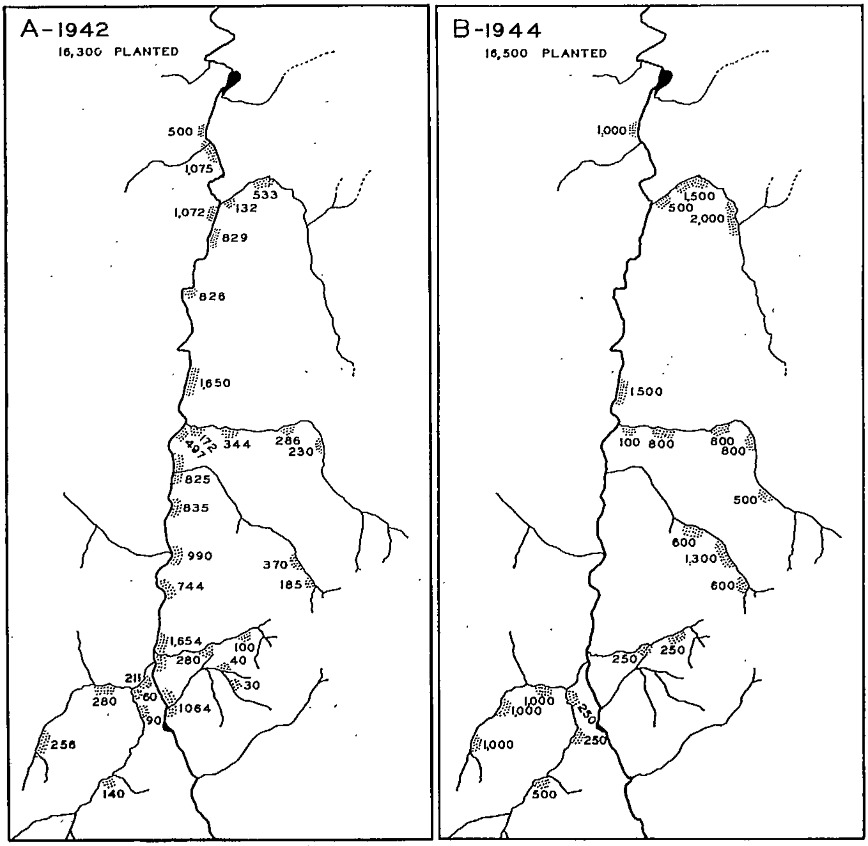

Figure 4. Sparse plantings of hatchery-reared Atlantic salmon underyearlings made in the experimental stretch of the Pollett River. Numbers liberated are shown adjacent to dots indicating areas of liberation. A—Planting mostly in main river. B—Planting mostly in tributaries.

In 1942, 1943 and 1944, the years of relatively sparse plantings, the underyearling salmon were liberated along much of the stream length in small quantities similar to natural densities observed in other salmon streams. This was done so that the young fish would have sufficient space immediately available to them. In 1945 and 1946, the 2 years of heavy plantings, the underyearlings were carried not more than 100 yards up or down stream from the truck and poured into the river in lots of several thousand at a time.

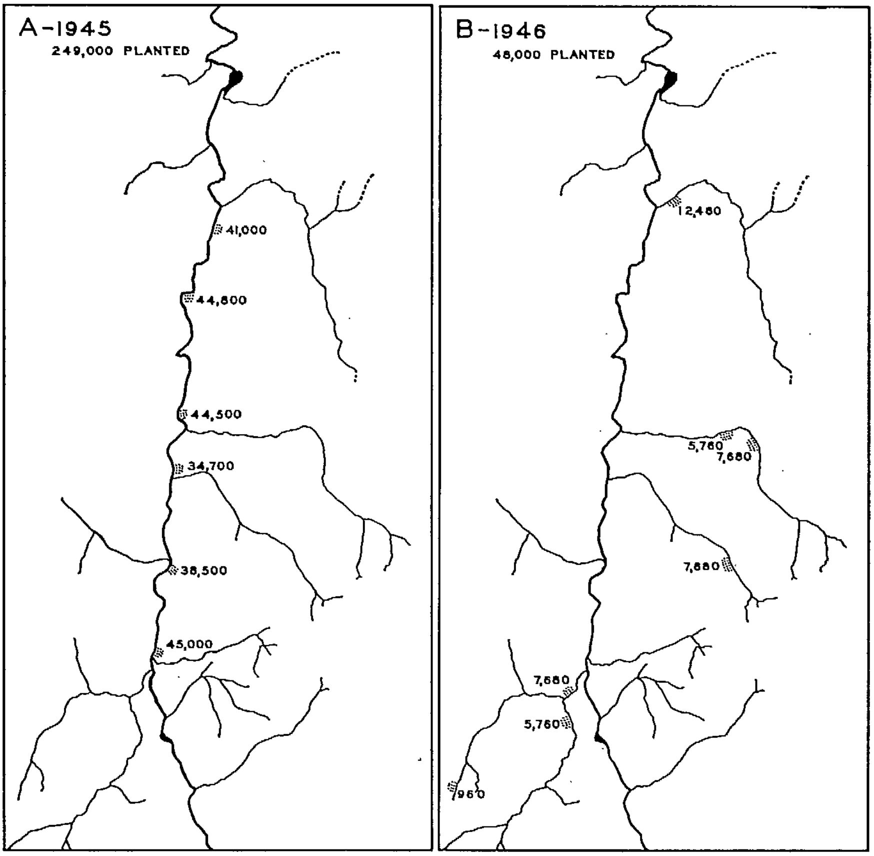

FIGURE 5. Heavy plantings of hatchery-reared Atlantic salmon underyearlings in the experimental stretch of the Pollett River. Numbers liberated are shown adjacent to dots indicating areas of liberation. **A**—All in main river. **B**—All in tributaries.

DISPERSAL FROM PLANTING SITES. The dispersal of the small fish from the immediate planting stations was examined during the few weeks immediately after the two heaviest plantings. In the main river planting, the fish distributed themselves fairly uniformly over the stream for about ½ mile above and 1 mile below planting stations within about 10 weeks (Fig. 6). Since the planting stations were not much more than 1½ miles apart (Fig. 5A) this resulted in relatively uniform dispersal and good utilization of the stream throughout the entire experimental area. In the tributary streams effective post-planting dispersal was limited to about ½ mile up and down stream. These limits were frequently associated with pools containing numbers of trout (*Salvelinus fontinalis*) of a size large enough to eat the newly-planted salmon (Elson, 1942). White and Huntsman (1938) found that newly-planted fry in the Apple River had little tendency to move through pools during their first summer. The Pollett fish, planted at summer's end, seem to have dispersed somewhat more rapidly than those of the Apple River planting.

This extensive dispersal of the planted fish throughout the stream warrants comparison of the results from the 5 plantings on the basis of numbers used and of whether they were planted in the main river or tributaries. Differences in detailed schemes of distribution appear to have had comparatively little effect on survival.

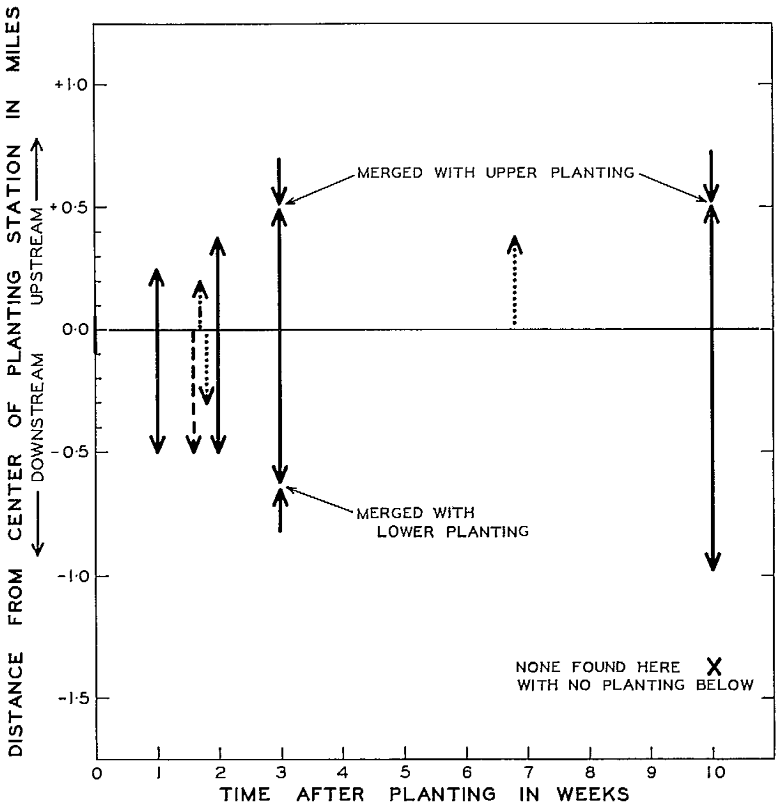

FIGURE 6. Natural dispersal of planted underyearling salmon from their planting stations, based on general spread (occasional individuals may move much farther). *Solid lines*—main river, 1945; *dashes*—Gladstone Creek, 1946; *dots and dashes*—Salmon Hole Creek, 1946; *dots only*—Babcock Brook, 1946.

ASSESSMENT OF PARR

FIRST PLANTING (Fig. 4A). Surveys were made, during the summer of 1943, by Dr A. G. Huntsman, Mr H. C. White and the author. Using one-man hand seines and visual observation, no parr and scarcely any fish of other species were found along the main river. But in tributary brooks which received plantings parr were found at an average density of 1.1 parr per 100 square yards of stream bottom. The general picture was one of almost negligible survival in the main river and moderate survival in the small, cooler brooks, particularly where the latter were overhung by trees and bushes and had good underwater cover. White and Huntsman (1938) found this type of seining to be about 25% efficient. Seining technique similar to that used on the Pollett was tested on known numbers of marked parr in adjacent streams. From 25% to 50% were recaptured (Huntsman, MS, 1945). On this basis the total parr in the brooks were estimated at between 2.2 and 4.4 per 100 square yards, or 800 to 1600 parr for the 10 miles of tributary salmon water, with probably less than an additional 500 in the main river.

SECOND PLANTING. In 1944, using techniques similar to the preceding year, parr appeared to be no more abundant than from the similar 1942 planting (Fig. 4A). About 10% of those found were 2-year-olds from this first planting. The general picture of better survival in the small brooks and almost no parr or other fish in the main river was the same as for the first planting.

THIRD PLANTING. The third planting was placed largely in the brooks (Fig. 4B). In 1945 no yearlings and only a few 2-year-olds were found in the main river, even immediately below the two main river planting stations used. Judging from the growth pattern shown by their scales, the 2-year-olds had descended from an adjacent brook in which they were planted in 1943. Of the parr taken in brooks 55% were yearlings from the third planting, 43% were 2-year-olds, and 2% were 3-year-olds. The relatively high proportion of 2-year-olds, especially considering that some of this year-class migrated as smolts in the spring, indicates relatively poor survival of the yearling class—almost certainly it must have been poorer than the survival from the second planting to yearling stage. Parr of all age-groups were captured in the tributaries at a rate of 107 per mile of stream. The rate of capture indicated the density of the parr population as 5.7 to 11.4 per 100 square yards. The total stream population of parr in the 10 miles of tributary streams was estimated to lie between 2000 and 4000 individuals. This included 900 to 1800 yearlings and represented most of the survivors from the third planting.

FOURTH PLANTING. Following the heavy 1945 planting of about 250,000 underyearlings (Fig. 5A), the effort to assess yearling survivors in 1946 was increased over that of earlier experiments. One-man seines were used only in spring and early summer. From July onward a 15-foot 2-man seine was used. In general, an attempt was made to cover short sections of stream thoroughly. An extensive search for parr was made in mid-August. The numbers found during the year at various stations in the main river are listed in Table I.

An estimate of summer abundance of parr was attempted using the seining results obtained in August. Similar seining was tested five times on marked native parr in a nearby stream. The mean removal, and its standard error, of small, known numbers of the previously marked parr was 27% ±9%. That is to say, this type of seining could be expected to take, on the average, about one-quarter of the parr present (not less than a tenth or more than half). On this basis, the August data indicate a total population for the experimental area of about 7000 parr, but not less than 3500 or more than 17,000. Studies at four of the seining stations were repeated in early October. By this time parr were found at much less than half the abundance indicated in August. This impression of decrease was strengthened by the results of additional visual search for parr throughout the experimental area. Later it will be shown that over 4000 smolts descended the following spring; so there must have been at least as many parr, mostly yearlings, in October. Considering the reduction in parr between August and October, 10,000 to 12,000 (2.3 to 2.8 per 100 sq yd) seems a reasonable figure for the midsummer population of parr in the main river; this figure is well within reasonable limits of error for the 1946 seining operation.

In addition to parr in the main river, a few were found by systematic seining in the tributary brooks. But even allowing for reasonable error in calculation, their total number probably did not exceed 500—not enough to warrant any alteration of the above estimate.

FIFTH PLANTING. The fifth planting (Fig. 5B) was made only in the tributary brooks and was a heavy one for these waters. Yearling parr from it were present in the system in 1947. Early in 1947 it was decided that future studies would be concentrated on the main river with little attention directed towards the small tributaries. Casual seining in the largest tributary, Babcock Brook (Fig. 1B), showed yearling parr in moderate numbers scattered along the brook. Data for estimating population strength in the brooks were not obtained, however.

In the main river, a systematic study was made of the fish in seven sample areas scattered along the experimental stretch. These sections were selected so that they included a length of rapids at the upper end and a pool running out to relatively shallow water at the lower end. Such an area appeared to be a sort of "habitat unit" for the several species of fish in the river. This type

TABLE I. Numbers of salmon parr seined in 1946, the year after planting 249,000 hatchery-reared underyearling salmon in a 10-mile stretch of the Pollett River, N.B. (without bird control). Number of young salmon found at each station is given as numerator; length of stream, in yards, examined at each station is given as denominator.

Station	Late April	Early June	Late June	Late July	Late Aug.	Early Sept.	Late Sept.	Early Oct.
In main river								
Elgin	...	...	...	...	5/50	...	...	4/100
Mapleton	...	...	...	...	85/150	59/150	...	0/200
Blakney	...	...	4/250	12/350	15/250	...	...	1/250
Jonah	...	...	...	...	8/50	...	...	...
Salmon Hole	...	...	...	...	19/300	...	...	...
Stuart	...	...	...	...	6/200	37/200	...	...
Moore Bridge	2/100	3/150	...	5/250	...	5/75	...	...
Collicutt	...	...	5/50	0/350	7/200	...	...	3/200
Horsman	...	...	...	...	2/400	...	...	...
Total	2/100	3/150	9/300	17/950	147/1,600	101/425	...	8/750
Parr/100 yd	2	2	3	2	9	24	...	1
In tributaries								
Gladstone	...	...	...	...	...	...	1/1,760	...
Salmon Hole Cr.	...	...	...	...	...	...	3/500	...
Babcock, upper	...	...	...	...	...	...	3/550	...
Babcock, lower	...	...	...	...	...	...	...	11/460
Total (all dates)	...	...	...	...	...	...	18/3,270	
Parr/100 yd	...	...	...	...	...	...	less than 1	

of selection, therefore, was associated with minimum movement of fish into or out of the sample area at the upper and lower ends while seining was in progress. Further, in making the selection of areas, an attempt was made to include various types of habitat in proportions similar to those occurring in the experimental area as a whole. This was done so that the combined results for all samples would represent, in miniature, the condition for the whole stream.

Fish populations within these sample areas were assessed using the assumption that the seining operations took nearly all the fish present. While this "minimum count" seining seldom, if ever, took all fish present, it did appear to give a useful indication of population strengths within the areas. A typical example of the results of such an operation is given in Table II. Further discussion of the validity of such estimates will be offered later (page 38 *et seq.*). The results of the 1947 study of fish populations in the main river appear in Table III.

TABLE II. Example of data obtained by "minimum count" seining procedure, without barrier nets to cut off sampling area.

STATION: Barchard's Meadow, near Mapleton. Date: July 23, 1947.

LOCATION: Upper end of sample section at road ford opposite mouth of Barchard Brook; lower end 50 yards down river at lip of shallow rapids.

WIDTH: Stream narrows to about 12 yards throughout section.

BOTTOM: Small and medium cobble, with finer gravel on rapids at upper and lower ends.

DEPTH: Mostly under 2 feet; maximum in pool 3 feet. This is a long, shallow pool with moderate rapids at upper and lower ends.

REMARKS: Seined mostly by downstream sweeps with 15-foot net; 2 men on net, 2 men to assist by scaring fish into scope of net.

Coverage No.	Time used	Fish caught				
		Salmon	Chub	Dace	Sucker	Eel
1	20 min	4	66	37	40	0
2	12 min	3	3	5	4	1
3	10 min	0	13	16	10	0
Total		7	82	58	54	1

TABLE III. Strength of fish populations in summer of 1947, in a 10-mile experimental stretch (approximately 435,000 sq yd) of the Pollett River, N.B., as found by "minimum count" seining, in 7 selected sample areas (see text, page 15). This was before control of mergansers and kingfishers, started in late June, had much chance to affect fish populations. For data on eels see Tables XVI and XVII. Index = average number per 100 sq yd. Stations are as follows: El—Elgin; Bar—Barchard; Bla—Blakney; Sal—Salmon Hole; Tho—Thorne; Bab—Babcock; Ho—Horsman.

	Length × width	Area	Salmon	Sucker	Chub	Dace	Other	Total	Total
	yards	*sq yd*	*no.*	*no.*	*no.*	*no.*	*no.*	*no.*	*index*
El..................	50×25	1,250	0	20	312	67	1	400	32.0
Bar..................	50×12	600	7	54	82	58	0	201	33.5
Bla..................	50×23	1,150	1	14	22	6	0	43	3.7
Sal..................	50×23	1,150	0	0	2	1	1	4	0.3
Tho..................	50×18	900	0	43	184	18	0	245	27.2
Bab..................	50×20	1,000	2	36	150	2	1	191	19.1
Ho..................	75×25	1,875	0	75	349	8	7	439	23.4
No..................	375 long	7,925	10	242	1,101	160	10	1,523	
Index..................			0.1	3.1	13.9	2 0	0.1	19.2	

Only one-third of the salmon parr found in the sample areas were yearlings, the rest being 2-year-olds from the fourth planting. On the basis of density of the parr observed in the sample areas (0.13 per 100 sq yd) the main river had a population of between 500 and 600 parr of which less than 200 were products of the fifth planting. Clearly, the underyearlings planted in the brooks did not descend the relatively short brooks in numbers sufficient to utilize the resources of the main stream to a worthwhile degree.

Assessment of Other Species

Throughout the years 1943 to 1946 very few other fish of any kind were captured or observed during the annual examinations for salmon parr. Captures amounted to less than a dozen adult lake chub (*Couesius plumbeus*) and an occasional blacknose dace (*Rhinichthys atratulus*) each year. A few large white suckers (*Catostomus commersoni*) were observed in the deepest pools.

In 1947 a general increase in coarse fish was observed; this involved primarily younger stages of all species. The systematic seining in sample areas permitted a quantitative evaluation of these other species. The index for all species combined, except eels, was about 20 fish per 100 square yards. *Couesius* contributed more than half the numbers. Captures and densities found are recorded in Table III. The relatively small number of eels (*Anguilla rostrata*) captured does not provide a true indication of the actual abundance of this species. When electrofishing was combined with seining in subsequent years, it became obvious that eels were one of the dominant, if not the dominant, species of fish in the area.

Assessment of Migrating Smolts

From 80% to 95% of Pollett parr become smolts as 2-year-olds. Hence successive smolt runs indicate, fairly well, smolt production from successive plantings.

Temperature of the water is one of the controlling factors for initiating transformation of parr to smolts and seaward migration of these smolts. Allen (1944) found that the feeding and growth which precede metamorphosis to the smolt stage only began as the water temperature rose to and above 7° C (44.6°F). White and Huntsman (1938), White (1940) and Hayes (1953) in Canada and Wolf (1950) in Sweden give diagrams in which intensity of daily smolt runs can be compared to water temperatures. Their diagrams show that the major part of any smolt migration occurred only after water temperatures had risen to a fairly consistent 10° C (50° F) or higher.

Comparison of the data from the Pollett for daily smolt catches and water temperature records shows a similar relationship (Fig. 7A, 7B, 17, 18, 19). This relationship shows particularly well in the data for the 1950 run (Fig. 18). In the Pollett, the smolt runs occur during the last half of May and the first half of June. Typically, the intensity of the daily runs showed a symmetrical bell-shaped frequency distribution with the peak occurring between May 20 and May 30. This typical distribution was skewed more or less by variations in temperature or other changes in water conditions. In years with large runs the descent occurred over a similar time interval to years with small runs.

First smolt run (1944). The day-by-day course of this run is illustrated in Fig. 7A. In all 663 smolts were passed through the weir; 250 were removed by anglers from a large pool immediately above the weir and 6 remained in this pool until late in the summer, apparently being discouraged from entering the trap by continuous low water late in the migrating season (Andrews, MS, 1944). The count was corrected by comparing the time and temperature relations of the smolt run from the North River (Fig. 7A), another Petitcodiac tributary, with the recorded portion of the Pollett run. Since the North River warms up before the Pollett in the spring, this correction is generous towards the Pollett.

The 1944 Pollett production has been set at about 2000 smolts.

Second smolt run (1945). Only 174 smolts were taken (Andrews, MS, 1945). Good records are available for the Pollett for the 5 years from 1949 to 1953 (Fig. 17, 18, 19). Spring warming of the water was very late in 1945, so there is every reason to believe that the run of smolts came somewhat later than average. By treating the 1945 run as having the average conditions for these 5 years, about 20% of the production should have been counted. The production from the second planting has been set at not over 1000 smolts.

THIRD SMOLT RUN (1946). The count was 333 smolts. The water warmed very slowly (Fig. 7B) as in 1945. The 1946 Pollett smolt run therefore, would probably not be underestimated by treating it as an average year in comparison with the years 1949 to 1953. Applying such a correction the total run is estimated at about 700 smolts.

