FISHERIES RESEARCH BOARD OF CANADA

MANUSCRIPT REPORTS OF THE BIOLOGICAL STATIONS

No. 439

Title

A Report on the Eel Investigation for 1950-51

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1951

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by

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Introduction

The writer has been employed by the Atlantic Biological Station during the summer and winter of 1950-51 to investigate the eel (*Anguilla bostoniensis* LeSeuer) in New Brunswick streams.

This report describes the work accomplished to date (March, 1951), and also discusses the significance of various observations made, both as they contribute to the knowledge of the life history of the American eel, and as they are pertinent to the objectives of the investigation.

For several years a number of Canadian fisheries biologists have felt that the presence of the eel in salmon streams constituted an inter-specific relationship that needed closer study in the interests of the enhanced propagation of the Atlantic salmon. Impetus was given to the desire for such an investigation when, in 1949, the introduction of the electro-fishing technique revealed the eel present in New Brunswick streams in unsuspected abundance.

The Petitcodiac river district was selected for this study to allow it close associations with current investigations of the Atlantic salmon.

A great deal of scientific attention has been given the European eel (*A. anguilla* L.), chiefly on the strength of its commercial importance; but a comparable interest in the American eel has seldom been shown, since it constitutes only a very minor fishery.

The specific concern of the investigation is based upon the reputation of the eel as a predator and competitor of other fish. These charges, or suggestions, occur frequently in both Canadian and European freshwater fisheries publications, and have been similarly directed towards the New Zealand long-finned eel (*A. dieffenbachii* Gray). Furthermore, popular opinion frequently ranks the eel as the dominant fish species, both in numbers and activity, in the lakes and streams where it is more eaily observed; and rightly or wrongly, such opinion has doubtless added to its characterization as a major hazard to the survival of more valued fish.

The freshwater life of the catadromous eel commences when, in the spring, as an elver, or tiny, transparent eel, it enters the rivers and streams from estuarial waters. These elvers may move considerable distances up stream and some enter lakes. They are reputed to be able to surmount almost any barrier or to enter "inaccessible" places.

The eel remains a varying number of years in fresh water, finally, according to Schmidt (1922), returning to the sea to spawn and die.

Some eels may enter fresh water only later in life, or perhaps return early to the estuaries. In any event, there have been observations of populations

of feeding, yellow eels in estuaries and in coastal salt waters (Menzies, 1932). There are also records (see later) which indicate that certain eels may leave the estuaries or salt water to hibernate in fresh water during the winter.

The eel perhaps begins its predatory role within two years of entering fresh water, or as soon as it is large enough to feed on the eggs of fishes. When it comes most seriously offensive as a predator upon salmon, will obviously depend upon its numbers, and upon the ecological niche it is maintaining in the salmon stream.

As a potential competitor for the food of the salmon, the eel becomes active, possibly from the moment it enters the salmon streams.

One of the main objectives of an eel investigation must, therefore, be to define the niche, or series of niches which the eel occupies in the stream, since its relation to the salmon, as either a predator or food competitor, will be governed by its ecological and physiological needs and limitations.

The general aim of the eel investigation may be stated as follows - to determine the relations of the eel to the salmon throughout their freshwater phase, and if these are deemed serious, to institute means to protect the salmon.

Distribution of the eel in Petitcodiac streams

Eels were found in every stream (ca. 25) where it was possible to use the electro-fishing apparatus. They have been reported for many other streams of the district, and indeed are probably present in every accessible stream in the province.

In Albert County, there are several brooks (e.g. Forty-five and Salmon rivers) where, according to report, no eels are present in the upper reaches. In each of these cases series of dams or falls, or both, have apparently prevented their further penetration up stream. Similar instances of either scarcity or absence of eels in streams above falls or dams have been reported by Cairns (1942C), Hobbs (1948), and Greeley (1935).