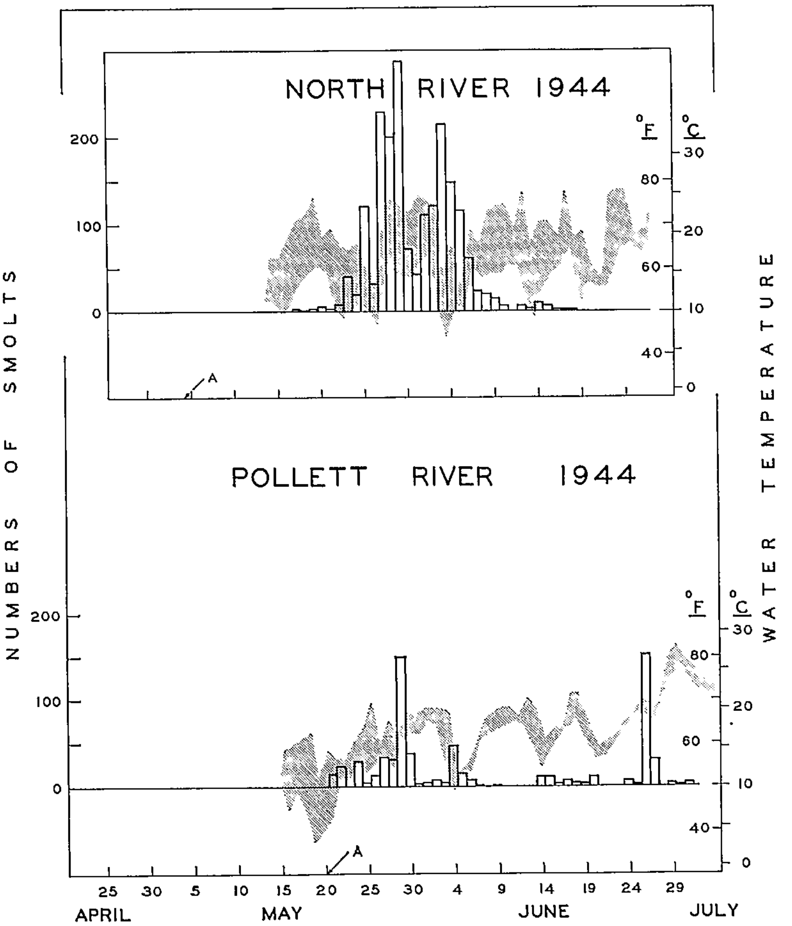

FIGURE 7A. *Below:* Pollett smolt run in 1944, from a sparse planting in the main river. *Above:* Smolt run from the North River, for comparison with incompletely-counted Pollett runs (see text). A—Dates on which counting weir became fully operative. *Grey area*—maximum and minimum daily water temperatures: note that most smolts moved down only as water temperatures reached and exceeded about 10°C (50°F).

On the nearby Bennett Brook (Fig. 1A) the smolt run is believed to have been completely counted. The seasonal course of increasing temperature was a little earlier than that for the Pollett (Fig. 7B). On the basis that the Pollett smolt run paralleled the order shown by the Bennett run, the complete Pollett count could not have exceeded 500 smolts.

Using a liberal estimate it is safe to say that the third planting in the Pollett did not yield more than 1000 2-year smolts.

FOURTH SMOLT RUN (1947). In all, 4282 smolts were passed through the trap (Fig. 17). Some correction to this number is desirable to compensate for the trap not being installed quite early enough (Andrews, MS, 1947) to take the entire run.

In 1949, when a good smolt count was obtained, temperature conditions more nearly resembled those of 1947 than in any other of the 5 years yielding complete counts (Fig. 17). Actually, in

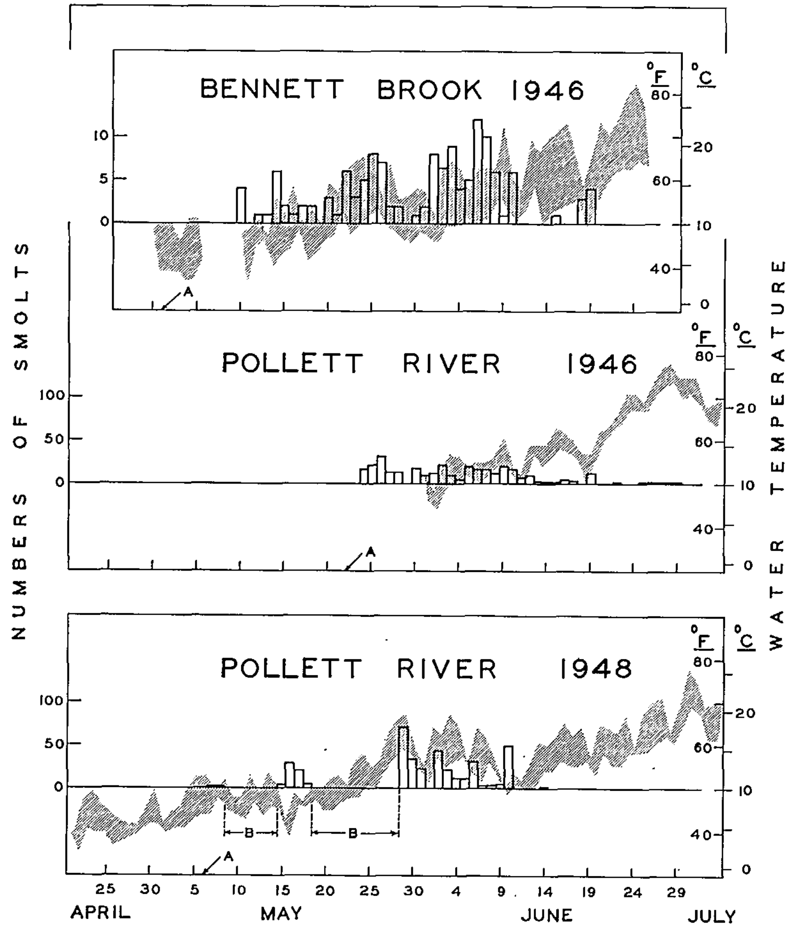

FIGURE 7B. *Middle:* Pollett smolt run in 1946, mostly from a sparse planting in the tributary brooks. *Lower:* Pollett smolt run in 1948, mostly from a heavy planting in the tributary brooks. (For a run from a heavy planting in the main river, see Figure 17.) *Upper:* Bennett Brook run, for comparison with the incompletely-counted Pollett runs (see text). **A**—as in Figure 7A. **B**—Periods of trap malfunction caused by spates.

1949 the water warmed up a few days earlier than in 1947, so that by using such a comparison for correcting the 1947 figure the production is likely to be a little over-estimated. Making adjustment on a percentage basis, in respect to calendar date, the corrected figure would be 5500 smolts.

Again in 1947 a counting weir was installed in Bennett Brook early enough to take practically the entire smolt run (Fig. 17). Applying a correction obtained from this stream gives an estimate of 4600 smolts for the Pollett.

Production of 2-year smolts from the fourth planting has been set at about 5000 smolts.

FIFTH SMOLT RUN (1948). In 1948 the counting weir was moved to a new site where there were better conditions for keeping it functioning during high water. But the wettest spring in 25 years again prevented a good count of smolts (Fig. 8); 360 smolts were counted through the trap.

The spring warming of the water in 1948 followed a similar pattern to the temperature rise in 1950 (compare Fig. 7B and 18). A similar pattern for the 1948 smolt run would suggest a total production of about 600 smolts. Within the seasonal and temperature characteristics already described, increases in water height, that is freshets, have a most important effect on the intensity of

FIGURE 8. Pollett smolt counting weir after peak of a heavy spate (about 3000 cfs) in 1948. **A**—The weir extends downstream for 350 feet across 120 feet of stream width, starting at the large tree on the right; the tops of the 12-foot poles of the A-frames look like a farmer's fence against the right bank of the river. Notice saw-logs and other heavy debris piled against the fence up to the cat-walk which was 8 feet above the river bottom. **B**—Gap from which heavily ballasted and cabled trap box (8 feet wide × 10 feet long × 6 feet high) was carried away by flood.

daily smolt runs. It might be suspected that the freshets which resulted in malfunction of the trap in 1948 also brought down large numbers of smolts. However, the temperature picture for 1948 shows that the water was not really warm enough for a major smolt movement until after the last freshet. Moreover, later experience has shown that only after a spring with continuous warm, low water, is a single freshet coming at the peak of the period for smolt descent (May 20 to May 31 for the Pollett) likely to bring down as much as even half of the total annual run. Hence there would seem to be little justification for estimating the total 1948 production as more than about 1000 smolts.

Summary of Production from the Five Plantings

The ages of smolts descending through the counting weir were studied by examining scales from approximately 10% of the fish handled each year. Each annual smolt run, except the first, was found to include a small proportion of 3-year-olds. This never exceeded 10% for plantings in the main river, or 20% for plantings in the brooks. These values are not high enough to warrant any enlargement of the estimates for total production beyond the values given above for production of 2-year smolts, since the methods used for deriving corrected estimates of smolt runs do not warrant setting total production more accurately than to the nearest 1000 smolts. Production from the various plantings is summarized in Table IV.

Table IV. Smolt production from hatchery-reared Atlantic salmon underyearlings planted in a 10-mile stretch of the main Pollett River (approx. 435,000 sq yd) and associated tributaries (approx. 30,000 sq yd). Lengths are to the tip of the tail, in centimetres; M = mean; s = standard deviation of values from the mean. No protection from mergansers and kingfishers was given.

Year Place	1942 River	1943 River	1944 Tribs.	1945 River	1946 Tribs.
Underyearlings planted					
Number	16,300	16,432	16,500	249,000	48,000
Length M and s	no data	3.3	4.2	3.7±0.4	3.6±0.5
Yearling parr in main river					
Estimated number	very few	very few	very few	12,000	200
Rate per 100 sq yd	...	...	...	2.8	under 0.1
2-Year-old smolts					
Estimated number	2,000	1,000	1,000	5,000	1,000
Length M and s	19.2±1.8	17.4±1.8	16.6±1.4	16.4±0.9	15.3±1.3
2-Year-old parr in main river					
Estimated number	very few	very few	very few	300	very few
Rate per 100 sq yd	...	...	...	under 0.1	...
3-Year-old smolts					
Estimated number	100	100	200	200	300
Length M and s	19.0±1.0	18.0±1.6	17.1±1.5	18.0±1.6	19.0±2.7
Total smolts					
Estimated number	2,000	1,000	1,000	5,000	1,000
Survival rate	12%	6%	6%	2%	4%
No. per 100 sq yd	0.5	0.2	3.3	1.1	3.3

For the main river exclusive of tributaries, the estimate of average production was obtained by combining the results from the first, second and fourth plantings. The mean and its standard error are 2800±1200 smolts per planting. Hence the average production from any similar series of plantings would probably be about 3000 smolts per year and would be unlikely to exceed 5000.

For the tributaries only, the average production of the third and fifth plantings was 1000 smolts. The data do not warrant use of any fiducial limits.

For the main river the heaviest planting, judging by its relatively low survival rate, involved an excessive number of underyearlings. It assured that plenty of fish were planted to permit production of the maximum number of smolts which the main stream could be expected to produce. The two sparse plantings in the main river show the maximum survival rates (6% to 12%) which can, in general, be expected if fish are not planted in excess. The two quantities, maximum numbers of smolts and best survival rate from underyearlings to smolts, can be combined to calculate the number of fish which should be planted to get maximum production without undue waste of hatchery stock. Basing calculations on the observed data it would be necessary to plant from 40,000 to 80,000 underyearlings in the main river in order to obtain the maximum yield of 5000 smolts (Fig. 9). Similarly 8000 to 16,000 underyearlings would be needed in the tributaries to get a maximum contribution of another 1000 smolts. Note that these would be maximum, not average, yields.

Averaging and rounding off the extreme values for underyearlings, it would appear that a planting of 70,000 underyearlings, placed in both main stream and

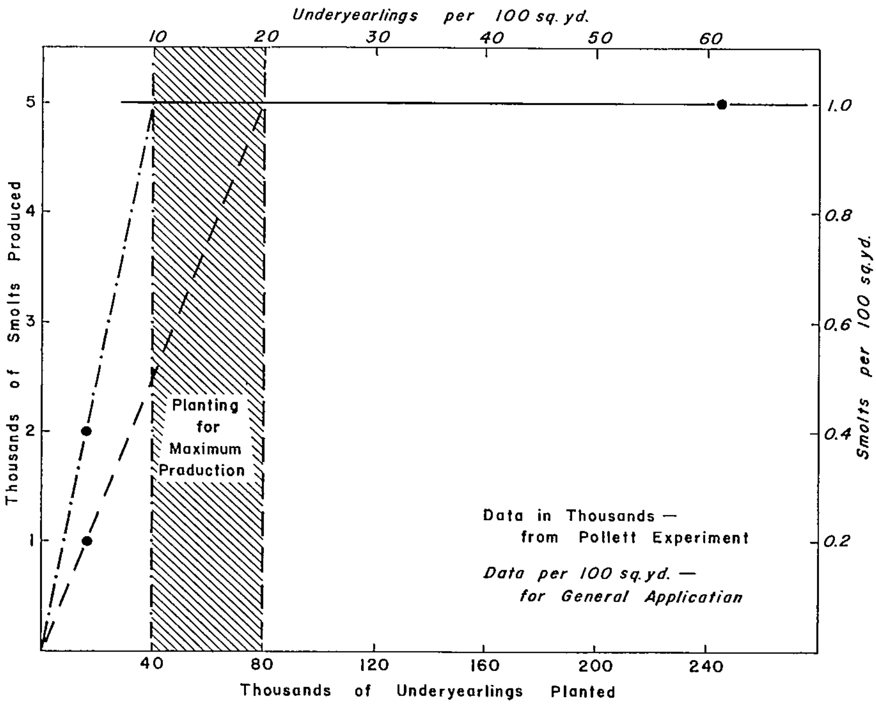

FIGURE 9. Diagrammatic representation, based on observed data, of the best numbers of salmon underyearlings to plant in the Pollett for maximum production of smolts with no other management procedure. *Solid line*—maximum production, from heavy planting; *broken line*—lowest observed survival rate from light planting; *broken line with dots*—highest observed survival rate from light planting; *grey band*—approximate number of salmon underyearlings (about $3\frac{1}{2}$ cm long in late August) to plant for maximum production of smolts.

tributaries, should give, in most years, the maximum production of 6000 smolts from this part of the Pollett system; or 60,000 fish planted in the main river only should give up to 5000 smolts. Since the tributaries are small trout brooks, and are also difficult to reach for planting, this latter choice could well be preferred from the point of view of practical fish culture. (Indices for the rate of planting and smolt production for the main river are approximately 14 underyearlings and 1 smolt per 100 sq yd of stream.)

A Possible Limiting Factor

Small-scale experiments (Elson, MS, 1941) showed that under favourable conditions 80% to 90% of parr in their pre-smolt winter could survive to become smolts in the following spring. On this basis it was anticipated that the Pollett, with an estimated capacity for 16,000 parr (see page 7), might yield up to 15,000 smolts if sufficient underyearlings were supplied. But even the very heavy fourth planting did not yield nearly this many smolts.

One factor which could have depressed smolt yields was the activity of fish-eating birds. White (1939) showed that mergansers (*Merganser americanus*) and kingfishers (*Megaceryle alcyon*) were important predators on young salmon. He also demonstrated that reduction of these birds over only the final year of a 3-year smolt stage was accompanied by a better than twofold increase in the output of smolts. This was in a stream where salmon and trout (*Salvelinus fontinalis*) were the dominant fish.

Two flocks of mergansers, each including about a dozen immature birds, and a number of kingfishers were observed during the first planting operation in 1942. Similar numbers of birds were encountered in subsequent years. Flocks of flying mergansers were reported to visit the stream at irregular intervals throughout the open-water period (March to December) each year. These mergansers were not disturbed by the local residents. Broods observed in late summer contained nearly full complements of young; hence Pollett mergansers could not, as a rule, have been unduly harried by wild predators. An exception to this was in 1946 when a brood of very young mergansers using the lower part of the experimental area was observed to decrease in numbers from 8 or 10 birds down to 2 and finally none by mid-July. During the same time a pair of bald eagles (*Haliaetus leucocephalus*) were, on several occasions, observed coursing the river in the vicinity occupied by this brood. No other ducks were seen on the river until late in September when, on several occasions, flocks of flying mergansers were seen feeding. Mr H. C. White, who made these observations, was convinced that the eagles had either eaten or frightened away the season's crop of young mergansers. Munro and Clemens (1937) imply that the bald eagle is the chief enemy of young mergansers, and a bad one. In his study of eagles in New Brunswick, Wright (1953) found that they are casual predators on ducks, while 90% of their food is fish. But the experimental area of the Pollett supports few fish large enough for use by eagles or available to them. It will be recalled that 1946 was the year when yearling parr from the heavy fourth planting were present; also that parr were relatively abundant during the summer but became noticeably scarcer in the autumn. This order of events lent additional strength to the suspicion that predation by fish-eating birds might be the important factor limiting smolt production.

Throughout the above studies no methodical record of fish-eating birds occurring on the experimental area had been kept. However, casual notes of occurrence were made from the beginning of the experiments. These are summarized in Table V.

TABLE V. Summary of pre-control merganser and kingfisher records from the 10-mile stretch of the Pollett River.

MERGANSERS

1942 Two broods totalling about 20 birds seen during planting operations in late August.

1943 No information.

1944 Three or four broods totalling 30 to 40 birds. Reported locally that flocks of mergansers are seen on open-water stretches during winter.

1945 Several broods totalling 30 or more birds reared on experimental area.

1946 May 28—6 adult females seen.

June—several broods living on experimental area until mid July when all disappeared following appearance of two bald eagles.

September–October—several flocks observed flying and feeding along river.

KINGFISHERS

Common; 3 to 6 broods, representing 20 to 40 birds, living on river each year.

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Part II. Production with Mergansers and Kingfishers Controlled

It was suspected early in the series of five experiments reported in Part I that the presence of mergansers and kingfishers might constitute something of a threat to the young salmon. But it was also decided that for the initial experiments, production should be studied under natural conditions, with no management procedure to be attempted other than the variations in planting of hatchery stock. By 1947 it had become increasingly apparent that the level of smolt production was very low and that predation by mergansers and kingfishers might be the limiting factor.

It was therefore decided to set up, on the Pollett, a study resembling White's (1939) experiment on Forest Glen Brook of the Margaree River. The new study would, however, differ in several important aspects. It would control the birds over the entire pre-smolt stage of the salmon. The salmon would be derived from planting known numbers of hatchery underyearlings. Control of the predators would be continued until at least three protected year-classes of young salmon had migrated to sea as smolts. In the Pollett River, in contrast to Forest Glen Brook, there were several species of coarse fish in the main body of water, but few trout. By studying any changes in relative abundance of these species and salmon there would be opportunity to learn whether control of the predators would allow these other species to increase to the final detriment of salmon production.

The information obtained from the first five planting experiments would serve as a background for judging possible effects of bird control. Throughout the test one standard procedure would be used for planting the new crops of salmon.

METHODS

Control of mergansers and kingfishers was obtained by systematic shooting and trapping of the birds. Four annual plantings of salmon were made, each similar to the heaviest planting of about 250,000 underyearlings made before control was started. Resulting changes in populations of fish were studied through systematic seining, each summer, of fish in the experimental area. Resulting production of smolts was measured by trapping the seaward migrants each spring.

Controlling the Birds

Mergansers. Merganser control operations were based on a knowledge of the behaviour of the birds which has been described by White (1936). At the beginning of the bird control experiment mergansers were removed from the entire Pollett River by shooting all those found. Hunters were armed with 20-gauge repeating shot guns and used long range loads of 1 ounce of No. 7½ shot; experience later showed 12-gauge to be a more practical choice. The hunt was organized so that two hunters walked downstream 3 or 4 miles to intercept another party of two hunters. The second pair of hunters lay in ambush at some pre-determined place. The task of the upstream party was to press any broods of young mergansers downstream as far as possible without alarming the birds. As the two parties converged the ducks were shot. Any survivors breaking back upstream were intercepted by the drivers, those going downstream, by the party in ambush. If the ducks were alarmed before reaching the downstream party, the two drivers proceeded to remove them as best they could. But frightened young mergansers often hide and are then difficult to hunt out. Such occurrences resulted in considerable delay and sometimes the necessity of repeating patrols later. When the patrol was completed on one section, the next 3 or 4 miles below were covered in a similar manner, the ambushing party being first allowed time to reach their new destination. Hunting was done by the same men year after year. With experience, these hunters became more proficient in removing mergansers, which are wary and active birds. The netting technique described by White (1939) was also used to advantage during the first year.

After the first year, broods were not allowed to hatch on the 10-mile experimental section. Each year at the end of June the river was patrolled from headwaters to mouth and any broods above and below the experimental area removed. This was done to facilitate protection on the experimental area since it was easier to remove flightless birds than to have to remove the same birds later in the season when they were able to fly.

Other than females with their broods, very few mergansers were encountered during the summer months. Almost every day throughout this period there was a crew of men on the river making fish censuses or tending to other duties in connection with the experiments. Alertness for mergansers was maintained and those seen were shot immediately or hunted out the next day. Local inhabitants assisted by reporting any mergansers they saw. By mid-September the young reared on other streams began to appear on the Pollett. Throughout the autumn and in the early winter southward-bound migrants appeared at frequent intervals. Sometimes these would be lone birds, sometimes they were in groups of 2 to 30. Even in the coldest months when most of the river was ice-bound there were frequent visitors to any open-water areas (Fig. 10). Commencing about the end of March northward-bound migrants and breeding birds appeared in numbers comparable to those seen in the autumn. This movement was usually over by June.

From autumn through spring, control was maintained by making patrols of the experimental area on a semi-weekly schedule—more frequently if the presence of birds indicated this to be desirable. These patrols were made by a 2-man team carrying shotguns and using long-range loads in shot sizes 4 to 6—the largest size for birds in heavy winter plumage. One hunter walked downriver 2 or 3 miles. There he met a second hunter who was in ambush. Then the second hunter

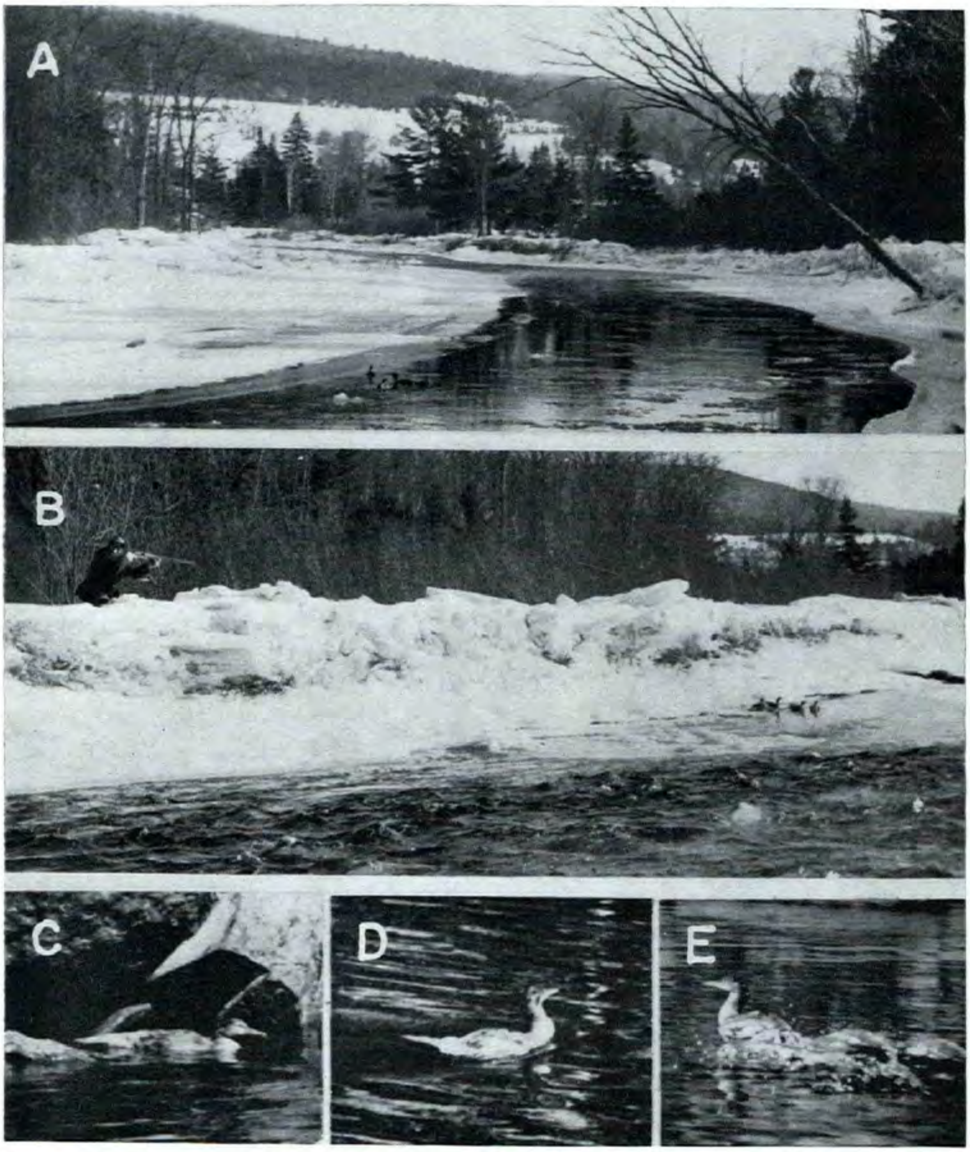

FIGURE 10. American mergansers (*Mergus merganser americanus*) on open reaches of the Pollett River. **A**—In early February; mergansers commonly rest at river bends which command a long approach from both up and down stream and provide open beaches in summer or expanse of shore ice in winter, making it easier for the birds to sense approaching danger. When alerted they take to the water preparatory to swimming or flying away or diving to escape threatening danger. **B**—Four mergansers successfully stalked. **C**, **D** and **E**—in August; an immature merganser in 3 characteristic poses, resting, alert, and fleeing.

would take his turn walking while the first drove to the next lower ambush by car. In this way the entire 10 miles could be covered in a few hours. Birds encountered tended to fly either up- or downstream, usually presenting a shot to one or other of the hunters. As the men gained proficiency in stalking the birds, more were shot. Birds not killed sometimes pitched 1 or 2 miles upstream on water already patrolled; or they would apparently return to the area within a day or so. Thus mere frightening did not give as effective protection to the young salmon as actual removal of the birds.

At certain seasons, particularly in late winter and early spring, decoys were frequently put out by the man in ambush. These were a material help in bringing high-flying birds within shotgun range, providing the birds had not been flushed closer than 1 or 2 miles from the decoys.

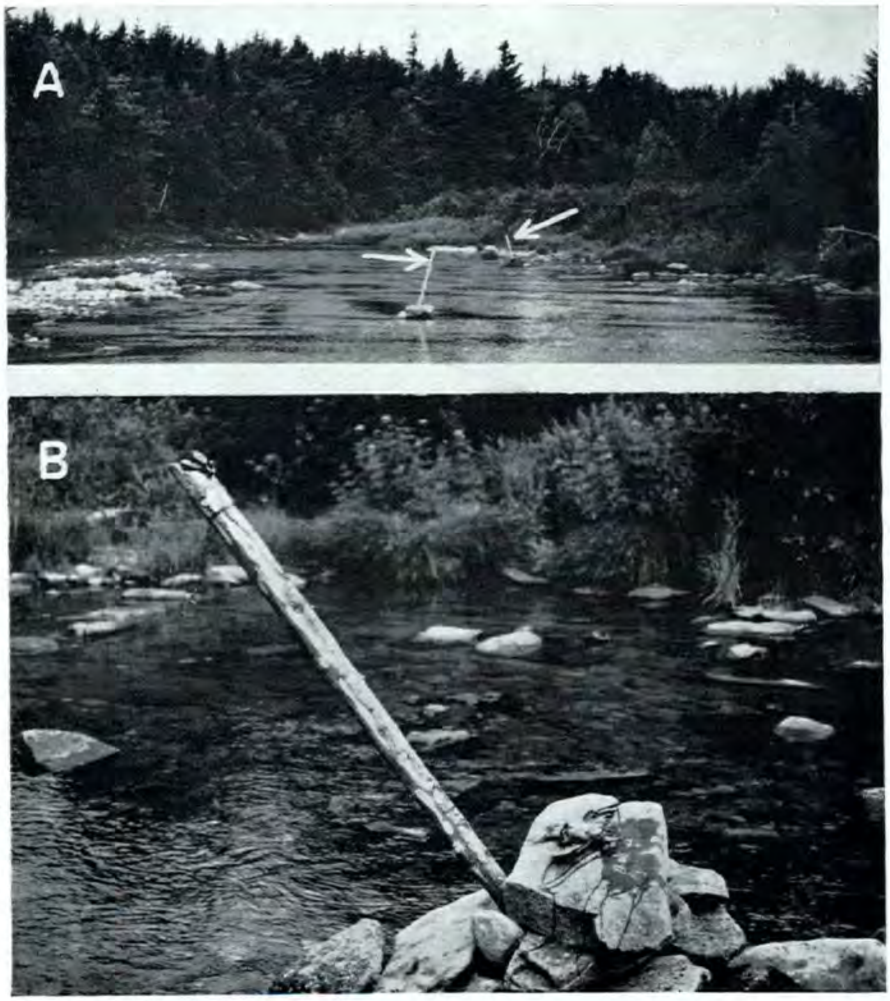

FIGURE 11. Kingfisher (*Megaceryle alcyon*) traps. **A**—Looking down-stream at two traps (white arrows) near the Salmon Hole seining area, one in mid stream to avoid taking small perching birds, the other near an open bank in an eddy where minnows congregated. **B**—Close-up of the downstream trap above: a drowned kingfisher just removed from this trap is laid on the rock pile supporting the stake.

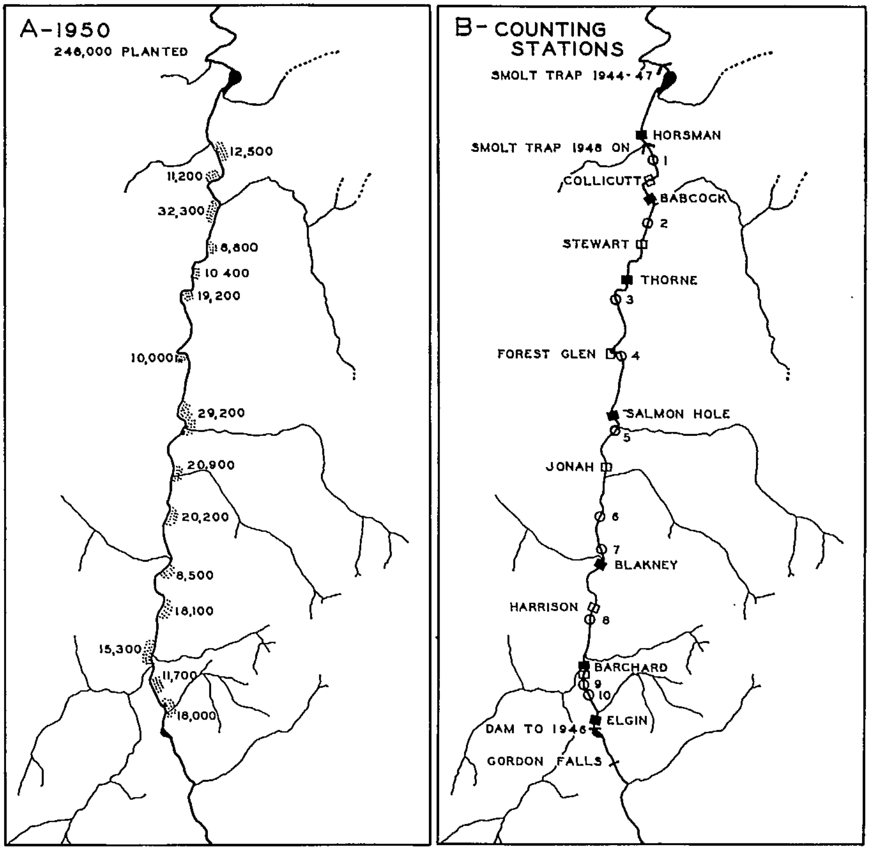

FIGURE 12. A—Heavy planting of salmon underyearlings given wide dispersal. Numbers liberated are shown adjacent to dots indicating areas of liberation. Compare with Figure 5A. B—Stations used for counting fish, including locations of smolt counting weir. Solid squares are seven selected sample series; hollow squares are six selected sample series; circles are 10 sample series selected by lot (see text). See also Figure 3B, C; 11A; 13A, B, C.

Experience showed that patrols afoot were most effective. Trails were cleared through the forest along the banks where necessary. From these the patrolling hunter could inspect the entire stream, frequently while out of sight himself. But in highwater periods, particularly in early spring, walking the river bank was often extremely difficult. Under such circumstances one hunter ran downriver by canoe while the other intercepted him at the usual places. This technique, while giving useful control, tended to result in a smaller proportion of kills than patrols afoot.

Records were kept for each patrol. The hunters listed the number of birds seen, or the times one bird was seen; made an on-the-spot estimate of the number of individuals involved in these sight records; noted the locality where each bird was seen and whether it was killed, wounded or had escaped; recorded whether the patrol was made by canoe or afoot and other pertinent details.

KINGFISHERS. A knowledge of the habits of kingfishers (White, 1953) simplified control procedures for these birds. Three different techniques were employed. Birds seen during the regular semi-weekly patrols were shot. Since most kingfishers were encountered during the summer months when mergansers were scarce, the guns could then be loaded with No. 7½ shot—more effective than larger sizes for such relatively small birds. Chief reliance for removing kingfishers during the periods of greatest abundance (August and September) was placed on the use of pole-traps. These were ordinary steel animal traps of the compact, jump-trap style in No. 0 size. The traps were set on the ends of poles placed nearly upright on the river bottom (Fig. 11). Poles were usually put in mid channel, which minimized the capture of other birds. They were frequently located at small pools where minnows congregated, to increase the attractiveness of the "perch" to kingfishers. Trap chains were attached to a slide-wire so that all trapped birds were immediately carried to the bottom of water deep enough to ensure prompt drowning. Traps were set in groups of two or three, located about a mile apart along the river. They were tended semi-weekly.

During the nesting season any kingfishers burrowing along the experimental area were dug out and eggs or young disposed of. Very few adults survived on the area long enough to complete nesting activities.

Records, similar to those for mergansers, were kept of all kingfishers encountered on the experimental area.

Measuring Smolt Production

Planting young salmon. In 1947, 1948 and 1949 plantings of about 250,000 young salmon were made in late August. Each planting was similar in detail to the heavy fourth planting (Fig. 5A) described in Part I. In 1950 another planting was made using similar numbers, but dispersing the fish more widely (Fig. 12A). It is now known that this difference in dispersal could have had no noticeable effect on final smolt production (Elson, 1957b). Thus the four plantings made from 1947 to 1950 can be considered as similar.

Assessment of fish populations. Each summer from 1948 parr and other fish in the experimental area were assessed by counting those found in the same seven sample areas selected in 1947. A similar technique of "minimum count seining" was employed in each year. In 1948 such assessment was made twice. The first time, it was made without barrier nets at the limits of the sampling areas. This was done so that results comparable to those obtained in 1947, with no bird control, would be obtained. The second time, barrier nets of ½-inch stretched mesh were set across the upper and lower ends of the sample areas and carefully weighted to the bottom with stones and gravel so that no fish could move into or out of the areas (Fig. 13). The results from this second study were compared to those from the first. Barrier nets were used in all subsequent years.

While most of the other species of fish were taken with about the same ease as salmon parr, eels were not thoroughly fished by this technique. Beginning in 1949 a 500-volt D.C. electrofishing apparatus (Smith and Elson, 1950) was frequently available for the population studies. With it a high proportion of eels, as well as other fish, could be removed from an area. In order to maintain continuity with the earlier assessments, the electrofishing gear was not employed on a sample area until after at least two coverages had been made using the earlier "minimum count" seining technique. Thereafter the area was fished over once more, very thoroughly, using the electrical apparatus. From 1952 on, electrofishing was used in all sampling (Fig. 3D).

To circumvent the uncertainty of all parr in a sample area being captured, data were treated to yield estimates of total parr in an area. These estimates in turn were used as a basis for calculating the total parr population in the experimental reach. This permitted evaluation of survival rates between underyearlings planted and parr a year later, and between parr and migrating smolts counted after still another year.

The estimation of total parr in a sample area involved the assumption that catchability remained constant. The results indicated that parr were captured in accord with this assumption. But the capture of other fish, particularly those which tended to move in schools, did not follow the assumption so well. However, field tests indicated that intensive minimum count seining did take about 80% to 90% of the individuals of all species except eels. Comparisons of the relative year-to-year abundance of these other species have been made on the basis of numbers actually caught in the sample areas.

For eels, the numbers taken by intensive electrofishing have been used as a basis for studying relative abundance.

COUNTING THE DESCENDING SMOLTS. The first year-class of smolts which had received protection from birds descended in 1949. By this time five seasons of experience in operating smolt-counting weirs on the Pollett had resulted in modifications and improvements to the apparatus. A new weir (Fig. 14) was set at the same location as in 1948 (Fig. 8), but on a somewhat different plan which allowed taking better advantage of the full width of the stream bed, while at the same time offering a substratum of bed rock and coarse stone. A sill about 8 feet wide and 1 to 1½ feet deep was built of large flat rocks as a foundation for the fence. The screening surface of the fence consisted of ¼-inch diameter upright steel rods with ½-inch spaces between rods. The main arm of the fence was 200 feet long across the 100-foot wide stream bed, so that it angled upstream at

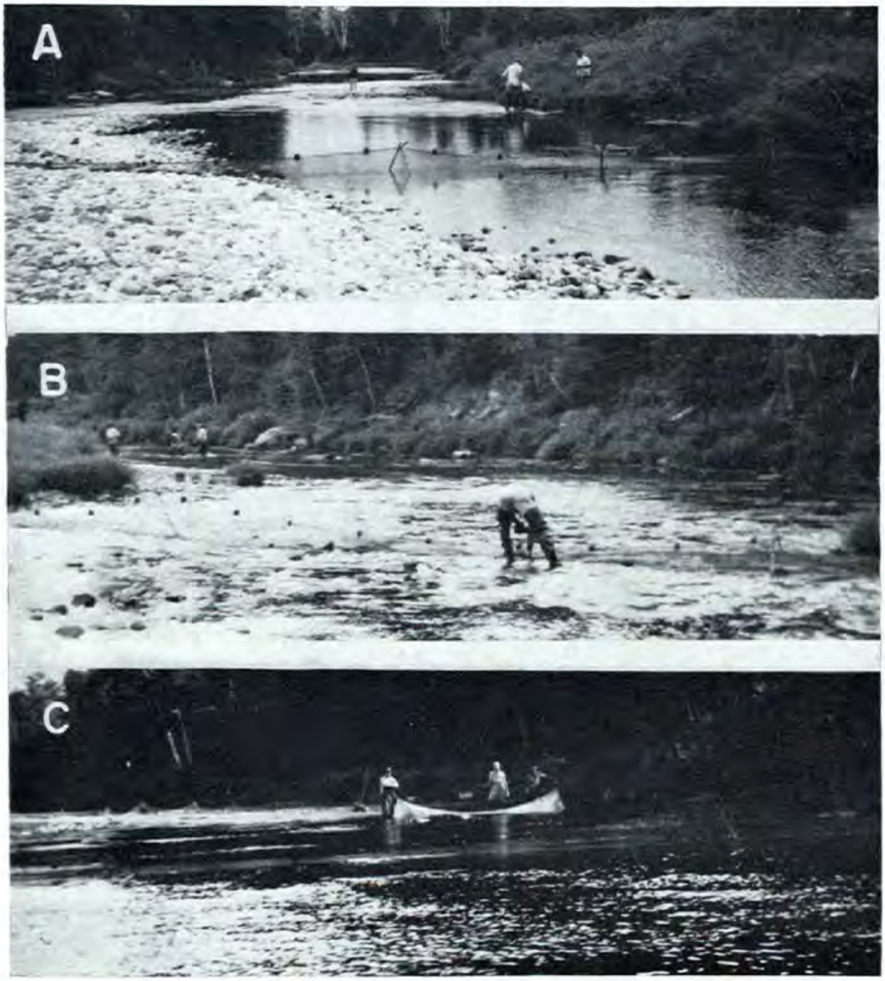

FIGURE 13. Three seining stations of the seven selected sample series, showing three principle types of stream in the experimental area. **A**—Elgin, relatively small, loose gravel with mixed riffle and flat areas. **B**—Blakney, mostly coarse rock with a little gravel and sand, in rapids. **C**—Horsman, mixed gravel and coarse rock with relatively slow-flowing water; the shallow pools are floored with flat bed rock. **A** and **B** looking downstream, **C** upstream. Barrier nets to delimit sample areas during seining can be seen in all three.

about a 30-degree slope to the direction of stream flow. The total open space of the screen thus exceeded the width of the stream channel by more than 30%. The purpose of this excess was partly to allow for friction of the water flowing between the rods, and partly to allow for a certain amount of blockage by flotsam during freshets, without having drastic reduction of the screening surface. The steel rods of the screen were 8 feet long, so that when set in panels placed against the framework based on 15-foot equilateral triangles, they formed a screen with a vertical height of almost 7 feet. At its downstream end this screen led by a funnel into a pound or trap box about 10 feet

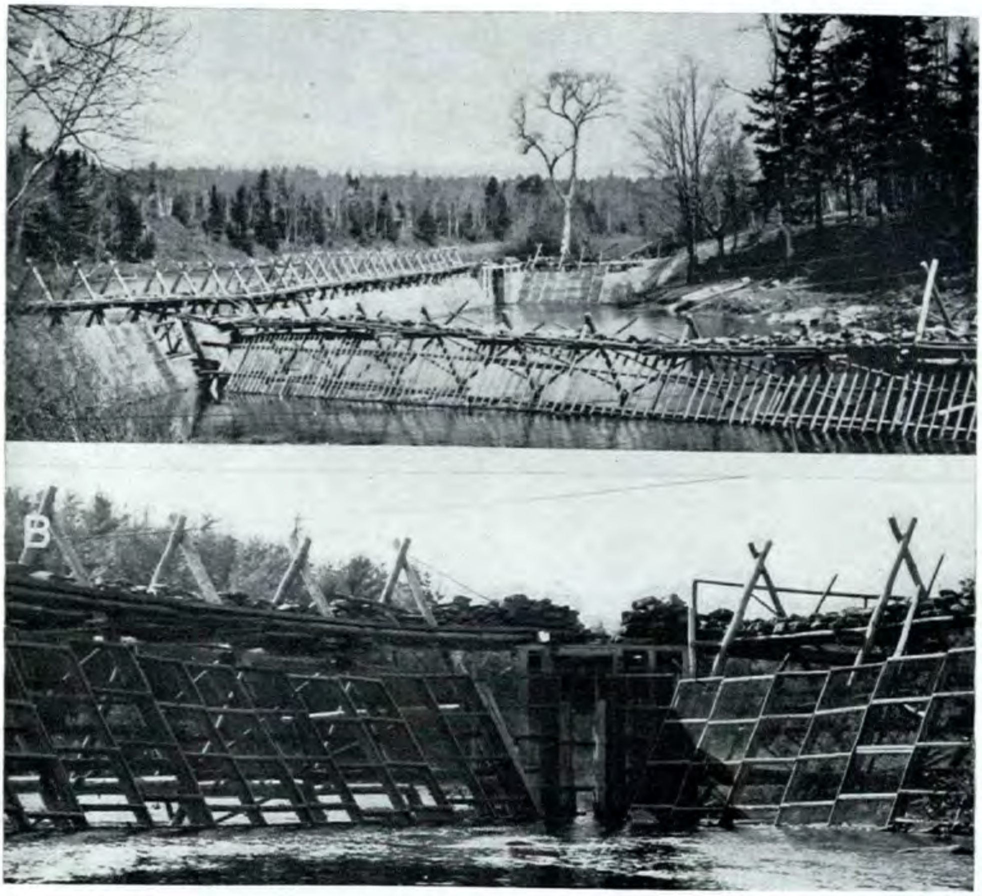

FIGURE 14. **A**—The Pollett smolt counting weir from 1949 on. Same location as in Figure 8, but running upstream from right bank; improved design of screen, which is also protected from heavy drift by trash rack in foreground. **B**—Detail of construction, with weir of $\frac{1}{4}$-inch steel rods set in wooden frames.

wide, 12 feet long and 8 feet high (Fig. 14B). A short stretch of similar screen led from the adjacent bank to the pound. The weir was protected against heavy logs, uprooted trees, etc., by a trash-rack of similar construction, but, using for a screen, spruce poles fastened 1 foot apart and extending downward only to normal spring water level. The trash-rack was also set at an angle of about 30 degrees to the direction of current flow, but in the opposite direction to the fish-counting weir. Its downstream end met the fish screen near the upper end of its long arm, so that heavy trash could be passed down along the trash-rack and through adjustable ports in the fish screen. The weir was designed to handle spring and summer freshets with discharges up to about 3000 cubic feet per second. Under extreme conditions 24-hour maintenance duties have been shared by a regular crew of 4 men, occasionally assisted for a few hours by 1 or 2 extra helpers. This smolt weir functioned without breakage or having the water rise above the screening surface throughout the five seasons of smolt descent from 1949 to 1953.