Several Petitcodiac streams, or sections of such streams, had very few eels. Those noted were the Lee brook, Salmon Hole creek, and a small unnamed brook, all tributaries to the Pollett river. No eels were found in several hundred yards of the upper Mitton brook, a small tributary to the Coverdale River. One of the pertinent characteristics of these streams was that they were colder waters than those in which eels are usually abundant; this condition in turn perhaps accounting in part for the fact that they had relatively large numbers of small brook trout and sculpin. These streams might be termed "trout" rather than "salmon" streams.

The suggestion that cold-water temperatures may act as a physiological barrier to the further freshwater distribution of eels, is supported by other evidence which is discussed in a later section of this paper. The practical importance of the observation lies in determining the extent to which the physico-chemical characteristics of the environment are common to the needs and capacities of eel and salmon.

Abundance of eels in streams

Method

The numbers of eels in sections of streams were determined by electro-fishing. The two generators used throughout these investigations were of the D. C. type. In most cases, estimates have been based on collections of eels made by a single, thorough shocking of a stream section of known dimensions. Repeated electro-fishing of the same section was carried out on two streams.

Efficiency of electro-fishing for eels

Section of the Nigus and Bennett brooks were thoroughly electro-fished several times. The efficiency of the method can, therefore, be determined by comparing the catch of the first effort with that of the total of several efforts. The assumption is made that all eels were removed, and that movements of eels into or out of the section had been negligible.

The results of three successive, thorough shockings of 100 yards of the upper Bennett brook are tabulated below. The average width of the stream was approximately 3 feet, and the average depth 6 inches. Two hundred and four eels were finally removed; the first collection of 138 thus representing 67.6% of the total catch, or, in other words, about two thirds.

Collection No.	Date	No. in first 50 yds.	No. in second 50 yds.	Totals
1	23 August	71 (66.3%)	67 (62.6%)	138 = 67.6%
2	24 August	17	23	40
3	29 August	19	7	26
		107	107	204

The lowermost 625 yards of the Nigus brook were repeatedly electro-fished, and the numbers of eels taken on each occasion in each 50 yards were recorded. The average stream width was about 6 feet and the average depth 8 to 12 inches during the collections. Eels smaller than 90 mm. were numerous in the stream, but were not taken. The attempt was made to collect and measure all eels 90 mm. and over. Table 1 summarizes the results.

These results indicate a fair degree of uniformity in efficiency of collection, and a value of approximately 64 per cent efficiency for the first shocking.

The type of stream bottom was fairly uniform throughout, but small sections did differ from the average condition. In such cases, the numbers of eels present varied from the normal abundance and were reflected in the efficiency of catch for their first shocking (see, for example, section 600-625 yards, where the stream bottom was an even bed of gravel and small stones, and was easily fished).

Table 1

Section (yards)	Collection #1 August	Collection #1 % of total	Collection #2 August	Collection #3 September	Collection #4 October	Totals
0- 50	40	54	11	18	5	74
50-100	56	72	16	6	0	78
100-150	60	57	30	12	3	105
150-200	64	57	27	15	6	112
200-250	60	56	28	15	4	107
250-300	62	50	32	25	3	122
300-350	89	61	42	13	2	146
350-400	50	62	11	17	3	81
400-450	63	66	13	19	1	96
450-500	126	73	34	13	0	173
500-550	111	80	19	6	1	137
550-600	64	57	38	8	2	112
600-625	45	87	6	1	0	52
Totals	890	64	307	168	30	1395

The results for the Bennett and Nigus brooks were very similar, being 68 per cent and 64 per cent efficiency respectively.

These were small streams, and their physical characteristics differed in many ways from those of the Pollett, Coverdale, and Turtle rivers. However, provided that corresponding effort of electro-fishing is maintained on larger streams, a thorough, initial shocking in a larger stream should take a similar proportion of the eels present. Deep water especially limits the efficiency of electro-fishing, since, besides hindering personnel, the resistance to the passage of the electrical current increases with the depth of water.