The weir was installed each year as early as water conditions permitted. It was always in operation before water temperatures reached 7° C (45° F). Each morning all fish trapped in the pound were removed for examination, marking and liberation (Fig. 15A, B). When there were

FIGURE 15. **A**—Smolts were removed from trap box with a hand seine and transferred in buckets to the marking shed. **B**—Shed where smolts were examined and marked, after which they were liberated below the weir via the small chute which discharges a little to the right of the man.

more than 100 or 200 smolts to be handled, they were transferred in pails to a tank located in a small building on the adjacent bank. They could then be handled as time permitted. A continuous flow of water passed through this tank and down a 4-inch wide galvanized steel trough to the river below the counting weir. Before liberation via this sluiceway all smolts were marked by removal of their adipose and right pelvic fins in 1949, adipose only in 1950, 1951 and 1952, and adipose and both pelvics in 1953.

RESULTS

Production of smolts from the four plantings given protection from birds is summarized in Table XIV and XV. The levels of production of the various species of fish living in the stream are compared with published values for other areas on pages 47 to 50. Discussion of the results and their significance for production of salmon in Maritime streams appears in Part III (page 51).

Birds Removed

Bird control operations were started in late June 1947 after the 2-year-old smolts from the heavy fourth planting had left the river. The salmon of the fifth (1946) planting could have received very little active protection from birds because that planting was made in the tributaries. Mergansers were never seen to use these small densely forested streams for feeding, and kingfishers only occasionally. Very few of the fish planted in the tributaries descended into the more open waters of the Pollett River, as shown in the surveys of fish during the summers of 1947 and 1948. Hence, the salmon planted in 1947 and descending in 1949 were the first to receive important benefit from the protective measures.

The active period of stream life of native Petitcodiac young salmon begins in early summer (May or June) when the small fry first make their way up out of the spawning gravels and begin feeding. It ends, usually 2 or more years afterward, in late May when they migrate to sea as smolts.

The activities of fish-eating birds on salmon streams can be divided into seasonal phases. Combined over a year, they add up to the annual pressure which the birds exert on year-classes of young salmon.

Mergansers. For mergansers, the seasonal phases are: the *summer period* of brood rearing during which the young birds are flightless and therefore confined to connected bodies of water; an *autumn period* of dispersal to other water courses beginning when the young can fly well and followed by southward migration; a *winter period* during which individuals and small flocks wintering within range of the area make periodic visits to places where there is open water and available food in otherwise ice-bound streams; a *spring period* of northward migration, breeding and nesting activity.

Occurrence of mergansers on the experimental area of the Pollett and the reduction in occurrence by control operations are indicated in Table VI. In this table the 12-month periods correspond to "years" of active stream life of the young salmon. Only in 1947, the first year of this study, did any broods of young mergansers occur on the area. Thereafter, control during the spring period eliminated potential nesters. Consequently, except for 1947, the records of the summer period are typical of conditions when control is exerted, rather than natural conditions. In Table VI, in the second column from the right, an average value is given for the occurrence of mergansers on the area for each of the four phases within the year, for the 6 consecutive years. Except as noted above for the summer period, these sight records provide an index of the potential activity of mergansers on the area if there had been no control.

Mergansers visited the area at about the same intensity throughout the fall, winter and spring months. During summer, with most birds involved in brood-rearing activities, there was a noticeable reduction of visits to the Pollett. Had there been no control, this summer reduction of activity would have been more than compensated for by the activities of locally-reared broods.

The control operations resulted in removal (killed and wounded) of about 50 birds a year. This effectiveness, measured against sight records of birds, was about 25%, which is reasonably effective hunting. However, the sight records sometimes involved one bird being seen two or more

TABLE VI. American mergansers sighted and removed from a 10-mile stretch of the Pollett River, N.B. Records are based on regular patrols of the area made on a twice-weekly basis throughout the year. (Years run from June to May.)

	1947–48	1948–49	1949–50	1950–51	1951–52	1952–53	Average	
							Season	Month
June to August (brood rearing season)								
Sighted	6[a]	2	20	13	40	8	15	5
Removed	6[a]	0	6	7	3	4	4	...
September to December (dispersal and southward migration)								
Sighted	15	19	164	59	178	74	85	21
Removed	3	7	54	11	41	21	23	...
January to March (winter visitors)								
Sighted	27	41	28	173	154	24	75	25
Removed	8	12	11	28	41	13	19	...
April and May (northward migration and nesting)								
Sighted	29	49	59	23	56	6	37	19
Removed	3	9	11	6	14	2	8	...
Total[b]								
Sighted (S)	77	111	271	268	428	112	212	...
Removed (R)	20	28	82	52	99	40	54	...
R/S, as percentage	26	25	30	19	23	36	25	...

[a] Adult females only; 36 young are not included, in order to keep data comparable to later years when no broods were allowed to hatch.
[b] Total represents annual pressure on year-classes of salmon.

times, perhaps on different days. Hence, the actual removal was somewhat greater than the percentage given indicates. It is believed that between 100 and 200 mergansers visited the experimental section of the Pollett each year. About half of these were removed. Since birds not killed were frightened off, at least for a time, the actual reduction in predation by visiting birds was much greater than one-half. Predation by broods was eliminated.

KINGFISHERS. The seasonal phases for kingfishers, in their relation to young salmon, resemble those for mergansers. There is a northern migration in late April and May, followed by the nesting period in June when only breeding adults are about; a rearing period in late June and July when locally-reared birds constitute the kingfisher population; a period of dispersal in late July and August when birds reared on other streams move into new areas (White, 1953); and one of southward migration in September and October. The record of kingfisher occurrence and removal during the 5 years of the bird control experiment is given in Table VII.

The flight of kingfishers is frequently so erratic as to make them a difficult target for the gunner. During patrols birds which were alarmed frequently flew into the woods and circled back to the river either upstream or downstream out of sight of the hunter. For this reason it is also difficult to interpret the meaning of sight records of these birds. On the other hand, they appeared to be very susceptible to capture in properly set pole-traps. This was shown by the fact that while many were taken in traps, very few live birds were seen on the area. When one was seen near a trap, the next patrol usually found a drowned bird in that trap, but saw no live birds. Apparently nearly all kingfishers visiting the area were either trapped or shot within a few days so the best available clue to kingfisher activity is the number removed from the area. The average annual removal over 6 years of fairly constant effort was 164 kingfishers.

TABLE VII. Kingfishers removed from a 10-mile stretch of the Pollett River, N.B. (About 15% of removal was by shooting, the balance by trapping; traps were usually set in July before the year's young appeared. About a dozen birds were seen in April of most years, when the principal effort of the field crew was construction of the smolt-counting weir.)

	1947–48	1948–49	1949–50	1950–51	1951–52	1952–53	Average[a]
June	19	19	6	1	17	6	10
July	...	13	39	1	24	30	21
August	...	114	101	42	60	33	70
September	136[b]	83	67	37	33	66	57
October	...	9	1	5	0	1	3
April	0	0	0	0	0	0	0
May	12	7	1	3	0	2	3
Total[c]	167	245	215	89	134	138	164

[a]June, 1948 to May, 1953.
[b]July through October.
[c]Represents the annual pressure on year-classes of salmon.

PRODUCTION OF YOUNG SALMON

PLANTINGS. Details of the four plantings are given in Table VIII. The figures for numbers planted were arrived at by making sample counts of about one-fifth of the weighed lots of fish brought in each truck load. The density of fingerlings planted, both in relation to ground over which they were spread at liberation, and also in relation to the total area to be populated is given in terms of fish per 100 square yards. The average density for the total area was 57 fingerlings. This is for convenient comparison with population measurements at other times. The mean length of the planted fish, taken from a sample of several hundred each year, was 1.42 ±0.20 inches (3.6 ±0.5 cm). Size at planting was fairly uniform from year to year (Table VIII).

TABLE VIII. Plantings of Atlantic salmon underyearlings made in a 10-mile stretch of the Pollett River, N.B., and afforded protection from mergansers and kingfishers. The standard error (SE) for numbers planted was calculated, as a percentage, for the mean numbers counted per shipping unit. Length (snout to tip of tail) of planted fish: M = mean length; s = standard deviation of values from the mean.

	Year	Dates	Number planted		Density		Length	
			Total	SE	Where planted	In total area	M	s
			no.	%	*no. per 100 sq. yd.*	*no. per 100 sq. yd.*	*cm*	*cm*
1	1947	21–27. viii	273,000	±3	975.0	62.5	3.4	0.4
2	1948	23–30. viii	235,000	±3	813.9	54.0	3.3	0.5
3	1949	27. viii–8. ix	243,000	±6	704.4	55.9	4.2	1.0
4	1950	28. viii–12. ix	246,000	±6	143.9	56.6	3.4	0.3
Average values			249,000	±4		57.3	3.6	0.5

PARR PRODUCED WITH BIRD CONTROL. In 1948 a comparison was made of the numbers of fish found in sample areas, first when no barrier nets were used, and later when barrier nets were employed to bound the areas during seining operations. Totalled results for the 7 areas are given in Table IX. There was no important difference between the results obtained by the two methods at any station.

TABLE IX. Comparison of total numbers of fish removed from the same 7 sample areas of the Pollett River, without barrier nets at limits of areas, and one week later with barrier nets (1948 data).

Species	Without nets	With nets
Salmo (Salmon)	396	389
Catostomus (Sucker)	568	635
Couesius (Chub)	2639	2802
Rhinichthys (Dace)	486	621
Anguilla (Eel)	22	16
Fundulus (Top minnow)	11	8
Salvelinus (Brook Trout)	4	0
Total fish	4126	4471

These results give confidence that valid comparisons can be made between the fish populations found in 1947, without barrier nets, before bird control had much chance to affect populations, and in subsequent years, with barrier nets, when control had had a chance to affect populations.

The numbers of parr and other fish found in the sampling areas in each year, using the method of "minimum count" seining, are given in Table X. To simplify comparisons these results have also been converted to a "population index" equal to the rate of occurrence, or density per 100 square yards.

TABLE X. Strength of fish populations in the summers of 1948 to 1952, in a 10-mile experimental stretch (approximately 435,000 sq yd) of the Pollett River, N.B., as found by "minimum count" seining in 7 selected sample areas. Populations increased following establishment of merganser and kingfisher control in 1947—compare with pre-control data in Table III. For data on eels see Table XVII. Index=average number per 100 sq yd. See Table III for names of Stations.

	Length × width	Area	Salmon	Sucker	Chub	Dace	Other	Total	Total
	yd	*sq yd*	*no.*	*no.*	*no.*	*no.*	*no.*	*no.*	*index*
1948									
El	60×25	1,500	59	23	224	205	0	511	34.1
Bar	60×12	720	94	33	170	173	0	470	65.3
Bla	50×23	1,150	51	6	39	24	0	120	10.4
Sal	50×23	1,150	92	9	59	44	0	204	17.7
Tho	60×18	1,080	45	104	811	119	0	1,079	99.9
Bab	50×20	1,000	45	86	553	47	0	731	73.3
Ho	50×25	1,250	1	374	946	9	8	1,338	107.0
No.	380 long	7,850	389	635	2,802	621	8	4,455	
Index			5.0	8.1	35.7	7.9	0.1	56.8	

TABLE X—*Concluded*

	Length × width	Area	Salmo	Sucker	Chubs	Dace	Other	Total	Total
	yd	*sq yd*	*no.*	*no.*	*no.*	*no.*	*no.*	*no.*	*index*
1949									
El	76×11	836	181	21	369	589	3	1,163	139.1
Bar	90×10	900	199	64	210	408	0	881	97.9
Bla	90×23	2,070	23	5	117	75	0	220	10.6
Sal	53×12	636	136	2	29	80	0	247	38.8
Tho	70×15	1,050	77	66	650	86	0	879	83.7
Bab	56×18	1,008	89	132	795	76	1	1,093	108.4
Ho	51×25	1,275	0	211	1,221	118	0	1,550	121.6
No.	486 long	7,775	705	501	3,391	1,432	4	6,033	
Index			9.1	6.4	43.6	18.4	0.1	77.6	
1950									
El	60×25	1,500	149	65	176	293	22	705	47.0
Bar	60×12	720	69	46	74	137	0	326	45.3
Bla	50×23	1,150	27	11	57	26	0	121	10.5
Sal	50×23	1,150	174	72	84	141	8	479	41.7
Tho	60×18	1,080	76	40	179	149	0	444	41.1
Bab	52×20	1,040	122	95	242	38	0	497	47.8
Ho	60×25	1,500	16	281	768	89	2	1,156	77.1
No.	392 long	8,140	633	610	1,580	873	32	3,728	
Index			7.8	7.5	19.4	10.7	0.4	45.8	
1951									
El	60×23	1,380	237	30	228	779	28	1,302	94.3
Bar	60×12	720	186	0	32	187	0	405	56.3
Bla	50×23	1,150	29	11	18	4	0	62	5.4
Sal	50×23	1,150	107	11	24	120	0	262	22.8
Tho	60×18	1,080	134	115	244	137	1	631	58.4
Bab	52×20	1,040	166	68	250	66	1	551	53.0
Ho	60×25	1,500	52	89	481	45	0	667	44.5
No.	392 long	8,020	911	324	1,277	1,338	30	3,880	
Index			11.4	4.0	15.9	16.7	0.4	48.4	
1952									
El	60×21	1,260	37	57	160	409	0	663	52.6
Bar	60×13	780	17	27	63	160	0	267	34.2
Bla	52×23	1,196	0	29	49	40	0	118	9.9
Sal	50×27	1,350	4	48	12	63	0	127	9.4
Tho	60×16	960	22	129	254	60	0	465	48.4
Bab	52×22	1,144	23	56	46	22	0	147	12.9
Ho	60×26	1,560	2	258	1,300	29	0	1,589	101.9
No.	394 long	8,250	105	604	1,884	783	0	3,376	
Index			1.3	7.3	22.8	9.5	0	40.9	

One objective of the seining studies was to permit comparison between the numbers of fingerlings planted and the resulting yearling parr; also between these parr and the resulting 2-year-old smolts. While this might be done by deriving similar population indices for the various stages, there is some value in attempting to express the results in terms of total fish planted, total parr in the river and total smolts migrating from the river. Direct estimates of fry and counts of smolts were made, so the problem for completing the chain of information is to estimate the total parr for the intermediate year. If the accuracy of the results from seining is satisfactory, then the total number of parr could be calculated quite simply. Multiplying the population index by the total

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area of the experimental stream measured in units similar to those used for the population index would give the required result. There are, however, two questions which must be answered before such procedure is accepted.

First, how good is the measurement of population strength obtained from the "minimum count" seining data? In Table XI, the numbers of parr removed from sample areas by "minimum count" seining can be compared with two independent estimates of total parr in the areas. Two evaluations are possible. For the first one, the total parr were assumed to be all those taken in the seining plus any additional parr taken by intensive electrofishing immediately after the "minimum count" seining was completed.

TABLE XI. Numbers of salmon parr in sample areas of the Pollett River as shown by capture with "minimum count" seining without electrofishing (columns 2–5), by total capture when intensive electrofishing is added after seining (column 7). Column 9 is the DeLury or Catch/Effort estimate obtained from the seine hauls (see text). For names of seining stations, see Table III.

Area	Seine				Electric	Total	Seine as % of total	C/E est.	Seine as % of C/E est.
	1	2	3	All					
	no.	*no.*	*no.*	*no.*	*no.*	*no.*	%	*no.*	%
1949									
El	141	40	...	181	31	212	85	197	92
Bar	184	15	...	199	4	203	98	200	100
Bla	16	7	...	23	14	37	62	28	82
Sal	66	70	...	136	...	...	...	...	...
Tho	66	11	...	77	30	107	72	79	98
Bab	76	13	...	89	11	100	89	92	97
Ho	0	0	...	0	0	0	...	...	...
Total[a]	483	86	...	569	90	659	86	596	95
1950									
El	90	41	18	149	17	166	90	185	81
Bar	41	22	6	69	4	73	95	77	90
Bla	16	11	...	27	5	32	84	53	51
Sal	50	56	68	174	15	189	92	...	...
Tho	40	20	16	76	23	99	77	95	80
Bab	82	20	20	122	6	128	95	124	98
Ho	8	7	1	16	1	17	94	19	84
Total	327	177	129	633	71	704	90	553	83
1951									
El	144	63	30	237	14	251	94	261	91

[a]Sal omitted.

For the second comparison, the figure for total parr was derived by adapting DeLury's (1947) catch/effort principle to the seining data. The essence of DeLury's method is that as fish are removed from a closed population by successive units of fishing effort, the catch per unit effort decreases in proportion to the population remaining at the time each effort is applied. The several sweeps of the "minimum count" seining operations each represented nearly uniform efforts to catch fish. Hence the capture figures for each sweep can be treated as catches per unit of fishing effort. To calculate total populations, values were established such that:

x = number of fish previously removed from population;

y = number of fish captured during each sweep or effort;

N = total number of sweeps employed, i.e., number of observed points used for locating the catch/effort line.

A straight line fitted to these points should intercept the x-axis at the point where x = entire population of fish at the beginning of the operation. This point of intercept can be found from the data by reducing the type algebraic formula for a sloping straight line ($y = mx + b$) to the solution for point of intercept of this line on the x-axis. The solution, using the symbols above, is:

$$\text{Estimate of population} = \frac{\Sigma x \; \Sigma xy - \Sigma x^2 \; \Sigma y}{N \Sigma xy - \Sigma x \; \Sigma y}$$

Data from seining at several stations (Tables XI and XII) have been arranged in Fig. 16 to illustrate graphically the calculation of populations by this method.

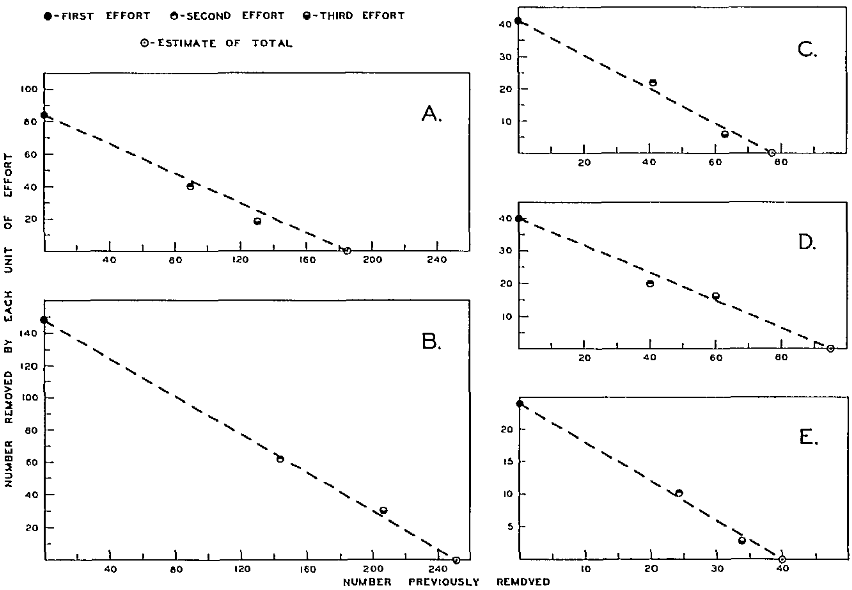

FIGURE 16. Catch/effort estimates of parr population using data from "minimum count" seining. A—Elgin, 1950. B—Elgin, 1951. C—Barchard, 1950. D—Thorne, 1950. E—Elgin, 1952. A to D without electrofishing; E with addition of electrofishing.

"Minimum count" seining when evaluated against seining plus subsequent thorough electrofishing took an arithmetic mean of 87% (standard error ±3) of total captures; when evaluated against catch/effort estimates it took 87% (±4) of the estimate of parr present (from Table XI). In 1952 the original "minimum count" seining system was discarded altogether. Repeated coverages of sample areas were made on the same general plan as before but electrofishing aid was employed throughout. For this seining, too, estimates calculated from catch/effort data (Table XII) indicate that capture was seldom complete, the mean rate of capture being 91% (±4). *Hence the DeLury estimates of total population must give closer approximations to actual population values than do assumptions of total catching by seining and/or electrofishing.* The estimates have the additional merit of permitting evaluation of their inherent accuracy.

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TABLE XII. Numbers of salmon parr in sample areas of the Pollett River as shown by total capture with "minimum count" seining with electrofishing aid throughout (columns 2–5). Column 6 is the DeLury or Catch/Effort estimate obtained from this seining (see text). Data collected in 1952. For names of seining stations, see Table III.

Area	Seine (+ electrofishing)				C/E est.	Seine as % of C/E est.
	1	2	3	All		
	no.	*no.*	*no.*	*no.*	*no.*	%
El....................	24	10	3	37	40	93
Bar....................	11	3	3	17	18	94
Bla....................	0	0	0	0	...	...
Sal....................	4	0	0	4	(4)	(100)
Tho....................	15	5	2	22	23	96
Bab....................	11	10	2	23	29	79
Ho....................	0	2	0	2	(2)	(100)
Total	65	30	10	105	116	91

Two aspects must be considered in evaluating these seining results. The first involves the efficiency of capture at individual stations. The second involves the validity of combining data from a group of stations to obtain an overall estimate of populations.

First, consider the efficiency of capture at individual stations. If this efficiency were normally distributed it could be described by the mean value and the standard deviation from it, 87 ± 13% (from Table XI). From this, the lower 95% confidence limit would be 61 % captured, which appears to fit the data reasonably well. The corresponding upper limit of 113% is obviously not applicable. Any general statement about efficiency at individual stations must be made with caution. Such efficiency is variable from place to place and time to time. It is therefore best judged by comparing total capture to estimated total population in a sampling station, as observed. This emphasizes the desirability of deriving standard types of estimates based on catch/effort or mark-and-recapture techniques rather than attempting simple modifications of capture figures by some general index of efficiency.

As to the second issue, however, when data from a group of stations are combined to give an overall sample, confidence limits appear to be applicable. For the combined data of the "minimum count" seining series given in Table XI, confidence limits have been estimated for the 7-sample "minimum count" seining series by using the calculated mean percentage capture and its standard error. Argument might be advanced for computing the average efficiency on a logarithmic basis (mean efficiency = 92%, upper and lower 95%, confidence limits 85% and 96% respectively). However, the data fit the simple arithmetic mean and its standard error, 87 ± 4%, reasonably well. Minimum and maximum limits for the total parr population in the 7-sample area combined have been set as follows: the minimum value is given by the total number of fish caught; a reasonably safe maximum value (1 chance in 44 of being wrong) by assuming that the total catch represented 79% of the fish available. Such limits have been used for computing the values in Table XIII.

Table XIII gives the indices for estimated parr populations in the 7 sample areas considered together. These are presented as minimum and maximum values between which the true value is believed to lie. For 1946, the minimum values were calculated on the assumption that the seining in that year took one-quarter of the fish present, the maximum value on the assumption that it took only one-tenth (see page 13). For 1948 and subsequently they were calculated on

TABLE XIII. Strengths of populations of Atlantic salmon parr in the 10-mile experimental stretch (about 435,000 sq yd) of the Pollett River, as measured in 3 independent series of sample areas. Index = average number of parr per 100 sq yd. "Minimum count" seining—minimum and maximum values for 1946 are based on capture of 1/4 and 1/10 of the fish present (text, p. 13); in other years the minimum is the actual rate of capture and the maximum is based on a rate of capture equal to 79% (text, p. 42). *Selected samples* (see text page 14)—the index is from cumulated data for all samples; *random samples*—the index is the mean and its standard error for 10 samples.

Year	Index obtained in sampling areas				Estimated total in main river (from "minimum count" data in 7 selected samples)		
	Minimum count 7 selected samples		Mark and recapture				
	Min.	Max.	6 selected samples	10 random samples	Min.	Max.	Average
1946	1.6	4.0	...	...	7,000	17,000	12,000
1947	0.13	0.16	...	...	<1,000	<1,000	<1,000
1948	5.0	6.3	...	...	22,000	27,000	25,000
1949	9.1	11.5	...	...	40,000	50,000	45,000
1950	7.8	9.8	8.5	...	34,000	43,000	39,000
1951	11.4	14.4	20.8	14.9±2.6	50,000	63,000	57,000
1952	1.3	1.6	1.2	1.0±0.2	6,000	7,000	7,000

the basis described in the last paragraph. With no bird control, an index of 55 to 60 for underyearlings planted was followed a year later by a parr index of about 2; with bird control and similar plantings, the average value for following parr indices was over 8.

But do these population indices for the sampling areas represent conditions in the river as a whole? This is the second question; and the answer must be at least a qualified "yes" to warrant estimation of total parr populations in the river. It will be recalled that the sampling areas were originally selected so that they would be broadly representative of the physical characteristics of the experimental part of the stream (see page 14). How successfully this was accomplished is shown by population studies made using two additional, independent series of sample areas, in 1950, 1951 and 1952. In one of these series 6 sample areas were used. These, like the first series of 7, were selected to represent, when considered together, the physical conditions of the stream as a whole (see page 14). In the second series, 10 sample areas were used. These were selected by lot. Two restrictions were applied to randomness. First, 3 stations were required to be in the 3 miles below Forest Glen Dam, while 7 were in the upper 7 miles; second, no water was used that was over 5 feet in depth (such deep water comprises less than 10% of the stream length, is difficult to seine or electrofish effectively, and is apparently relatively unimportant for young salmon production). In both series, parr populations were estimated by adapting the Schnabel (1938) technique of marking, releasing, recapture, marking unmarked fish, release and recapture, and so on for several repetitions. As employed on the Pollett, this system of estimating parr populations gave values with 95% confidence limits usually well within a range of ±10% of the estimated value, frequently within less than half this range. For the 6 selected samples, as with the earlier 7-sample series, an index to represent the whole stream must be obtained by considering all stations together. For the randomly selected 10 samples a representative index is best selected by calculating a mean value and its standard error. The parr indices for these 2 additional series are given in Table XIII. For any particular year the parr indices derived from each of the three independent studies were of the same general magnitude. Hence, the results from the 7-sample series are acceptable as being representative of conditions throughout the experimental area.

The total parr resulting from the annual plantings of about 250,000 fingerlings have been calculated from the data of the 7-sample "minimum count" seining and are given in Table XIII. The plantings (average overall index was 57 hatchery underyearlings per 100 sq yd), repeated in successive years, resulted in summer populations of about 40,000 to 45,000 2- and 3-year-old parr (population index 9 or 10 per 100 sq yd), when the planted fish were given protection from kingfishers and mergansers. Approximately 35,000 to 40,000 of these would be yearlings (index = 8 to 9), a survival rate of nearly 15% over the year intervening since they were planted.

SMOLTS PRODUCED WITH BIRD CONTROL. The smolt-counting weir suffered no breakages during this period and appeared to be capable of intercepting all descending smolts. But no check was made below to see whether this had actually happened. Approximately 4% of the marked smolts were retaken a second time in the trap, indicating that a few fish moved upstream through the weir. This is believed to be largely a result of the marked smolts having been liberated close behind the weir, so that throughout the day after liberation many newly-marked fish stayed in the shaded, turbulent water created by the screen. Observation indicated that sometimes these smolts made persistent attempts to press up through the turbulence and that some squeezed through between rods or through small holes in the stones and gravel forming the footing of the screen. On the other hand, schools of downward-moving fish were never observed to make actual contact with the upstream surface of the screen. The "leakage" downstream is believed to have been much less than that upstream. Not more than one or two smolts a year were taken which had been marked in preceding years, suggesting that no large number moved back and remained above the trap.

In an independent experiment extending over 5 years (1950 to 1954), 10,564 smolts were marked and liberated 1½ miles above this weir; 9213 of these or 87% were recorded passing through

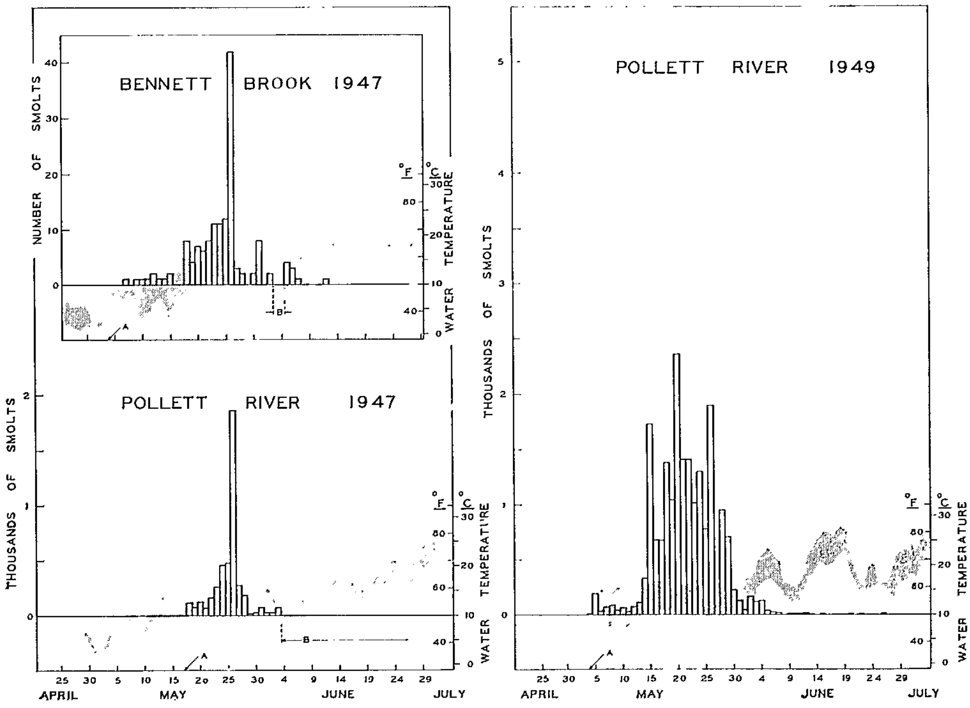

FIGURE 17. Numbers of 2-year old Atlantic salmon smolts, from similar plantings of 250,000 underyearlings each, descending daily through the Pollett trap, without (1947) and with (1949) benefit from bird control throughout stream life. Bennett Brook data are included for comparison with Pollett data for 1947 (text, p. 18). **A**—Dates of trap installation. **B**—Periods of trap malfunction caused by spates. *Grey area*—Daily maximum and minimum water temperatures. Note that most smolts descended as temperature reached and exceeded about 10°C (50°F); see also Figures 7, 18, and 19.

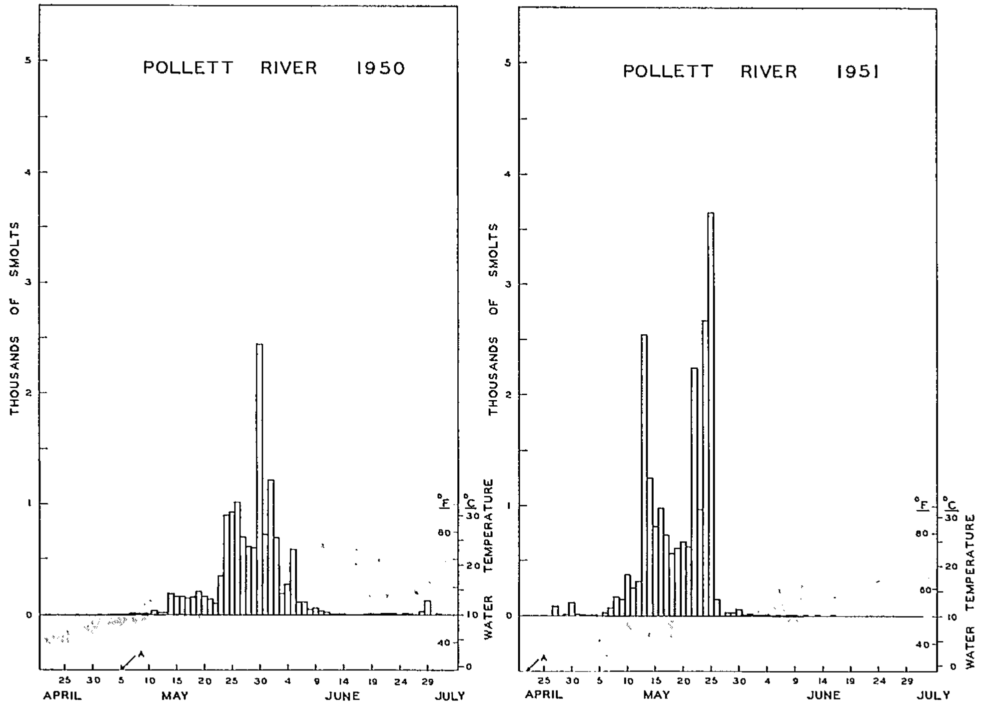

FIGURE 18. Pollett smolt runs, with bird control. The 1950 and 1951 runs were composed of about 85% 2-year olds and 15% 3-year olds from annual plantings of 250,000 underyearlings. Symbols as in Figure 17.

the weir. The check on these marked smolts is known to have been incomplete. Also, there could well have been some mortality of these marked fish in the intervening mile and a half. This shows that the weir took at least 87% of the smolts moving down past it if not a much higher proportion. In the following discussion it will be assumed that the counts obtained are correct evaluations of the smolt runs.

Daily smolt runs for each year are shown in Fig. 17, 18 and 19. Table XIV gives the proportions of 2- and 3-year-old smolts observed and Table XV gives smolt production figures. Planting 250,000 fingerlings in the area gave an average of nearly 20,000 smolts (index = 5 per 100 sq yd). Two-year-olds constituted 88% of the runs and 3-year-olds about 12%. Average size of these fish was similar to that of fish from the much scantier runs produced before bird control was employed (compare Tables IV and XIV).

EFFECTS OF BIRD CONTROL ON OTHER FISH

Other species of fish, as well as salmon, increased in abundance following the application of bird control. These changes can be compared with the changes in abundance of parr by referring to Tables III and X. The tables give both the numbers of fish caught, and a general population index for each species calculated from the numbers of fish caught in the 7 sample areas as a whole. The changes in abundance of the 5 important species of fish, after bird control was established, are indicated in Fig. 20.

For the present purpose, changes in populations of other species are of interest chiefly as they may be related to changes in production of young salmon. The populations of parr, measured in the same way and at the same time as the other species, provide a useful basis for such comparison. Parr increased by 3 times their pre-bird control level in the first year after control was

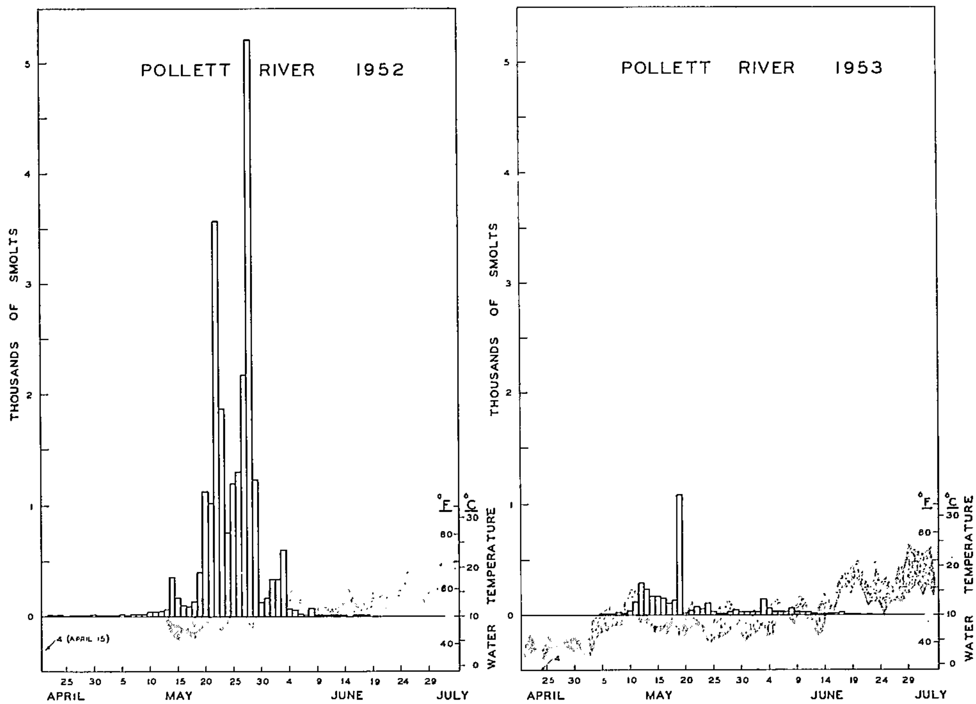

FIGURE 19. Pollett smolt runs, with bird control. *1952*—95% 2-year olds, 5% 3-year olds from annual plantings of 250,000 underyearlings. *1953*—75% 3-year olds from same planting as most 1952 smolts and 25% 2-year olds from a small accidental natural spawning. Symbols as in Figure 17.

TABLE XIV. Total lengths (snout to tip of tail) and ages of smolts from hatchery-reared Atlantic salmon underyearlings planted in the Pollett River, N.B., and given protection from mergansers and kingfishers. Percentages and lengths are given as means plus or minus standard deviation.

Year	Size of sample	Percentage in age groups		Mean lengths		
		2-year	3-year	Overall	2-year	3-year
	no.	%	%	*mm*	*mm*	*mm*
1949	501	98.4	1.6	162±11	161±11	190±27
1950	495	82.8	17.2	160±15	156±12	181±14
1951	498	86.9	13.1	163±15	159±11	183±19
1952	602	95.0	5.0	159±11	158±10	179±11
1953	200	25.5	74.5	180±15	168±16	184±12
Means for all years		[a]88.2±6.2 [b]88.3±5.7	[a]11.8±6.2 [b]11.6±6.0	161±12	159±11	182±15

[a]Mean of percentages in the annual crop (1950–52 data).

[b]Mean of percentages from plantings (1949–53 data).

TABLE XV. Numbers of smolts counted each year, calculated numbers of 2- and 3-year olds (see Table XIV), and estimated total production from each year's planting of hatchery-reared Atlantic salmon underyearlings in the Pollett River, N.B. (Table VIII), given protection from mergansers and kingfishers.

Smolt year	Smolts in each run			Smolts from each planting	
	Count	Calculated no. in run		Planting year	Resulting smolts
		2-year	3-year		
1949	19,925	19,606	319	...	...
1950	13,190	10,921	2,269	1947	21,875
1951	20,349	17,683	2,666	1948	13,587
1952	22,852	21,709	1,143	1949	18,826
1953	3,556	907	2,649	1950	24,358
Mean	19,079[a]				19,662[b]
s	±4,133				±4,634

[a] Based on 1949–52.

[b] Based on 1947–50 plantings, 1949–53 smolt runs.

started, and by 7 times 4 years later. Minnows and suckers were first enumerated in 1947, 2 months after control had started; it seems likely that these species had already benefited from removal of broods of kingfishers and mergansers. But their combined abundance increased to from 3 to 4 times the 1947 level in the first 2 years; then subsequently fluctuated at around twice the 1947 level.

Whether or not eels increased similarly in numbers, as a result of bird control, is not altogether clear. The uncertainty arises from the fact that capture of eels before using electrofishing was ineffective and therefore may not have given a valid index of abundance. Few eels under 10 inches long were taken by seining. Electrofishing showed these small eels to be the most abundant group. All data on eels captured have, however, been assembled in Table XVI. Where electrofishing data were incomplete or lacking entirely, the capture by seining has been multiplied by 40 (see Table XVI) to derive an estimate of abundance.

Figure 20 incorporates the best available information on changes in abundance of eels. They may have increased by as much as 10 times in the 2 years after bird control started (Table XVII). But this cannot be regarded as being so well established as the increases in other species. The population then appears to have become stable at 5 to 8 times the measured pre-control abundance. White (1953, 1957) found that eels are not an important food of kingfishers. Nor are they much eaten by mergansers unless these ducks cannot readily get other kinds of fish, which latter may well have been the pre-control condition on the Pollett. Possibly eels have increased because the increase in smaller minnows meant that they had improved food supplies. In any case, it seems necessary to accept, tentatively, an increase in the eel population of an order at least comparable to that which applied for minnows and suckers.

PRODUCTION IN THE POLLETT COMPARED TO THAT IN OTHER STREAMS

How does the fish population of this experimental stream compare with some of those recorded for natural salmon waters? Hayes (1953) suggests relative values for abundance of fish in the salmon-rearing grounds of the LaHave River, one of the better known salmon-angling streams of Nova Scotia. Judging

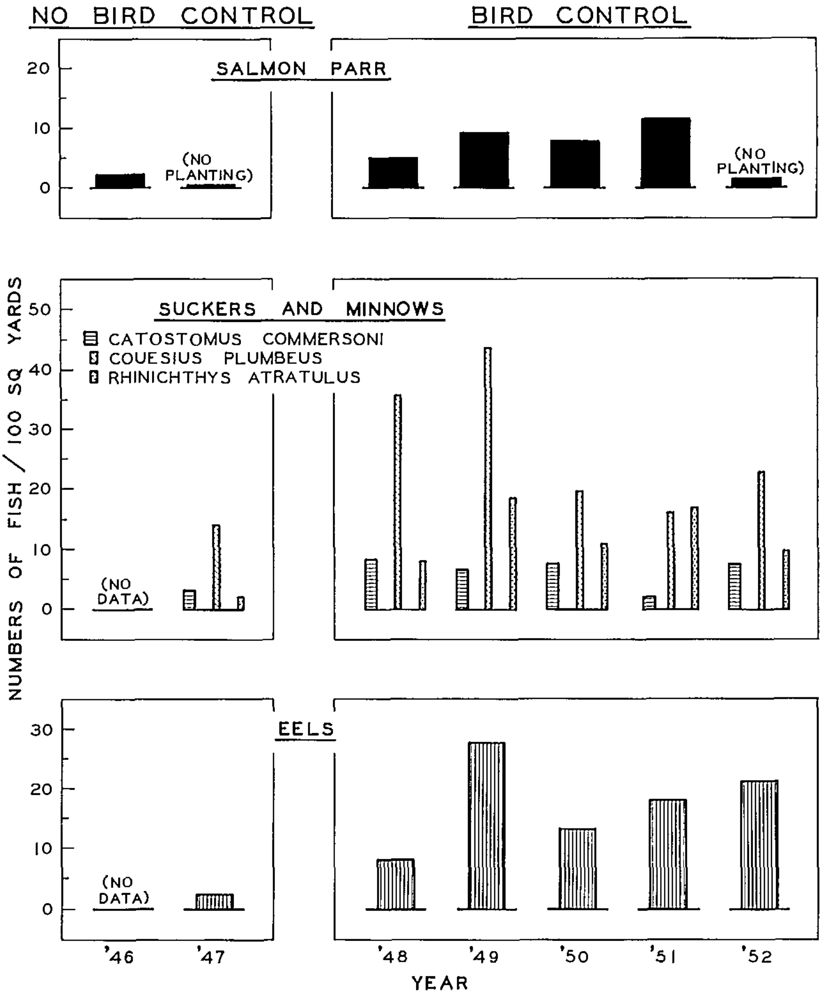

FIGURE 20. Densities of fish populations in the 10-mile experimental stretch of the Pollett, as indicated by seining in the same seven selected sample areas each year. Widths of columns are roughly proportional to the average weight of individuals for each species.

from his Table IV, the values he gives are approximately equivalent to number of fish per 100 square yards. They are: salmon, underyearlings—over 3, and parr—about 1; speckled trout—about 3; coarse fish other than eels—about 50. Larsen (1955) gives figures for a number of small Danish trout streams. Brown trout were the dominant salmonid. Average numbers per 100 sq yd, derived from his observations, are: indigenous Salmonidae 44; eels 7; minnows, etc., 5. Elson and Kerswill (1955) show 39 and 53 parr per 100 sq yd for native stocks of Miramichi salmon. The latter number, 53, occurred with bird control and included 10 parr of a size comparable to those in the Pollett. Pollett salmon were

TABLE XVI. Comparison of capture of eels by "minimum count" seining with no electrofishing aid (S), followed immediately by electrofishing (E), in 7 sample areas. The "index" shown is the average number of eels per 100 sq yd. The grand average ratio of seined to electrofished eels is 47 to 1820, or 1:39—almost 1:40. See Table III for names of areas.

Area	1947	1948	1949		1950	1951		1952
	S	S	S	E	E	S	E	E
El	1	0	12	121	122	6	101	219
Bar	1	0	10	404	91	4	78	414
Bla	2	0	10	270	76	8	...	320
Sal	0	8	17	...	238	5	...	306
Tho	0	3	1	302	176	3	...	185
Bab	1	5	2	195	123	4	...	147
Ho	0	0	2	349	248	6	...	168
Total	5	16	54	1,641	1,074	36	181	1,759
Index	0.06	0.20	0.70	23.65	13.19	0.45	8.62	21.32
Total of pairs	...	...	37	1,641	...	10	179	...
Ratio			1:44			1:18		

TABLE XVII. General abundance of eels (average number per 100 sq yd) as found in 7 selected sample areas of the Pollett River used for studying fish populations, calculated as 40 times the catch by seining for 1947, 1948, 1949 and 1951, and as catch by electrofishing in 1950 and 1952.

Year	1947	1948	1949	1950	1951	1952
Abundance	2.5	8.2	27.8	13.2	18.0	21.3

planted each year *after* the census was made so that the youngest group does not appear in the population studies. Studies of survival indicate that a few weeks after planting the total abundance of young salmon of all age-groups together would have been around 20 to 30 per 100 sq yd. The normal time for turnover of a crop of Pollett smolts is 2 years, instead of 3 as in the Miramichi. Hence, the rate of production of young salmon for the Pollett is far ahead of the LaHave, is perhaps not very different from the Danish streams, and compares favourably with the Miramichi. In the Miramichi tributaries other species of fish have been found to be less than half as abundant as in the Pollett (Keenleyside, 1959).