From the results of these experiments it is perhaps safe to state that in shallow streams (up to two, or two-and-a-half-feet) a single, thorough shocking will take about two thirds of the eels present.

Numbers of eels

Eels were collected from sections of the Pollett, Coverdale, and Turtle rivers by salmon investigation crews, and by the writer and an assistant from the Nigus and Bennett brooks. In the case of the first three streams, single shockings were made, whilst for the other two streams eels were taken in repeated shockings, as has been mentioned above. The actual numbers of eels taken have been listed in Table II and no efficiency factor has been employed.

Almost every eel present there must have been taken in the Bennett brook section. In the Nigus brook no attempt was made to take eels under 90 mm. Collections from the three rivers were biassed in favour of larger eels and in particular missed the smallest eels present. This statement is based upon the writer's own observations and is partly borne out by the accompanying size-frequency histograms. The need of recognizing these facts lies in the importance of the relationship between the sizes of eels and their interaction with salmon.

Table II. Numbers of eels electro-fished from sections of five streams.

Date	River	Width yds.	Area sq. yds.	Length yds.	No. of eels	No. per 100 yds.	No. per sq. yd.	No. per acre
June 13	Up. Coverdale	12½	812	65	52	80	.064	310
14	Lwr. Coverdale	22	1100	50	179	358	.163	788
15	Lwr. Turtle	13	650	50	131	262	.202	976
15	Up. Turtle	8	400	50	144	288	.360	1742
	Pollett River							
15	Scott's	14	476	34	70	206	.147	712
July 28	Babcock	18	936	52	123	237	.131	636
29	Mapleton	12	720	60	91	151	.130	612
31	Elgin	24	1440	60	122	203	.085	410
Aug. 2	Blakeney	22	1100	50	76	153	.070	334
3	Barry	33	1100	33	154	462	.140	678
3	Barry	33	1650	50	238	476	.144	698
4	Thorne's	28	924	33	176	528	.180	922
4	Thorne's	28	980	35	145	414	.148	716
Aug. 24-29	Bennett	1	100	100	204	204	2.040	9874
Aug.-Sept.	Nigus	2	1250	625	1373	220	1.098	5316

These data may also be grouped as in Table III which allows a more direct comparison of the five streams. The figures still, however, refer to small sections of the streams.

Table III. Estimates of numbers of eels present in five streams.

River	Width yds.	No. per 100 yds.	No. per sq. yd.	No. per acre
Bennett	1	204	2.04	9874
Nigus	2	220	1.10	5316
Turtle	10	275	0.262	1268
Coverdale	17	201	0.121	585
Pollett	23	294	0.133	620

The errors involved in such estimates are appreciated; nevertheless, the values determined for each stream vary sufficiently and consistently enough to be of likely significance.

Discussion

Hobbs (1948), with reference to the New Zealand long-finned eel, has admitted that what determines the density of populations attained in different easily-accessible streams, is not known; but he suggests that the type and amount of "cover" available is of greater importance to eels than to trout. Observations of the eel in New Brunswick streams tend to support the suggestion.

Eels live a semi-subterranean life, and though specific data are lacking at this time, the writer has frequently noticed that larger eels, when they are found in streams, are usually in sections where the stream bottom is of boulders and larger stones; whilst smaller eels are typically found among smaller stones and in a bottom of gravel and small pebbles.

These observations were made whilst electro-fishing for eels, when they could be observed struggling out of the stream bed towards the positive electrode. During the collecting of eels from the Pollett, Coverdale and Turtle rivers, it became a habit of the crew to direct the electrode towards large stones for larger eels and to anticipate small eels from gravelly riffles and among small stones.

The size-distribution of eels will also, of course, be affected by other factors (physico-chemical properties of the water, food availability, migrations), but the type of stream bottom can directly limit the numbers and sizes of eels present in a stream, and in this way modify the inter-specific relationship of eels and salmon.