Figure 20 shows not only changes in abundance, but also in the relative importance of the principal species, including salmon parr, as weight of fish produced in the stream. In this figure the heights of the columns represent numbers and the widths are proportional to the average weight of individuals for the various species. Hence, the areas of the columns are proportional to the total weight of each species as found in the sample areas. The histograms show

how the productive capacity of the stream has been utilized. In Table XVIII these weights have been converted to approximate equivalents in pounds per acre so that Pollett production can easily be compared to standing crops in other waters as reported by other authors. The total Pollett standing crop of about 70 lb/acre (78 kg/ha) is less than half the 170 lb/acre (190 kg/ha) for Ellerslie Brook, P.E.I. (Saunders and Smith, 1955). But only one-third of the trout streams listed by Carlander (1953) had standing crops of more than 70 lb/acre. The Pollett should be classed as a moderately productive stream. It probably would rate well up in a listing of Atlantic salmon streams.

TABLE XVIII. Weight of standing crop of fish in the Pollett River, with 250,000 salmon fingerlings planted in the preceding year—as pounds per acre to the nearest 5 lb. (The following average weights per fish were determined during seining operations: salmon parr—0.050 lb; minnows and suckers—0.0063 lb; eels—0.044 lb).

	Salmon parr	Minnows and suckers	Eels	Total
	lb/acre	*lb/acre*	*lb/acre*	*lb/acre*
NO BIRD CONTROL				
1946	5	No measurements		
1947	No planting	5	5	10
General level	5	5	5	15
BIRD CONTROL				
1948	10	15	15	40
1949	20	20	60	100
1950	20	10	30	60
1951	25	10	40	75
General level	20	15	35	70

After 4 years of protection from birds the total standing crops of fish had increased by about 5 times (from Table XVIII—from about 15 to 70 lb/acre). Salmon parr increased by 4 to 5 times and held this gain consistently. The final gain for minnows and suckers amounted to 2 or 3 times. Eels appear to have increased most noticeably in their utilization of the stream's productive capacity, perhaps by 6 or 8 times. This apparent increase for eels may be a result of incomplete assessment in the years before electrofishing was used. Despite any effect bird control may have had on the eel population, young salmon did increase their utilization of the stream by several times.

Part III. Discussion and Conclusions

It is clear from the Pollett experiments that many more young salmon could be produced when kingfishers and mergansers were reduced. To have value for salmon management this improvement must be measured at the smolt stage rather than earlier. Salmon do not become a useful commodity until they have spent one or more years at sea after having transformed to smolts. So there would be no advantage in increasing younger parr unless the increase was carried over first to migrating smolts, then to usable salmon. The relationship between number of smolts descending to sea and the return of mature salmon to fisheries may vary over a considerable range from place to place and from time to time (Elson, 1957c). It still requires more precise definition. But increasing the supply of smolts, by one means or another, seems to be the chief method by which management of inland rearing grounds can be expected to yield increase in stocks of salmon. Huntsman (1941) examined the commercial salmon catches of the Margaree area resulting from the smolt runs studied by White (1939). He concluded that there was a positive relationship, in this instance, between increase in smolt output and increase in the resulting commercial fishery; both were approximately doubled, with smolt output being the only obvious explanation for increased commercial catch.

White's Margaree experiment provided protection only over the final year of a 3-year smolt stage. In the Pollett experiment, protection from birds was provided over the entire freshwater life of the young salmon. It is not surprising, therefore, that increase in Pollett smolt production was somewhat greater than the approximate doubling achieved for Forest Glen Brook on the Margaree.

INCREASES OBSERVED IN FISH POPULATIONS

Increase in Salmon Smolt Output

If we consider only the Pollett smolt runs resulting from plantings of 250,000 fingerlings, production jumped to 4 times (from 5000 to 20,000 smolts per year, approximately). However, it is unlikely that the Pollett, without bird control, was capable of producing even 5000 smolts in most years; the year-class which yielded 5000 smolts was relieved from the usual pressure exerted by merganser broods during its most vulnerable year, as discussed on page 22.

For small plantings the estimation of damage from bird predation is less easy. The earlier sparse plantings of 16,000 underyearlings, which were subjected to pressure by merganser broods, yielded an average of about 1000 smolts. For a different, recently-concluded series of observations made in this same experimental area when young salmon were not present in excessive numbers and were given protection from birds, the calculated survival rate from planted fingerlings to smolts was 15% (Elson, 1957b), or equivalent to 2400 smolts from a planting of 16,000 underyearlings. Hence it seems likely that the yield from the plantings of 16,000 was reduced from a potential of over 2000 smolts to something near 1000 by bird predation.

Table XIX summarizes the results from the 7 planting experiments in which most or all of the fish were planted in the main river. All figures, which are

Table XIX. Smolt production from known plantings of hatchery-reared underyearling salmon in the 10-mile experimental area (approximately 435,000 sq yd) of the Pollett River, N.B.

	Year of planting	Number of underyearlings planted	Parr 1 year after planting	Total smolts produced from planting
No bird control	1942	16,000	3,000	2,000
	1943	16,000	2,000	1,000
	1945	249,000	12,000	5,000
	Av. (light and heavy plantings)		6,000	3,000
Control of mergansers and kingfishers	1947	273,000	25,000	22,000
	1948	235,000	45,000	14,000
	1949	243,000	39,000	19,000
	1950	246,000	57,000	24,000
	Average	249,000	44,000	20,000

derived from Tables IV, XIII and XV, have been rounded as noted, even though for both light plantings and all 4 heavy smolt runs the fish were actually counted individually.

The yields of smolts from these plantings fall into two groups: light yields of 5000 or less, and heavy yields of over 10,000. Light yields occurred with unrestricted predation; heavy yields with control of mergansers and kingfishers. The dominant type of predation leading to the light yields was of the "type C" described by Ricker (1954); that is, the predators removed all individuals in excess of a certain minimum number. In the 10-mile experimental stretch of the Pollett this minimum number for parr was apparently of the order of 6000; and for smolts 9 months later, about 3000. Thus unrestricted predation by mergansers and kingfishers limited standing crops of late-summer parr in the Pollett to a little over 1 parr per 100 sq yd, and smolt production to a little under 1 smolt per 100 sq yd. But with organized control of these birds, standing crops of parr from heavy plantings were increased to 9 or 10 per 100 sq yd and smolt production to nearly 5 smolts per 100 sq yd. Thus bird control increased average smolt production to more than 5 times the production without control.

Increase in Other Fishes

Where predator control is envisaged as a management procedure for increasing fish, it is important to consider its possible secondary effects through altering established biological interrelationships among several associated species (Vladykov, 1943). In the Pollett experiments such interrelationships were taken into consideration by studying the effect of bird removal on the various fishes associated in this stream with salmon. The one abundant salmon-eating fish, the eel, may have increased as much as or even more than did salmon. Brook trout, which can also be serious enemies of young salmon (White, 1939; Vladykov, 1943) were not originally an important constituent of these Pollett fish populations (Table III) and did not increase enough to become so. But regardless of effects on other species, the fact remains that production of salmon smolts was greatly enhanced, and the improvement was maintained over several years.

AMOUNT OF REDUCTION IN PREDATION

Can we measure the reduction in predation which brought about the changes noted? This is an important consideration from the standpoint of practical management. Measurement requires some sort of unit. A useful unit in this case is 1 bird feeding on the stream for 1 day. We shall call such units "merganser-days" and "kingfisher-days". The units will be equivalent to the average number of fish eaten each day by an individual of the particular kind of bird. For the younger mergansers this unit appears to average about half the value, in weight of fish, of that for adults (see Appendix I). However, for measuring incidence the two will be given equal value.

Let us consider, initially, the amount of pressure which an uncontrolled bird population might place on the fish-producing capacity of the stream—the "potential pressure". This potential pressure is only likely to be applied by mobile birds like mergansers if they are in the vicinity while their prey is sufficiently plentiful to allow satisfactory foraging. No methodical observations on the incidence of the birds were made prior to beginning bird control. But there is no reason to think that the incidence of fish-eating birds was potentially less than during the experiment on their control. It is unlikely that the river, assuming it had carried ample fish for food, would have been visited by more birds when they were being killed and frightened off by control measures, than when they were not. Hence, the records made during control provide a reasonable measure of potential predation. The "residual pressure" remaining despite control operations can also be measured from the same records. The difference between potential and residual pressure will then be a measure of the reduction in pressure accomplished by control.

PREDATION BY MERGANSERS

Merganser pressure on the Pollett falls into two categories; that by broods of young, each usually with an accompanying adult, reared during the summer months in a relatively restricted area; and that at other times of the year by fully grown, flying birds which may move rapidly into or out of an area. These two categories will be differentiated as "juvenile pressure" and "adult pressure".

On the 10 miles of the experimental area, the summer brood population amounted to about 40 birds (Table VI). These would normally be present for about 80 days (mid-June to the end of August) before their powers of flight were well enough developed to permit foraging more widely. This is roughly equivalent to 3000 merganser-days per year.

This juvenile pressure was entirely removed by control.

Estimation of the incidence of flying mergansers during other than the summer months is somewhat more problematical. However, using the data of Table VI it will be found that average removal for the 4 years of heavy parr populations was 28 individuals during the autumn, 23 in winter and 10 in the spring, an average of 60 birds removed per year exclusive of the brood-rearing season. This does not include birds frightened away by patrols. The sighting records were well spread in time throughout periods of open water. They were so grouped (Table VI—average number sighted for seasons from September to May and divide by 9 months) as to suggest that the Pollett could well have had about 20 birds at all times, providing they could get sufficient food and were undisturbed. The yearly time duration for such a population can be conservatively set as from September to November, April and May, the 5 months of assured open water, aside from time of occupation by broods. The potential adult pressure is then calculated as 20 mergansers for 150 days, or 3000 merganser-days.

A clue to amount of residual adult predation is to be found in the records of birds seen during the years of bird control. With patrols made on a semi-weekly basis, a bird sighted may have been on the river from zero to about 3½ days and should average 1.75 days. Allowing something for birds not seen, each sight record represents about 2 merganser-days of preying on local stocks of fish. There was an average of 270 sight records per year for years with good parr populations which excludes 1947-48 and 1952–53 of Table VI. The average residual pressure with control was calculated as being in the neighbourhood of 500 merganser-days.

Thus control operations reduced the annual pressure by mergansers from a potential of 6000 merganser-days (juvenile plus adult categories) to a residual of 500 merganser-days from the adult category only, or a removal of about 90% of the original "potential merganser pressure".

PREDATION BY KINGFISHERS

Kingfishers, under natural conditions, occurred on the stream from early April through to mid-October (Table VII). These occurrences can be classified roughly as follows: April, most of May and October, migrant stragglers; June and July, five pairs of nesting birds, i.e., 10 birds for 60 days; July, 35 nestlings for 25 days (White, 1953); August and September, 60 migrants for 60 days. (Average August and September removal during control was about 60 birds per month and birds removed were replaced by others within a few days; this is a time of wide dispersal from rearing grounds, as White's banding studies have shown.) The potential pressure thus amounted to about 5000 kingfisher-days. Residual pressure left despite control can be calculated similarly as for mergansers. Removal by trapping or shooting was prompt and complete. With semi-weekly or more frequent patrols for tending and re-setting traps, no more than 2 days on the river need be allowed for each bird removed. Residual pressure thus averaged 164 birds for 2 days or about 350 kingfisher-days. This again represents a removal of over 90% of the original potential pressure by kingfishers.

MECHANICS OF PREDATOR-PREY RELATIONSHIPS

As a step towards understanding how, on the Pollett, a given reduction in the numbers of bird predators can affect the numbers of fish prey, it is useful to know something about the patterns of behaviour and other characteristics, like size, which favour this sort of relationship between two animals. White (1953, 1957) has given excellent descriptions of the birds' ways of feeding. As a first consideration, yearling and older salmon parr are generally of a size well suited to both mergansers and kingfishers. But kingfishers also take smaller fish, such as small minnows and sticklebacks, about as readily; whereas mergansers seem to exhibit some bias towards the largest fish available to them, for example, suckers and trout up to about a foot in length.

Importance of Behaviour Patterns of Predators and Prey

Both species of birds hunt by sight, but under different conditions. The merganser forages with its eyes below the surface of the water, where rapids and depth present little handicap for such a strong swimmer and bottom crevices may be probed (Lindroth and Bergstrom, 1959). But the bird is relatively conspicuous to its intended prey and must often overtake it in escape or pull it from hiding. The kingfisher, on the other hand, forages from the air, with excellent opportunity for surprise attack, but is somewhat more handicapped in ability to see from the air and then catch fish in rapids and in deep water, or to pursue them into hiding.

Older salmon parr, like underyearlings (Elson, 1942), tend to be widely dispersed throughout salmon-rearing streams. Areas of swift current and broken water are favoured. When they occur in relatively slow-flowing water it is usually in close association with cover provided by overhanging or submerged vegetation or other objects, cranies under stones or relatively deep water. Each individual tends to maintain a home territory of one to several square yards free from other fish. This territorial behaviour is most pronounced in rapids; in pools or still water the parr may move about more, sometimes associated with other parr or even fish of other species in loose schooling behaviour. On being alarmed, young salmon usually dart for cover.

In contrast to young salmon, most of the cyprinids found in Maritime salmon streams tend to occupy the slower-flowing areas such as pools and eddies. They frequently accumulate in schools. These schools tend to range more widely than do individual young salmon and have no observed tendency to maintain a home territory against intruders. Distribution is consequently more erratic than that of young salmon. When alarmed the school tends to flee by swimming away, and individuals often disperse suddenly and widely.

Eels are largely nocturnal in habit and lie hidden under rocks or banks during the day.

If, in the following discussion of "forage ratios", the reader will keep these respective behaviour patterns in mind, it will simplify understanding of why certain food items appear to be more important to one species of fish-eating bird than another.

Forage Ratios of Different Fishes

It is a common observation that many predacious animals eat certain kinds of prey more readily than others. Lindroth (1955) offers evidence that mergansers select young salmon and European sea-trout parr in preference to other species of fish present. Eipper (1956) found that kingfishers took young Salmonidae more readily than other, more abundant species.

"Forage ratio" is the term suggested by Hess and Swartz (1941) to designate the ratio between the percentage which an organism contributes to the food and the percentage which it contributes to the local population of food organisms (by numbers). Allen (1942) pointed out that this ratio, which he called "the availability factor", probably reflected the availability of the organism, as

Table XX. Proportions of different kinds of fish found in stomachs of 117 mergansers shot on the Pollett River, in relation to relative abundance of the fish. Merganser food analysis from White (1957, Table XVI). Fish population analysis from Tables III, X and XVII of this report. *A*—percentage of fish, by numbers, in merganser food; *B*—percentage of fish, by numbers, in total fish population. The ratio A/B is forage ratio for fish in merganser food.

	1949	1950	1951	1952	Av.	A/B
	%	%	%	%	%	
Salmon.............A	22.4	42.9	46.3	56.7	42.1	4.1
B	8.6	13.2	17.2	2.1	10.3	
Suckers............A	32.9	17.1	21.2	16.4	21.9	2.4
B	6.1	12.7	6.0	11.7	9.1	
Chub...............A	17.7	14.3	9.5	13.0	13.8	0.4
B	41.4	32.9	23.9	36.7	33.7	
Dace...............A	9.3	3.8	9.1	4.4	6.7	0.4
B	17.5	18.1	25.2	15.3	19.0	
Eels...............A	3.8	2.9	3.0	4.8	3.8	0.1
B	26.4	22.4	27.1	34.2	27.5	
Others.............A	13.9	19.2	10.7	4.4	12.1	24.2
B	0.1	0.7	0.6	0.0	0.5	

affected by its size, structure and habits, to the feeding animal. Allen went a step further and suggested the term "apparent available density" for the product of the density of the organism multiplied by its forage ratio.

Data on food of the birds in question while on the Pollett are given in Tables XX and XXI.

TABLE XXI. Proportions of different kinds of fish used by kingfishers in 97 meals, as found on the Pollett River, in relation to relative abundance of the fish. Kingfisher food analysis from White (1953, Table III). Fish population analysis from Tables III, X and XVII of this report. *A*—percentage of fish, by numbers, in kingfisher food; *B*—percentage of fish, by numbers, in total fish population. The ratio A/B is forage ratio for fish in kingfisher food.

	1946–47	1948–49	Av.	A/B
	%	%	%	
Salmon. . . . . A	13.6	11.7	12.7	3.1
B	0.5	7.7	4.1	
Suckers. . . . . A	28.2	15.2	21.7	1.6
B	14.3	12.5	13.4	
Chub. . . . . A	33.0	44.0	38.5	0.7
B	64.1	54.9	59.2	
Dace. . . . . A	3.9	14.4	9.2	0.9
B	9.2	12.2	10.7	
Eels. . . . . A	1.9	0.0	1.0	0.1
B	11.5	12.6	12.1	
Others. . . . . A	19.4	14.8	17.1	42.8
B	0.5	0.2	0.4	

Mergansers (Table XX) had eaten more salmon than other kinds of fish, relative to the abundance of each. On the average, salmon formed a little less than one-half (42%) of merganser food, although other kinds of fish were more abundant. For mergansers, salmon parr had a forage ratio of 4.1, suckers a little more than half this, small minnows less than one-quarter and eels one-fortieth that for salmon.

Kingfishers (Table XXI) had only used salmon for one-quarter as much of their food (13%) as did mergansers, and used relatively more other fish, especially small suckers and minnows. The forage ratio of salmon, for kingfishers, was 3.1, suckers about half this, small minnows about half and eels less than one-thirtieth the value for salmon.

Both kinds of birds used fish of infrequent occurrence in the Pollett for about 15% of their food. The species involved included speckled trout, which occur near cool springs and tributary brooks in spring and autumn, but not generally throughout the main river in summer. Sticklebacks, top minnows and some other small fish, whose habits make them particularly vulnerable to kingfisher attack, were used more by kingfishers.

In sum, the different occurrences of the various fish species in the food of these birds appear to be largely explainable on the basis of Allen's "apparent available density". In a good salmon-rearing stream this value *should* be high for young salmon unless previously drastically reduced by predators or some catastrophe.

Effects of Control on Parr Populations

In Tables XXII and XXIII the potential yearly removal of young salmon by the two species of birds is given for conditions both without control of the birds and with control.

Table XXII. Potential yearly removal by mergansers (in thousands of fish), calculated as the number of fish which merganser populations of average abundance could eat in the course of a year, from stocks in the 10-mile long experimental stretch of the Pollett River. The "no control" situation is for adequate stocking of salmon and no control of the birds; "with control" is for bird control at the level described in the text. Salmon are calculated as 42% of the merganser food requirement (Table XX). *Ad.* = mergansers old enough to fly well; *juv.* = young birds unable to fly well. *Index* = removal of fish by mergansers, per 100 sq yd of stream. (See Appendix I for method of calculation and sources of information).

	Merganser-days		Required numbers of fish of all species			Required numbers of young salmon					
						Adult		Juvenile		Both	
	Ad. total	Juv. total	Ad. total	Juv. total	Both total	Total	Index	Total	Index	Total	Index
			10^3	10^3	10^3	10^3		10^3		10^3	
No control	3,000	3,000	120	60	180	50	11.0	25	5.5	75	17
With control	500	0	20	0	20	10	1.8	0	0	10	2
Potential saving			100	60	160	40	9	25	6	65	15

Uncontrolled merganser activity was apparently capable of removing from the area about 75,000 young salmon per year. This number of young salmon is greater than the approximately 40,000 to 45,000 which the Pollett can be expected to support each year (Table XIX). With control, the potential removal by mergansers was reduced to about 10,000 per year, a figure well below the demonstrated parr-producing capacity of the area, and therefore leaving a good stock of young salmon to become smolts.

TABLE XXIII. Potential yearly removal by kingfishers, calculated as the approximate number of fish which kingfisher populations of average abundance could eat in the course of a year, from stocks in the 10-mile experimental stretch of the Pollett River. The "no control" situation is for adequate stocking of salmon and no control of the birds; "with control" is for bird control at the level described in the text. Salmon are calculated as 13% of the kingfisher food requirement (Table XXI). (See Appendix II for method of calculation and sources of information).

	Kingfisher-days	Required numbers of fish of all species	Required numbers of young salmon	
	Total	Total	Total	Index
No control	5,000	120,000	15,000	3
With control	350	10,000	1,000	0.2
Potential saving		110,000	14,000	3

Uncontrolled kingfisher activity could apparently remove about 15,000 parr each year. By control, this tax on the parr was reduced to a negligible 1000 parr. Even if not controlled, kingfisher activity is apparently not capable of reducing a moderately heavy crop of young salmon by an amount which would seriously affect smolt production. However, if the crop of parr were low, i.e., much less than three-quarters of the normal 40,000, then uncontrolled feeding by kingfishers might noticeably reduce smolt runs. Control of kingfishers is of secondary importance to control of mergansers for increasing salmon stocks.

TYPES OF PREDATOR–PREY RELATIONSHIPS

The statement has already been made (page 53) that Pollett salmon had apparently been subjected to predation similar to the "type C" of Ricker (1954). A necessary condition for such a situation is that the predators, as a group, have a food requirement substantially in excess of what can be supplied by the population of the particular species of prey under consideration.

Similar bird control was in force on the Pollett for 9 consecutive years, including 3 years subsequent to those listed in Table X. Parr in these later years came from one very heavy planting, and two experiments on sparse natural spawning. Pertinent data on incidence of birds and abundance of fish have been assembled in Table XXIV.

There has not been any sustained trend in the yearly number of birds removed during control. The linear correlation of mergansers killed with time during the last 7 years is completely insignificant ($r = 0.01$). Hence, the control measures did not seriously or cumulatively affect the general stocks of birds available to the Pollett each year. They merely prevented prolonged feeding activity by these stocks. In Fig. 21 the yearly abundance of birds, as measured by the numbers removed through control operations, has been plotted against

TABLE XXIV. Numbers of fish-eating birds removed annually from a 10-mile section of the Pollett River, and the abundance of fish in the stream expressed in the index: average number per 100 sq yd estimated from sampling areas.

Birds removed			Abundance of fish		
During year ending in May of	Mergansers	Kingfishers	In summer of	Salmon parr index	Minnows and suckers index
	no.	*no.*		*no./100 yd²*	*no./100 yd²*
1948	14	167	1947	0.1	19.1
1949	28	245	1948	5.0	51.6
1950	82	215	1949	9.1	67.8
1951	52	89	1950	7.8	38.0
1952	99	134	1951	11.4	36.5
1953	40	138	1952	1.3	39.6
1954	71	108	1953	12.1	29.9
1955	61	157	1954	3.7	27.7
1956	48	192	1955	2.3	46.7

the yearly abundance of fish, as measured in the sampling areas. These diagrams illustrate the relationships between the two species of birds and their prey in the Pollett River.

MERGANSERS VERSUS PARR. A positive relationship was found to exist between mergansers killed and abundance of salmon parr. This is illustrated in the upper left-hand part of Fig. 21. The correlation coefficient is $r = 0.82$ ($P < 0.01$), showing that about 65% of the variability in merganser kill is associated with parr abundance. The general situation, illustrated by the solid straight line of best fit, is that with similar control effort the average annual kill would be about 25 mergansers in the absence of parr; and for each increase of 1 parr per 100 sq yd the annual kill of mergansers would increase by 5 birds.

Thus the more parr there are, the more mergansers tend to accumulate and feed on them. This tendency of mergansers to accumulate in an area with abundant parr fulfils the condition for Ricker's type C predation situation, that the mergansers as a group should have a food requirement in excess of what local parr can supply. As long as the general stock of mergansers remains at a normally high level, full production of salmon parr by a stream to which the birds have unlimited access is unlikely to be obtained unless some control is exerted on the mergansers coming to that stream.

There is a further implication in these observations. If control of mergansers is used to build up local stocks of parr, then still greater numbers of mergansers are likely to flock into the areas of improved parr populations. Hence, localized control programs can only be relaxed at risk of losing much or all of the benefit gained. The greater the benefit has been, the greater the risk and the greater the loss that may result.

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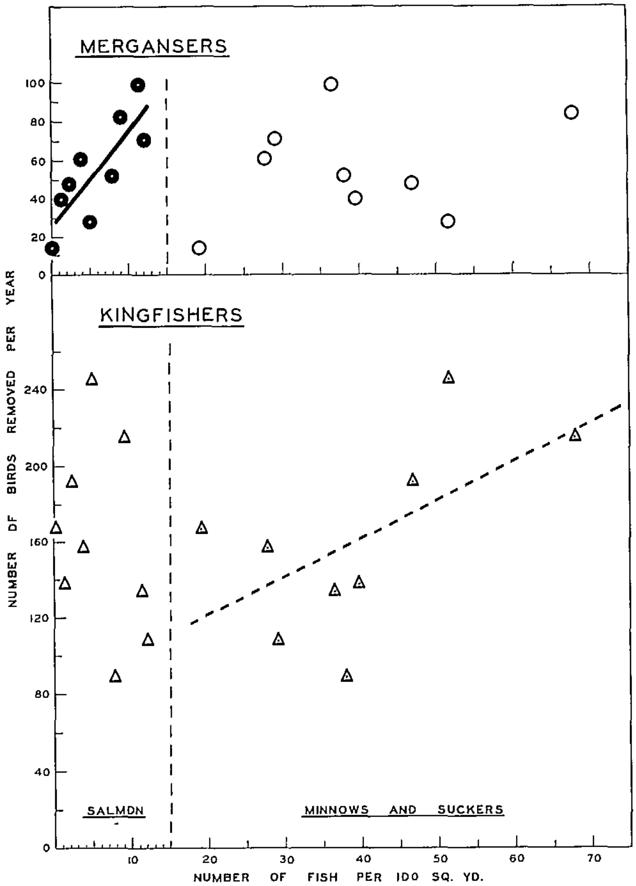

FIGURE 21. Yearly incidence of fish-eating birds, as measured by annual kill, in relation to abundance of fish as measured by seining. *Solid line*—A strong tendency is indicated for merganser incidence to depend on parr abundance, but not on abundance of other species. *Broken line*—There appears to be some tendency for kingfisher incidence to depend on the abundance of the smaller coarse fish, but not on salmon.

MERGANSERS VERSUS COARSE FISH. In the upper right-hand part of Fig. 21 merganser removal is plotted against the combined abundance of minnows and suckers. Despite the fact that minnows and suckers were several times more abundant than salmon, no relationship is evident between abundance of mergansers and abundance of these coarse fish. Nevertheless, White's (1957) analysis of merganser food shows that the birds do eat many of these fish. For example, in 1952, with a parr index of 1.3 and other fish (excluding eels) 39.6, parr formed 57% of Pollett merganser food and occurred in 79% of stomachs (Tables X, XX). The 43% of food contributed by other species must have been an important factor in permitting the birds to stay on the Pollett at all.

It appears, then, that mergansers are particularly likely to accumulate in areas having young salmon. But if salmon are scarce, a sufficient abundance of other fish can permit the birds to remain on an area while such parr and coarse fish as they encounter fill their food requirements. This agrees with White's (1957) contention that an abundance of coarse fish does not provide relief to salmon from merganser depredations, but rather the contrary.

KINGFISHERS VERSUS PARR. No correlation between abundance of kingfishers and salmon parr is indicated (lower left part of Fig. 21). That is, even though salmon had a higher forage ratio than other fish, their abundance was not associated with larger numbers of kingfishers coming to the stream. This is the opposite of the situation for mergansers. The relationship between kingfishers and parr fits Ricker's type A predation situation, where more or less fixed numbers of the predator take more or less fixed numbers of the prey. The number of kingfisher-days on the Pollett (Table XXIII) has not been great enough to reduce moderately heavy parr populations to a point where smolt runs would be seriously affected. Little, if any, of the improvement to smolt runs which accompanied bird control can, therefore, be attributed to removal of kingfishers.

KINGFISHERS VERSUS COARSE FISH. There appears to have been some tendency for kingfisher incidence to increase in years when coarse fish were more abundant. This is illustrated by the dotted straight line of best fit drawn for the points in the lower right-hand section of Fig. 21. The correlation coefficient is suggestive ($r = 0.59$, $P < 0.1$); at this level only about 35% of the variability in kingfisher kill would be associated with abundance of fish. The relationship found suggests that even with fish rather scarce about 90 kingfishers would probably be encountered on this part of the river each year, and for each increase of 1 coarse fish per 100 sq yd, the annual removal of kingfishers would increase by 2 birds. This relationship is not nearly as strong or as well established as that between mergansers and parr. Neither is there much likelihood that increases in coarse fish could be sufficiently great to be accompanied by a kingfisher population large enough to make serious inroads on a good population of young salmon.

PREDATION BY BIRDS WAS REMOVED AS A LIMITING FACTOR

The question might be raised, if control of mergansers, as applied, allowed such large increases in parr production and smolt output, would not complete elimination of the birds have accomplished still more benefit? The answer from the Pollett is that all practical benefit was apparently gained. This can be determined by comparing the amount of residual predation each year to the corresponding loss between parr and smolt stages.

Estimates of residual predation have been made by converting yearly sight records of ducks (Table VI) to twice as many "merganser-days" (see page 54). These in turn have been converted to estimates of parr removed by considering the daily food requirements of mergansers as 1.0 lb (Appendix I), the fact that merganser food on the Pollett has averaged 42% salmon parr (Table XX), and that these Pollett parr weighed about 0.05 lb each (Table XVIII). The loss of young salmon between parr and smolt stages has been calculated as the difference between the estimated total parr population for any one year and the resulting total production of 2- and 3-year smolts (Table XIX). The yearly figures will be found in Table XXV. Residual predation could have accounted for an average of 5000 parr per year.

The average loss between parr and smolt stages was over 20,000 per year, or 4 times the amount attributable to residual predation. Largest losses were from the heaviest parr populations (Table XXV). But heavier parr populations were also accompanied by heavier merganser populations (compare Tables XXV and XXIV). Any appearance of connection between total loss and loss through residual merganser predation is thus an artifact produced by the more fundamental relationship between abundance of parr and abundance of ducks, as described above.

TABLE XXV. Estimated total loss of parr between yearling and smolt stage (column 4, which is the difference between 2 and 3), compared to potential removal by residual mergansers during the same period despite control measures (column 5). Loss to mergansers can explain only about a quarter of the total loss.

1 Year ending in May	2 Parr in previous summer	3 Output of smolts	4 Loss of parr	5 Parr removed by mergansers
1949	25,000	22,000	3,000	2,000
1950	45,000	14,000	31,000	5,000
1951	40,000	19,000	21,000	5,000
1952	55,000	24,000	31,000	7,000
Average	40,000	20,000	20,000	5,000

The degree of control applied on the Pollett removed predation by mergansers as the limiting factor for smolt output. Kingfishers were apparently not capable of limiting this output, given an ample stock of very young salmon. Hence, with the bird control applied, some other feature of the environment must have then taken over the limiting function and kept smolt output to a level of about 20,000 per year.

GENERAL EVALUATION OF BIRD CONTROL FOR INCREASING ATLANTIC SALMON

The Pollett River was selected for a study of salmon-merganser interrelationships not because of the intrinsic values of Pollett salmon fisheries, which are minor, but rather to serve as a convenient and suitable study area for the problem. How, then, can the final results be expressed in generally useful terms?

Control of kingfishers did not add a useful increment to Pollett smolt production, and could never do so unless merganser activity was at a low level. Kingfisher pressure on the Pollett amounted to 55 kingfisher-days per acre per year (1 bird for 2 acres), a population of 1 bird per half-mile of stream 10 yards wide, over the approximate 100-day season of kingfisher activity. This density of kingfishers was unimportant to salmon production. A population of twice this density, however, could reduce salmon production to only half of what it might be with bird control. Control of kingfishers would then be desirable.

There is no question, however, that, for the Pollett, mergansers operating at a normal level of activity were the factor limiting smolt production. In general terms this uncontrolled activity involved a potential 50 merganser-days per acre per year. At a rough approximation this is equivalent to a potential removal of nearly 50 lb of fish per acre per year, or nearly three-quarters of an average standing crop of all fish for the stream (Table XVIII). The control applied reduced this potential removal to about 5 lb per acre per year. This is the reduction which permitted a production of more than 5 times the original smolt output. For salmon, the loss to mergansers was reduced from a potential 20 lb per acre per year to about 2 lb. The first figure approaches both the annual production of salmon and the annual standing crops produced when there was control. (Standing crop of young salmon and annual production were similar for the Pollett because of its predominantly 2-year smolt history.)

Much increase in merganser predation over that obtained during the control experiments would jeopardize production of full smolt output. Hence, for maximum smolt output merganser activity should be limited to about 1 bird for 50 acres of water. This is equivalent to 5 miles of a stream like the Pollett, or 15 miles of similar stream 10 yards wide. This limit of only 1 bird applies for about 8 months of the year, or the entire open-water season, whichever is greatest.

The Pollett level of salmon production is as good as that of several famous Canadian Atlantic salmon streams, and better than many others. White's various papers indicate that similar benefits could be expected on a large number of Maritime salmon streams. In evaluating his analysis of merganser food from different areas, the fact should be kept in mind that where predation has been heavy and salmon parr as a result are sparse, parr may well be of minor importance as merganser food. Merganser predation may nevertheless be severely limiting salmon smolt output in such areas.

Consideration of the economic status of the American merganser on Canadian salmon streams would not be complete without reference to the detailed study which Munro and Clemens (1937) made on the Pacific coast. They attacked the general problem of the relation of mergansers to trout and salmon in British Columbia. Many species of fish were involved, including several desirable species which have predator-prey interrelationships among themselves. While the authors stated that "the problem (of mergansers *versus* Salmonidae) is not a local one", they nevertheless concluded that "circumstances may . . . arise which warrant a reduction . . . in certain localities". This is, in fact, tacit admission that the problem is one for local consideration. It is interesting, for example, to speculate on the effects of the local merganser population on the production of desirable fish in the Cowichan River. They report 75 birds using about 450 acres of stream during the brood-rearing season. This is equivalent to a removal of at least 10 to 15 lb/acre of fish per year. Neave (1949) states that the natural productivity of the Cowichan is not high. It seems unlikely that mergansers would seriously injure the stock of tiny, night-migrating pink and chum salmon fry. But what are their total effects on the young of those desirable species which grow in the river to a more acceptable size for the birds (coho and chinook salmon, steelhead and cutthroat trout)? These are the questions which must be answered in order to determine the relation between mergansers and Salmonidae. They tend to be local problems. Warrant for accepting or rejecting control of the birds can properly be made only on a local basis, although, as in the Atlantic provinces, one sample study may exemplify the situation for other similar streams.

Experience in the Maritimes, including that on the Pollett, shows that control must be applied locally, but it must be intensive. Mergansers, except during the summer brood-rearing period, are extremely mobile predators. They can and do drop in on salmon streams, feed briefly, then move elsewhere. There are vast wilderness areas in the Atlantic provinces where mergansers can rear their young unhindered by man. Effective control should then be aimed at protecting fish in specific areas, rather than at widespread and promiscuous killing of mergansers. It can only be effective where, without control, the birds are making serious inroads on the capacity of an area to produce desired species of fish.

SUMMARY

Nine annual plantings of hatchery-reared Atlantic salmon underyearlings were made in a 10-mile stretch of the Pollett River, New Brunswick. All plantings involved fish of similar size and were made at the same season of the year. From 16,000 to 250,000 underyearlings were used. These plantings provided the only young salmon in the area, because native salmon were barred from it by a dam with no fish-ladder. A high falls at the upper end prevented upstream movement out of the experimental area.

Populations of parr resulting from these plantings, as well as associated populations of other fish, were studied. Techniques for quantitative assessment of stream-dwelling fish were improved about midway in the study. Production of smolts from each planting was measured by counting descending migrants in the spring as they collected in a trap at the lower end of the experimental area.

Production from the five earliest plantings was studied under natural conditions, except for introducing the salmon. Parr from the four lighter plantings were very scarce 1 year after planting. The heaviest planting (250,000 underyearlings) was followed in 1 year by 10,000 to 12,000 parr, but these had been noticeably reduced in another 3 months. Fish of other species were scarce throughout this period. Smolt production from the main river, under natural conditions, averaged 3000 smolts per year, the highest production being about 5000 smolts.

Systematic and intensive control of the two most conspicuous predators on fish in the area was then applied. These predators were the American merganser (*Mergus merganser*) and the belted kingfisher (*Megaceryle alcyon*). Concurrently, four annual plantings of 250,000 underyearlings were made and their survivors were assessed as river-dwelling parr and as seaward-migrating smolts. With this bird control, resulting parr populations varied between about 25,000 and 55,000 fish, average standing crop of 1- and 2-year-olds being 40,000 to 45,000 parr. The average yield of smolts per planting was nearly 20,000 (lowest 13,600; highest 24,300).

Control of these birds made possible an average smolt output not less than 5 times as great as without control, and quite possibly the increase was more than this.

Most species of coarse fish in the river approximately doubled their numbers as a result of the protection offered. With the possible exception of eels, no other species benefited as much as salmon. The initial high level of salmon smolt output was maintained in the new balance of species with bird predators removed. Compared to other salmon streams, the Pollett is fairly productive.

Mergansers and kingfishers take salmon parr more readily than they do other fish that are equally or more abundant. Evidence was obtained that

merganser incidence increased when parr were more abundant, though not necessarily when coarse fish were. Even during control operations, the mergansers that came to the experimental area each year were sufficient to have removed all the parr the area could support, had the control not removed the birds. Kingfisher incidence was less clearly affected by abundance of fish and not at all by abundance of salmon. It tended to be at a more or less constant level from year to year. Kingfishers using the Pollett were not capable of removing more than about one-third of a full parr crop. Their control is of minor importance as compared to control of mergansers.

Control of the type employed to increase the Pollett smolt output by 5 times or more must limit merganser activity to a level of only 1 bird on 50 acres of water, or about 15 miles of stream 10 yards wide, for the entire open-water season. Control of kingfishers on such a stream as the Pollett is unlikely to add a useful increment to smolt output, unless incidence of kingfishers should increase much beyond a rate equivalent to about 1 bird per half-mile of stream 10 yards wide, or roughly 1 bird for 2 acres of water.

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From 1947 the project was continued as part of the work of the Fisheries Research Board's Biological Station, St. Andrews, N.B. During the study of bird control Mr. White gave generously from his extensive experience in this type of field work, of both thought and actual physical effort, as well as making readily available information from his own researches on food and habits of the birds. Only the unstinting effort of the field crew, headed first by Mr. H. W. Coates, then by Mr. P. R. Graves, made possible the accumulation of facts on which Part II of this report is based. Counting migrants, hunting birds and seining fish, on the systematic bases required, involved much physical effort and ingenuity, often under adverse conditions and far beyond normal working hours.

Photographs kindly provided by others include: Fig. 2B—Royal Canadian Air Force aerial photo; 3A, 15A, 15B—Moncton Transcript; 3D, 11A, 11B—Dr. C. J. Kerswill; 14A, 14B—Dr. D. G. Wilder; and 10A, 10B by members of the Pollett field staff. Mr. P. W. G. McMullon prepared the charts in their final form. I wish to thank all who have co-operated in providing material, as well as those whose stimulating discussion and helpful criticism have contributed to the completed report. I would be remiss did I not acknowledge with gratitude the patient typing and retyping of the manuscript, at various times by Mrs. Hazel L. Grant, Miss Elizabeth D. McAuley and Mrs. Ruth M. Barr.

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APPENDIX I. Basic data for calculation of potential annual removal of young salmon by mergansers as given in Table XXII, with sources of information.

A. Daily food requirement of adult mergansers, from two sources:

(a) $\frac{1}{3}$ to $\frac{1}{2}$ body weight eaten daily (Sayler and Lagler, 1940; Solman, MS 1950; White, 1936, 1957).

Average weight of adults = 2.563 lb

$$\text{Food requirement} = \frac{1}{2}\left(\frac{2.563}{3} + \frac{2.563}{2}\right) = 1.051 \text{ lb/day}$$

(b) Eaten in 19 merganser-days — 18.75 lb (White, 1937).

Eaten in 657 merganser-days — 682.60 lb (White, 1957, Table IB).

$$\text{Average daily consumption } \frac{701.35}{676} = 1.038 \text{ lb.}$$

$$\text{Value used} = \frac{1.051 + 1.038}{2} = \text{about } 1.0 \text{ lb.}$$

B. Daily food requirement of juvenile mergansers, from two sources:

(a) Assume $\frac{1}{3}$ body weight eaten daily (see same references as for adults).

Average weight of juveniles = 1.25 lb (Solman, MS 1950).

$$\text{Food requirement} = \frac{1.25}{3} = 0.417 \text{ lb/day.}$$

(b) Eaten in 420 merganser-days — 233 lb (White, 1957, Table IA).

$$\text{Average consumption} = \frac{233}{420} = 0.555 \text{ lb.}$$

$$\text{Value used} = \frac{0.417 + 0.555}{2} = \text{about } 0.5 \text{ lb.}$$

C. Converting weight of food requirement to equivalent numbers of young salmon:

(a) Assume that all species occur in the same weight-groups as salmon. Since minnows and suckers were, on the average, smaller than young salmon, the numbers of coarse fish used are somewhat underestimated; salmon are not affected.

(b) For small parr, average weight = 0.016 lb (White, 1936).

(c) For large parr, average weight = 0.050 lb (Table XVIII).

(d) The fraction, by number, of salmon in merganser food collected on the Pollett River was about 42% (Table XX).

D. Calculated potential requirement per merganser-day, from the above:

	Small fish only		Large fish only		Small and large fish combined	
	All species	Salmon only	All species	Salmon only	All species	Salmon only
Adult mergansers	63	26	20	8	40	17
Juvenile mergansers	32	13	10	4	20	8

APPENDIX II. Basic data for calculation of potential annual removal of young salmon by kingfishers, as given in Table XXIII, with sources of information.

A. Daily food requirement of kingfishers:

(a) 0.344 lb per day for captive birds of pre-flight age (White, 1936).
For very small salmon (hatchery-reared, 7 cm long), av. weight = 0.008 lb each.
For small parr, av. weight = 0.016 lb each (White, 1936).
For large parr, av. weight = 0.050 lb each (Table XVIII).

(b) 40 fish about 6 cm long per day fed to captive pre-flight birds (White, 1936).
20 fish over 7 cm ($2\frac{3}{4}$ inches) long per day for wild birds (White, 1936, 1953).

(c) The fraction, by number, of salmon in kingfisher food collected on the Pollett River, was about 13% (Table XXI).

B Potential requirement per kingfisher-day, calculated from the above, assuming that all fish are sorted into size groups similar to those for salmon:

Very small fish		Small fish		Large fish		Approximate average	
All species	Salmon only	All species	Salmon only	All species	Salmon only	All species	Salmon only
43	6	21	3	7	1	24	3

SUPPLEMENT

The Fundamentals of Merganser Control for Increasing Production of Salmon Smolts from Streams

CONTENTS

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INTRODUCTION

Careful study has shown that on many Maritime streams the merganser is one of the chief enemies of young salmon.

This fish-duck will eat almost any kind of fish from 3 inches to a foot in length. Its habits of living and feeding are such that it thrives particularly well on the kinds of streams where salmon live. The habits of both mergansers and young salmon are such that salmon are one of the kinds of fish that the duck meets most often and finds easiest to catch.

Mergansers are fairly common on many salmon streams. But they are also alert and wary birds, expert at keeping out of reach or even out of sight of their enemies, including man.

For these reasons, even people who frequent salmon streams may not realize what serious enemies mergansers can be to young salmon. Even some who know this fail to realize that mergansers can come and go easily, especially once they are old enough to fly, and can, if allowed to feed for even a few days at a time, do tremendous damage to stocks of young salmon.

Preventing such damage is far more difficult than it appears at first glance. It can be done best if one understands how the nature and habits of the two animals, mergansers and young salmon, fit together like pieces in a jig-saw puzzle.

This supplement outlines the principles which apply to successful control of mergansers on salmon streams and is directed to those who wish to consider such a form of fisheries management. It should help management personnel to understand that their work is something more than just hunting ducks.

Identifying the Birds

American and red-breasted mergansers. (**Shoot only these!**). Most of us who have spent much time along Maritime salmon or trout streams of about 30 feet or more in width have seen mergansers. These fish-eating ducks go by different names in different places. Saw-bill, sheldrake, shelduck, fish-duck, goosander, skitter duck are the most common names used, or in French, *le harle and le bec-scie.* In the summertime we see the broods of young with their mothers on the streams in small flocks of about 3 to 15 birds—grey backs, white breasts and reddish head and neck; often the crest can be seen on the head and neck. In the late summer as several broods gather together, they may be in flocks of 20 to 40, with the larger flocks usually being seen on the lower reaches of larger rivers. By then the ducks may be flying. From late autumn right through to spring they may be seen along streams where there is open water, coming and going singly or in flocks of up to a hundred or more. The adult males are now large handsome birds with greenish black heads and white breasts which may become stained almost a salmon pink. Most of these are the common or

American merganser (*le harle d'Amérique*) in which the male has no crest. A few may be the slightly smaller red-breasted merganser (*le bec-scie*), in which the male, too, has a crest. The red-breasted merganser occurs most commonly on lakes and estuaries, but the common merganser seems to be most at home on our clear, swift salmon streams. Both are about equally serious enemies of young salmon when they inhabit salmon-rearing streams. So there is little need to differentiate between the two species as long as control operations are concentrated on the rearing streams, as for the most part they should be.