Sizes of eels in different streams

Results

Most of the eels collected from the Petitcodiac rivers last summer were measured by the writer within a few hours or days after having been killed and preserved in formalin.

The eels were measured from the snout to the tip of the caudal fin for total lengths.

Size-frequency histograms of samples of eels from the various streams are given in figures 1 to 5.

The mean lengths of eels from the five streams were as follows: Bennett brook (N=173) 159.0 mm., Nigus brook (N=1373) 168.0 mm., Turtle creek (N=527) 179.7 mm., Coverdale river (N=603) 162.4 mm., Pollett river (N=1442) 198.2 mm.

As already stated, the Bennett brook collections took perhaps all of the eels present in 100 yards of the headwaters of the stream. Numerous small eels or elvers, less than 90 mm. were not collected in the Nigus brook, a condition which is reflected in the histogram for this stream (fig. 1).

Four of these rivers (i.e. excluding the Bennett brook) are direct tributaries of the Petitcodiac river; but whereas the collecting area for the Nigus was immediately adjacent to the main river, those of the remaining streams were removed from it by a varying number of miles. This accounts for the numerous elvers present in the Nigus as compared to the other streams. A useful comparison of the sizes of eels present in a small and a large stream can better be made, therefore, by comparing the frequencies of size groups above, say, 120 mm. This has been done, on a percentage basis, for the Nigus and the Pollett, as shown in figure 6. This comparison demonstrates that the smaller stream had relatively more small eels (say up to 16 cms.) and fewer larger eels. The converse holds true for the larger stream. It has been suggested above that the density of populations of eels is governed in part by the physical characteristics of the stream bottom and this in turn influences the sizes of eels present, as it provides suitable territory for them.

The largest eels were taken in the Pollett river, but very few eels with a total length greater than 35 cms. were found in any of the streams.

Discussion

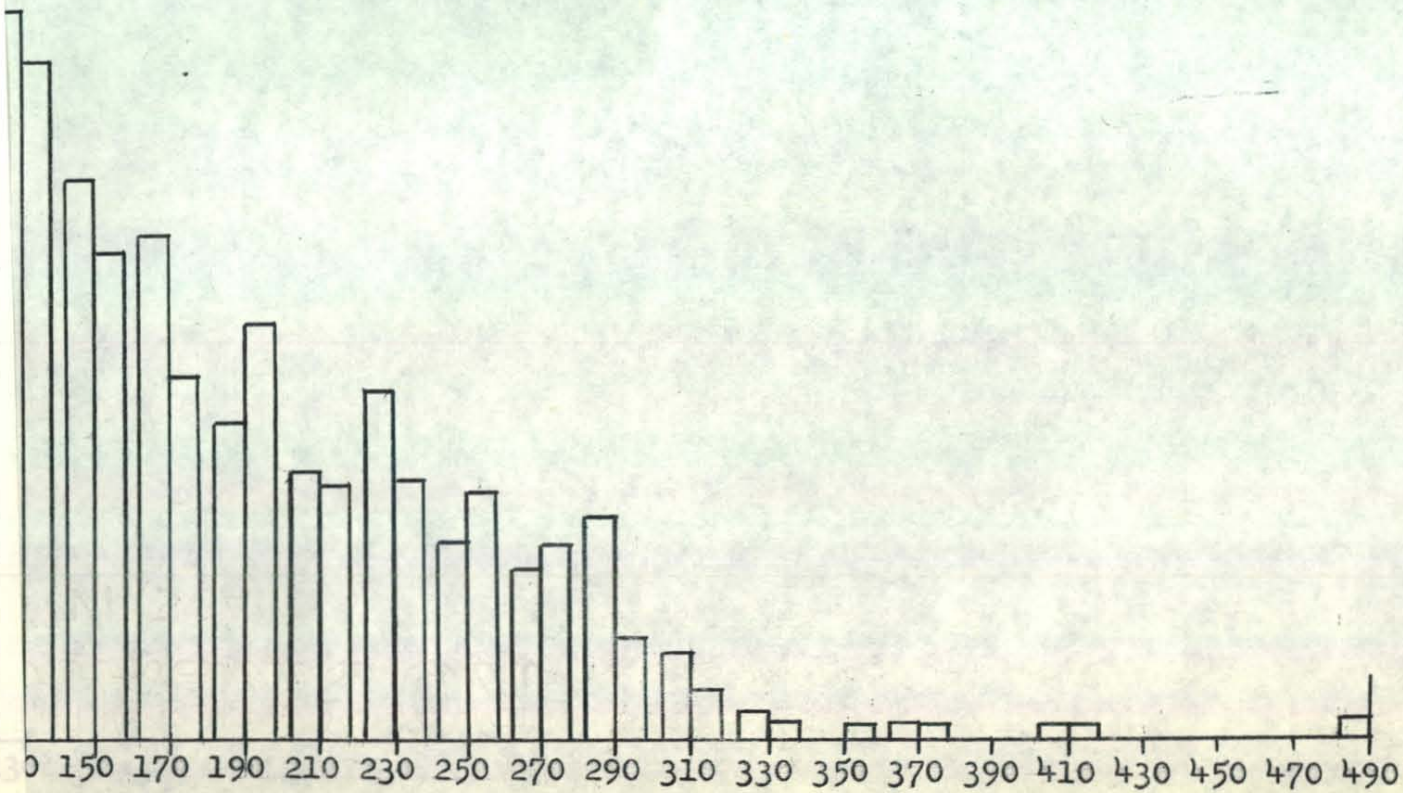
The size-distributions of eels in streams can be determined fairly readily from sampling by electro-fishing.

The value of such information should be acknowledged in view of possible critical phases in the relationship between salmon and eel, which may be determined by the size of the latter.

There are other important aspects in the knowledge of the sizes of eels present, as would exist, for example, in the event of the adoption of an

Size-frequency distribution of 1371 eels removed from lower 625 yards of Nigus Brook; August-September, 1950.

Note: Eels less than 90 mm. total length were numerous, but were not taken.



Total lengths - 10 mm. classes.

Fig. 2. Size-frequency distribution of 1373 eels taken in seven sections of the Pollett River; summer 1950.

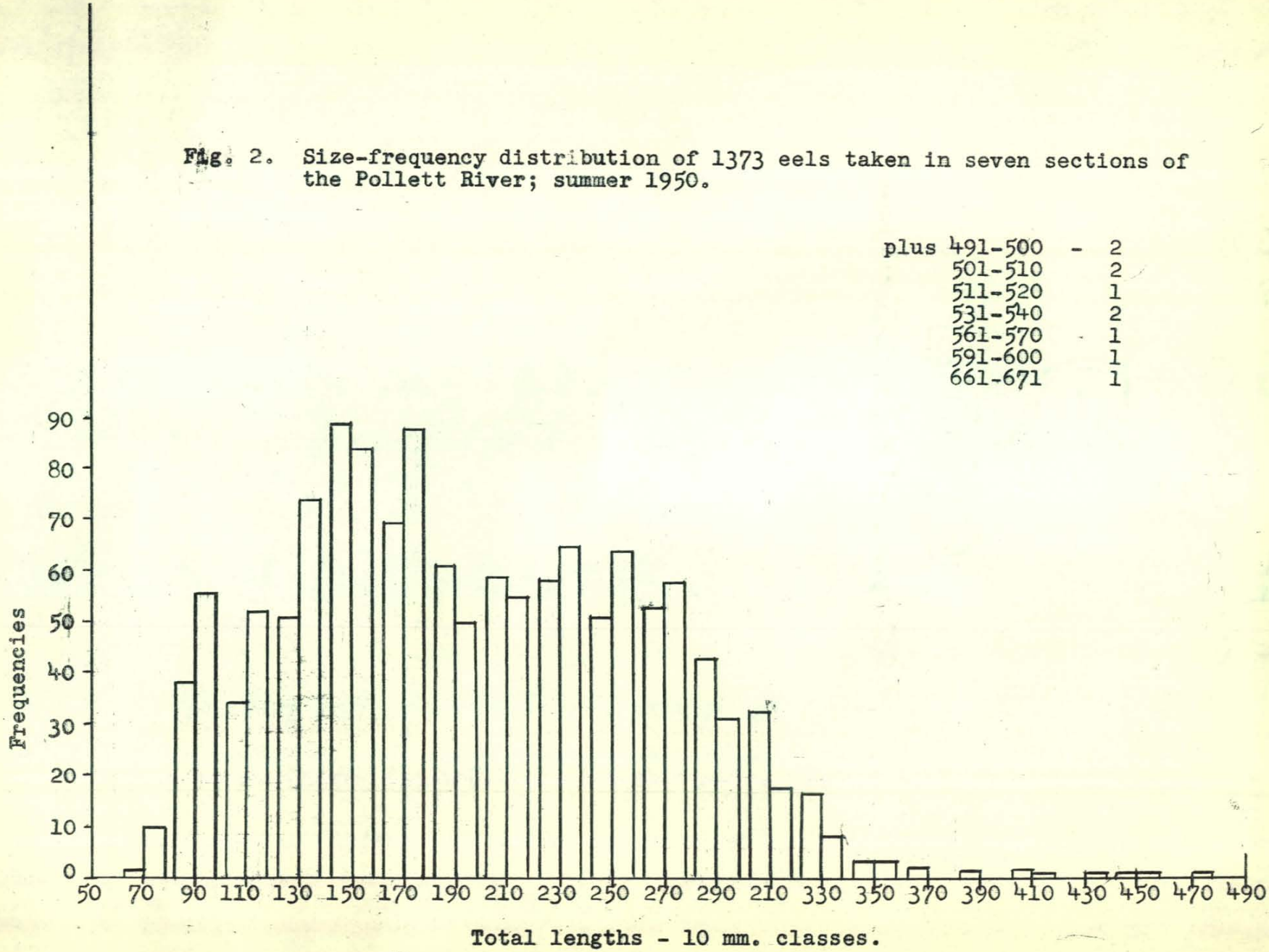


Fig. 3. Size-frequency distribution of 603 eels taken from the two sections of the Coverdale River; summer 1950.