A word of warning is in order at this point. There are other kinds of ducks, including important game species, which are sometimes met with in the same areas as mergansers.

HOODED MERGANSER. (**Don't shoot!**) The little hooded merganser, often called "wood duck", while a true merganser with the typical slender bill of these birds, is largely an insect eater. It is easily distinguishable by its conspicuous crest or "hood" and brownish rather than greyish colour. It is not likely to be encountered on swift streams, and should not, of course, be shot in a merganser control program.

BLACK DUCK. (**Don't shoot!**) The occasional black duck, sometimes with young, may be seen. More often black ducks are found on backwaters and beaver ponds. There should be no difficulty in telling the difference between these large, very dark brown, broad-beaked dabbling ducks and the light grey, red-headed, slim-beaked and more active mergansers. Black ducks should not be shot.

WHISTLER. (**Don't shoot!**) A duck which is much more likely to be mistaken for the merganser is the golden-eye, commonly called "whistler" in the Maritimes. Both young and old birds look something like mergansers. They are, however, somewhat chunkier. Whistlers have relatively short necks with noticeably large rounded heads, and stubby broad black bills. But mergansers have rather snaky heads and necks, with long slender bills which are reddish in large birds. When young, even as downy ducklings, whistlers tend to be a dull brownish-grey on the head and neck, but mergansers are a rather bright reddish-brown on these parts. The crest of long brown feathers on the back of the head and neck of half-grown and older mergansers also distinguishes them from whistlers, which have no such crest. The two kinds of ducks differ noticeably in behaviour. Whistlers move about less than mergansers when feeding, and are often seen tipping bottom up in typical barn-yard duck fashion. Mergansers often dive completely below the surface and swim some distance under water when hunting food. When alarmed a brood of young whistlers may bunch up, then swim off in a close flock, and if pressed are quite likely to hide along banks. Mergansers more than a few days old will move off more quickly and will literally get up and run on top of the water, even up or down swift rapids. They kick up wakes like so many small speed boats. Whistlers should not be shot.

All wild ducks in Canada come under protection of the Migratory Birds Convention Act. *Anyone proposing control must get permission from the proper*

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authorities. All persons actually doing the control should acquaint themselves well with the kinds of ducks on the area they are managing.

"CONTROL" IS MORE THAN JUST HUNTING

The key to useful control lies in the idea of *managing a body of water to get more fish.*

Mere casual shooting of mergansers as they are accidentally seen along a river or in front of an angling camp will not give control. Fish saved at that time will almost certainly be eaten by other mergansers later, perhaps in late autumn or early spring when no one is about. Such casual shooting is to be strongly discouraged. Only when control is planned on a systematic basis to extend over the entire season of open water does it offer promise of greatly increasing the numbers of fish in a body of water.

Mergansers are kept off streams in order to allow more salmon to live. This means that one should constantly be thinking of the job in terms of getting more salmon, not just of cutting down the mergansers.

Hunting mergansers is one thing, but keeping them off a stream completely enough to get more salmon smolts is another. We could properly think ourselves successful in hunting mergansers if we killed about a quarter of the birds encountered each time. But this might not give enough protection to assure more young salmon getting to sea. *The important thing is* not how many are killed, but *how many mergansers are left on the stream and for how long.*

To show a good result the hunter will have to be very conscientious about his work. He must not only do a good job of hunting, but, in order to know whether this is being done right, he must learn how to tell whether enough protection is being given to the fish.

One of the best ways of telling this is to keep dated records of mergansers seen on and removed from a body of water. From such records it is possible to estimate the success of a program in terms of protection given the fish. Good records should be regarded as one of the important tools of control.

Details of successful merganser hunting are not given in this text. These are matters which are best worked out individually by each hunter or team of hunters and for each particular bit of water. Hunters must, of course, be *good stalkers* and *good wing-shots*. They should be *able to learn* from their own experience and that of others. Two tools to be commended are patience, and the occasional use of decoys.

Above all, keep in mind that *long periods with no control or ineffective control can undo the entire effort which has gone before.*

DEFINITIONS

It often saves a great deal of time, and also helps to get ideas across more clearly, when for specialized subjects we use particular words to express certain ideas. So, in talking about the specialized subject of getting more young salmon to live in a river by keeping away their enemies, it will help if a few special words can be used to carry particular ideas. Nine words of this kind and their meanings are given below. They are, mostly, in the order in which they occur in this text.

Animal—the dictionary says, "a being with life, sensation and voluntary movement". Please do not think of animals only as warm-blooded, 4-legged animals. Worms, snails, insects, fish and birds are also animals, and we will use the word here to cover all these forms.

Control—one meaning given for this word in the dictionary is "restraint", and this is the meaning used here. For us it will mean keeping mergansers off a stream well enough that the few that manage to do some feeding on the stream in spite of patrols will not be able to do serious damage to the stocks of young salmon in that stream.

Management—the dictionary meaning that fits here is "to handle". "Fisheries management" or "salmon management" would include such things as laws governing protection and the enforcement of those laws; making fishways or otherwise clearing away obstructions to salmon movements; planting hatchery stock. Clearly, control of natural enemies of the fish will also be a form of management.

Production—our dictionary meaning is "bear" or "yield". We are all familiar with the idea of production from a factory, or a farm, or even the production of hay or grain from one field of a farm. By good management we can increase production. But we must know what we are about. Planting more seed is not always the answer. An acre of good land will produce more oats if seeded at 1 to 2 bushels per acre than if seeded at 10 bushels per acre. With too heavy seeding the young plants tend to smother themselves and we end up with a smaller crop than if we had seeded properly. A salmon stream is just some rather stony land covered by flowing water. It can produce just so much plant life which in turn can support just so much animal life per acre. With good management we can get the most production from our underwater "field". But to accomplish this we must know enough about production possibilities of our "field" that we do not either expect something impossibly large or settle for something far below what we might get. We must also know what form of management to apply and how to apply it.

Prey—the dictionary meaning we shall use is "animal hunted or killed by another meat-eating animal for food". We speak of mice, rabbits and partridges as the prey of foxes, bobcats, hawks or owls. Insects living under water are a common prey of trout and salmon. Young salmon, along with other fish, are prey of mergansers. "Prey" can also be used as a verb, to mean taking other animals for food.

Predator—this useful word will probably not be found in the dictionary, but a closely-related word, "predatory", may be there. It is a rather new word and is now used quite widely to mean "an animal which eats or preys upon other animals".

Predation—the nearest relative you will probably find to this word in the dictionary is "predacious". Predation is "the act of preying upon or eating other animals".

Residual—means "left over". Toward the end of this outline we shall discuss "residual predation", meaning particularly the amount of fish (especially young salmon) eaten by the mergansers which are able to feed on a stream in spite of control measures.

Merganser-day—this technical term is very useful for measuring the amount of predation. A merganser will eat, on the average, about 1 lb of fish a day. This amounts to about 30 parr, taken as they come for size. Thus, a merganser-day might be used to mean the number of fish one bird removes in one day. (Most of us are familiar with a similar term, "man-hours" of work, which may be used to mean either 1 man working for 1 hour, or the amount of work 1 man does in 1 hour.) There will be 10 merganser-days of predation on a stream when 1 merganser is present for 10 days or when 10 mergansers are there for 1 day.

WHAT CONTROL OF MERGANSERS CAN DO FOR SALMON

Control of mergansers has been shown to be one of the most promising kinds of salmon management. It can make a stream produce up to 5 times as many smolts as without control, perhaps even more. In many areas it may even be *the most important form of management* because if young salmon are increased by other means, such as protecting more spawners, or planting more hatchery stock, it is still possible for mergansers to eat nearly all of them before they get to sea as smolts.

MERGANSER CONTROL IN A NUTSHELL

Control of mergansers, for convenience "merganser control" or "bird control", is obtained by patrolling with shotguns the particular stream that is to be managed. This should be done as often as can be arranged, up to twice a week. Patrolling may be done on foot, by canoe or by other means. As many mergansers as possible are shot during patrols, and others are scared away, at least for a while. A good control man will probably learn to kill about one-fifth to one-quarter of the birds on his beat of a stream. But birds only scared away may come back, or other mergansers may come to the stream at a time when there is no patrol. What these birds eat is the residual predation mentioned above.

Now on 55 acres of an average Maritimes salmon stream, 750 to 900 merganser-days of predation is enough to cut young salmon down so that they are scarce. This is the amount of predation performed by 3 mergansers present throughout the open-water season on a stream 15 miles long and 10 yards wide (about 55 acres of stream bottom).

In fact, with this amount of predation salmon parr will be so scarce that unless there are much greater numbers of other suitable fish present, a flock of mergansers hardly finds it worth while to stay around for very long—they can easily fly a bit farther to better hunting.

But if, by control, the residual predation can be cut down to 250 or 300 merganser-days, then the river will support all the parr that can over-winter in it to become smolts and go to sea the next spring. This level of residual predation is what would be present if there were just one bird for each 15 miles of stream 10 yards wide throughout the open-water season.

Studies on a number of Maritime streams have shown that mergansers are often found at an average density for the year of nearly 10 birds on a 15-mile-long by 10-yards-wide section. This means that there could be up to 2500 or 3000 merganser-days of predation on such an area.

If we think about numbers of birds, this means that for each such area the natural average of about 10 birds must be reduced by control to 3 birds *before* any real good can be done on the stream we are attempting to manage. Then, in order that the management can give some result, the average of 3 birds must be further cut down. Beyond this point every little bit helps a lot. If we can cut the figure to 1 bird, all possible good will be done and it would be a waste of effort, for this stream, to attempt still more control.

The figures given above are *averages* for the entire open-water season. In practice, it would be far more likely that several birds might come at once. For example, suppose a flock of 10 birds comes 2 days before the next patrol and stays until the patrol. They will put in 20 merganser-days of predation. This uses up 18 more merganser-days than the allowable amount on those 2 days. So to balance this there will need to be 18 days with *no* mergansers on this area.

The rule-of-thumb, then, for successful merganser control is as follows:

With no control, a stream giving average production of young salmon may be visited by mergansers at an average rate of about 10 birds for each 15 miles length $\times$ 10 yards width (= 55 acres) of stream.

Before bird control can give an increase in the smolt production from a particular crop of young salmon these 10 birds must be reduced to fewer than 3 birds.

As the birds are reduced from 3 to 1 per year, salmon production will rise higher and higher.

Reducing the birds below one would give a few more parr, but the stream will probably not be able to support these through to smolt stage, and they will die from other causes. Until more is learned about these other limitations, there is not much point in trying to keep mergansers below the standard of 1 bird per 55 acres of stream.

PRINCIPLES OF PREDATION AND HOW THEY APPLY TO SUCCESSFUL MERGANSER CONTROL

The previous section gave a rule-of-thumb for applying merganser control to protect young salmon and thus increase the production of salmon from a stream.

Some readers may wish to think the situation through for themselves. Certainly the background of biological facts which justifies this particular kind of predator control is a rather complicated one. If you would like to understand the basic principles better, this section can help to guide your thinking.

Weaknesses of Some Systems of Control

Control of mergansers for salmon management is a form of predator control, the merganser being the predator and its prey young salmon. Studies of predator control, in livestock raising as well as in fish and game management, have shown that control is seldom as simple as it may appear at first glance.

In the public mind payment of bounties often seems the best way to control predators. But experience has shown time and again that bounty payments seldom produce the desired degree of control. As a home-grown example of this, New Brunswick had a bounty on porcupines (as a "predator" on trees) for years and still pays bounties on bears and bobcats[1]. But the records show that over a long period of years about the same number of bounties have been paid out each year. In other words, this control simply harvested an excess "crop" of the predators but did not reduce their general numbers enough to make them noticeably scarcer, except perhaps in local areas. This is typical of most control by bounties. On the cattle ranges of western United States it was found that employing professional hunters gave far better control of wolves and other predators than bounty payments. It is important to realize that predator control seldom exterminates the predator. In fact, complete extermination is usually not necessary, and may even be undesirable.

One difficulty with the bounty system and with other systems of predator control is that they may fail to take account of some important biological principles relating predators to their prey. Unless the nature of the particular relationship between predator and prey is understood, control of the predator becomes guesswork. It is purely a gamble whether the operations will disrupt the relationship in favour of the prey. Unfortunately the operations may be expensive, and the stakes excessively high.

When a predator–prey relationship is thoroughly understood, it then becomes possible to define the way in which effective control must affect the predator. The element of gambling can then be largely removed. The costs of a necessary program can be balanced against the probable gain. A reasonable decision can then be made about whether or not to attempt a particular predator control program.

Basic Types of Predator–Prey Relationships

When it is suggested that predator control may give useful benefits, the idea that increased numbers of the desirable animals will have more value, in dollars, than the control costs is included almost automatically. In other words, numbers are being considered. The number of predators present, the number of prey the predators will eat, and the number of prey present are good starting points.

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[1]These bounties were removed in 1961.

NUMBERS AND MOBILITY OF PREDATORS

The number of predators present will tend to come under one of two conditions.

CONDITION 1: The number of predators will be more or less constant. This tends to be the case with animals living within a rather well defined home range. Examples are predacious fish like trout, eels, pickerel, bass and the fresh-water cusk or ling, as it is sometimes called. Condition 1 would also include many warm-blooded predators like mink, otter, bears, bobcats and some birds under particular circumstances. Kingfishers throughout the season, and young mergansers before they can fly, come in this last group.

CONDITION 2: The number of predators may be quite variable, increasing or decreasing quickly. Such predators must be capable of moving rapidly from one feeding area to another distant one. Some birds which can easily fly long distances tend to be predators of this kind. Mergansers when able to fly are an excellent example of Condition 2 predators.

NUMERICAL PREDATOR–PREY RELATIONSHIPS, AND NUMBERS OF PREY

A very important aspect of predator–prey relationships is the total numbers of prey which the predators present can eat. Still more important is the proportion that these victims constitute of the total prey animals present. That is to say, it may make a great deal of difference whether the predators take 1/10 or 9/10 of the prey animals.

When predators are present in more or less constant numbers (Condition 1), their demands on the prey animals will tend to come under Type A or Type B, below.

TYPE A PREDATION. First, the predators may take a more or less *fixed number* of the prey, this being all they require for food. Let this be called Type A Predation, following the lead of Dr W. E. Ricker, a Canadian authority in this field of fish population dynamics. Warm-blooded animals that tend to occupy home ranges will usually exert this type of predation on their prey population. This is because they are restricted in range and their food requirements from day to day tend to be constant. Examples of Type A predators would, under ordinary circumstances, be most of the mammals mentioned above, like mink, otters, bears, and so on. Hawks and owls would probably also come in here most of the time; so do kingfishers, as a rule. *Young, flightless mergansers confined to their rearing stream and adjacent waters tend to be examples of Type A predators*, although if sufficiently abundant they may verge into Type C (see below).

TYPE B PREDATION. In Type B predation, instead of taking a fixed number of the prey, a given number of predators take whatever they encounter and so get a *fixed proportion* of the prey animals present during a season. That is, the predators may take 1/10, or 1/4, or 1/2 of the prey, depending on how often one of the predators encounters and captures one of the prey. This type of predation with a given number of predators present is more likely to occur when the predators are able to get along well on quite variable amounts of food from day to day. The predacious fishes mentioned above offer familiar examples of Type B predation. They can eat a lot of food in a day or can get by with little or none, depending on their good fortune.

When the number of predators is able to change quickly and perhaps greatly (Condition 2), still a third relationship is likely to be present.

TYPE C PREDATION. When the number of predators can increase or decrease readily, there is no limit to predation set by the appetite of individual predators (as there is in Type A), or by the frequency of contact between predator and prey (as in Type B). In this third type the prey are removed down to a certain minimum number where it is no longer worth while for the predator to hunt the prey out, so he moves elsewhere. *This Type C predation tends to be the relationship between mergansers which can fly well and young salmon parr in the streams where mergansers feed.*

WHAT MERGANSER CONTROL INVOLVES

Thus mergansers can exhibit two types of numerical relationship to the young salmon, their prey. In the one situation a given number of flightless young birds requires a given number of fish per day from their rearing stream (Type A). The other situation involves a variable number of birds which may remain on a stream, or keep returning to it, until the fish are eaten down to such a low level of abundance that a day's fishing doesn't give the birds enough to eat (Type C).

These two situations require somewhat different approaches from the point of view of getting control of the birds.

In the Type A situation, for every bird removed a number of fish will be saved equivalent to the bird's food requirements for the balance of what would have been its normal stay on the stream. This Type A situation is the condition usually imagined when the subject of predator control is discussed.

Unfortunately, in the relation between mergansers and salmon the Type C situation develops *after* the Type A situation has run its course. So any young salmon saved from the broods merely become that much more food available to attract and feed so many more older mergansers. This is so, of course, only if there is not sufficient control over the Type C situation (flying birds in autumn, winter and spring). But, and this point is very important, studies over a long period of years have shown that the more young salmon there are in a stream, the more mergansers will come and feed on that stream. This explains why control needs to be really thorough, if it is tried at all, in order to increase production of smolts.

In order to gain control over the Type C situation, it is necessary first to reduce the mergansers to a more or less fixed number, that is, bring them down to the Type A situation. Even then, before any benefit can be achieved, they must be further reduced in number. They must now be taken below the point where residual predation would leave only the number of parr that makes it hardly worth while for the birds to stay. This would still leave about the level of parr abundance that Type C predation leaves anyway. Only as this point is passed does control really begin to have a useful effect.

To understand this last point we must remember that without any control far more mergansers will come to a stream, over the year, than it can possibly supply with enough food. They may stay while feeding is moderately good, but then move on.

Standards for Effective Control

On the basis of studies that have been made by the Fisheries Research Board of Canada and by the Canadian Wildlife Service in both New Brunswick and Nova Scotia, it is possible to give some figures to serve as a useful guide in attempting merganser control.

Taken as averages for the entire open-water season on ordinary to good salmon streams, *without control, mergansers commonly occur at a rate of 5 to 10 birds for each 15 miles length and 10 yards width of stream*, with the higher rate being close to the average value observed. This average is based on total young birds in summer plus older birds throughout the year.

On Maritime streams giving average salmon production, *control which reduces mergansers to a density of 3 birds per 15 miles length and 10 yards width is unlikely to give a noticeable increase of smolts over the uncontrolled situation; but as the birds are reduced below this level, larger and larger benefits will be obtained.*

With complete merganser control a stream can raise many more parr than it can hold over their final winter to become smolts. Because of this surplus potential parr production, *a little* merganser predation does no harm. *The maximum benefit* from merganser control *is likely to be obtained when mergansers are reduced to a level of 1 bird per 15 miles of stream 10 yards wide.* Reduction to this level of "residual predation" (see below) by mergansers should be the present aim of merganser control programs.

Residual Predation: Its Importance and How to Estimate It

Residual predation is the amount of predation remaining in spite of the effort to remove the predators. It is also the factor which determines the success of merganser control, as has already been explained.

Now the tax which any single merganser levies on the parr population of a stream will be governed by two things. These are the number of parr that he eats in one day and the number of days that he spends on the stream. Thus we use the term "merganser-day" to mean the average number of fish which one merganser will eat in one day. If a merganser were to eat only salmon parr, one merganser-day would mean that about 30 yearling and older parr were eaten.

The figure given above as a satisfactory standard for control was derived from the normal production of young salmon parr in a number of Maritime salmon streams. The next step was to calculate the predation loss in terms of merganser-days, which such a population of parr could stand without being reduced below the minimum number needed. This minimum number is the number of parr that can over-winter in the stream to become smolts next spring, when intensive bird control is employed.

It follows from the above that in attempting control of mergansers to achieve greater salmon production *the one most important factor governing success is the amount of residual predation.* This can conveniently be measured as the number of residual merganser-days. Put in another way, it matters very little how many ducks are killed in the course of control operations except in so far as this killing reduces residual predation to an acceptable level.

To get a really accurate measure of residual predation would require daily inspection of the entire salmon-rearing area of a stream throughout the whole of every day and all year long. Such an aim would clearly be impractical. However, it has been found by experience that patrols twice a week, and if necessary at times even once a week, can give useful control and a worthwhile estimate of residual predation. The procedure is to assume that any birds seen on one patrol, but not seen on the patrol before, have been on the river for half of the time between the two patrols. If a number of birds are seen but not killed on the first patrol and the same or a greater number are seen on the second patrol, it must be assumed that the first number stayed on the stream all the time between patrols, but that any new birds were only on for half the time.

An example will help to make this clear:

Date of patrol	Days since last patrol	Mergansers		
		Seen	Killed	Left on
Nov. 15	. . .	12	5	7
Nov. 20	5	15	2	13

7 ducks left on for 5 days = 35 merganser-days
(15 − 7) = 8 ducks on for 5/2 days = 20 merganser-days
Total predation since last patrol = 55 merganser-days

Had the patrols been 10 days apart instead of 5 days, the calculated residual predation would have been twice as great, or 110 merganser-days. In a stream where young salmon are the dominant fish, 5 days with the above number of mergansers present would result in the loss of over 1500 parr. For a 10-day period, the loss is more than 3000 parr (remember, 1 merganser-day = about 30 parr).

We indicated earlier that effective control of mergansers on salmon streams means having only 1 bird left on each 15 miles of stream 10 yards wide. This is based on a bird being present throughout the open-water season of 8 to 10 months, and is equivalent to some 250 to 300 merganser-days of predation on such an area. One bird per 15 miles is an easier standard for the average person to picture than is the one defined in terms of residual merganser-days. Nevertheless the latter does provide a more flexible and more fundamental standard.

In conclusion, it should be fully understood that control of mergansers as a form of management for salmon streams is like any other form of management. To bring the desired results it must be subjected to constant scrutiny and assessment in each place where it is applied. It cannot be regarded as a simple and pleasurable little diversion which will bring in great returns for almost no investment of effort. Its success depends, as should be clear from this account, on the careful adjustment of biological balances. Attempted improperly and without understanding, it is altogether likely to bring in little or no returns for a considerable cost in effort and loss of wildlife. Approached intelligently, it is one of the most promising tools available for increasing salmon stocks. For many streams it may well be an essential form of management before other methods of conservation which concern the freshwater stages of salmon can have any hope of success.

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