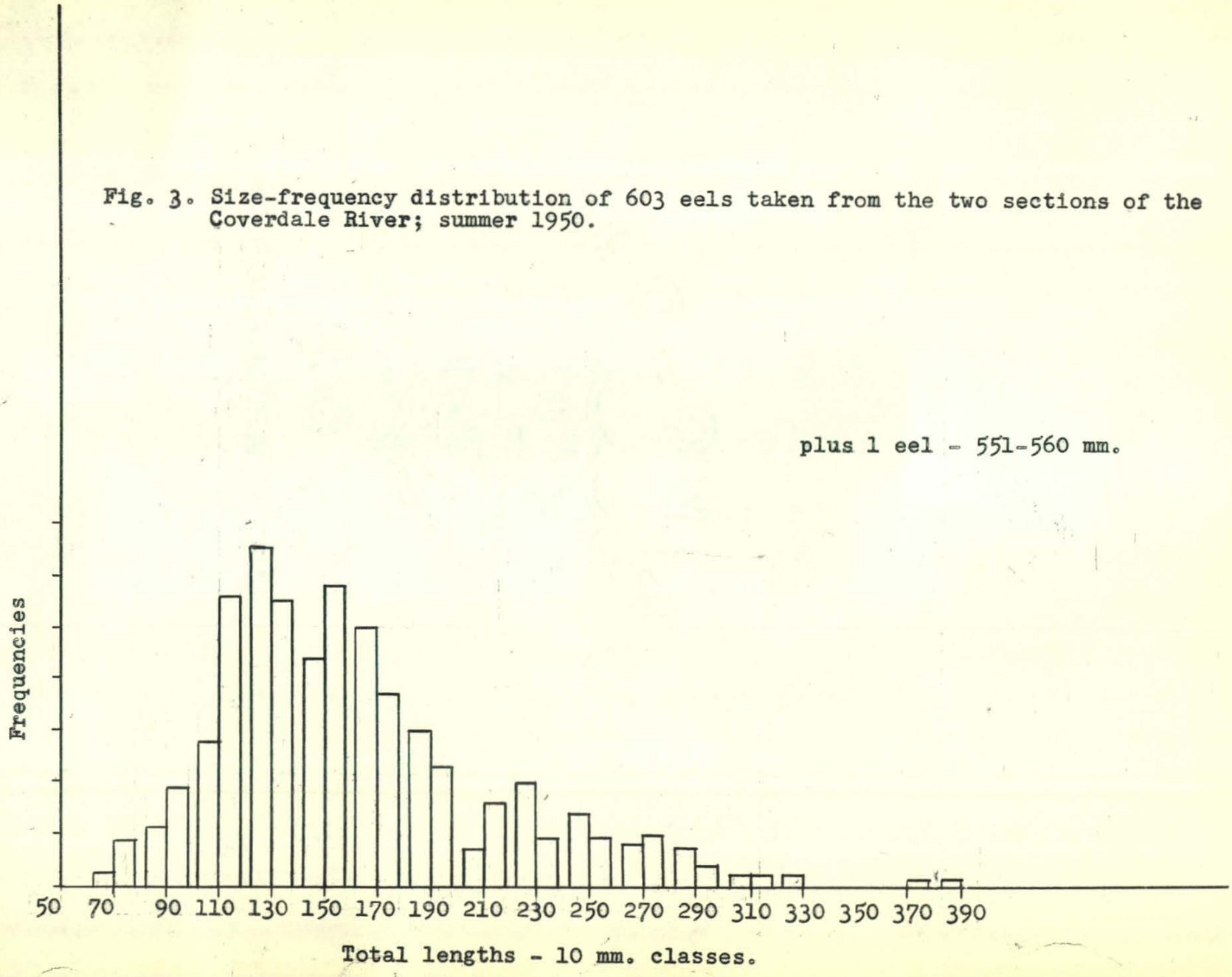


Fig. 4. Size-frequency distribution of 173 eels taken in the Bennett Brook; Summer, 1950.

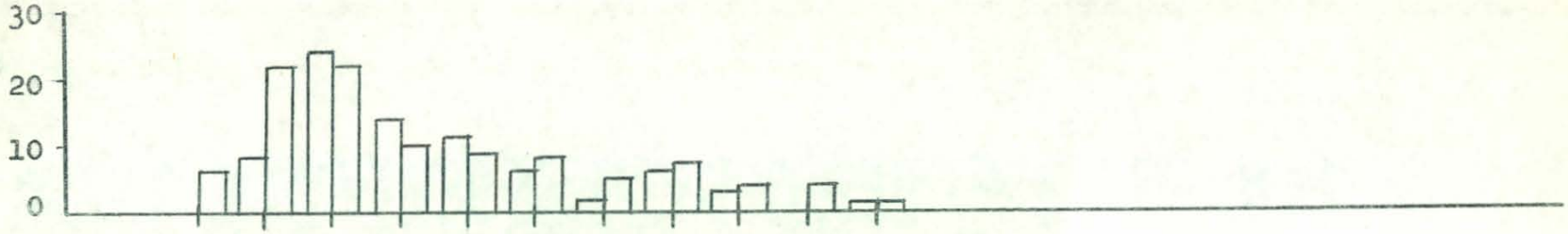


Fig. 5. Size-frequency distribution of 527 eels taken in two sections of the Turtle Creek; Summer, 1950.

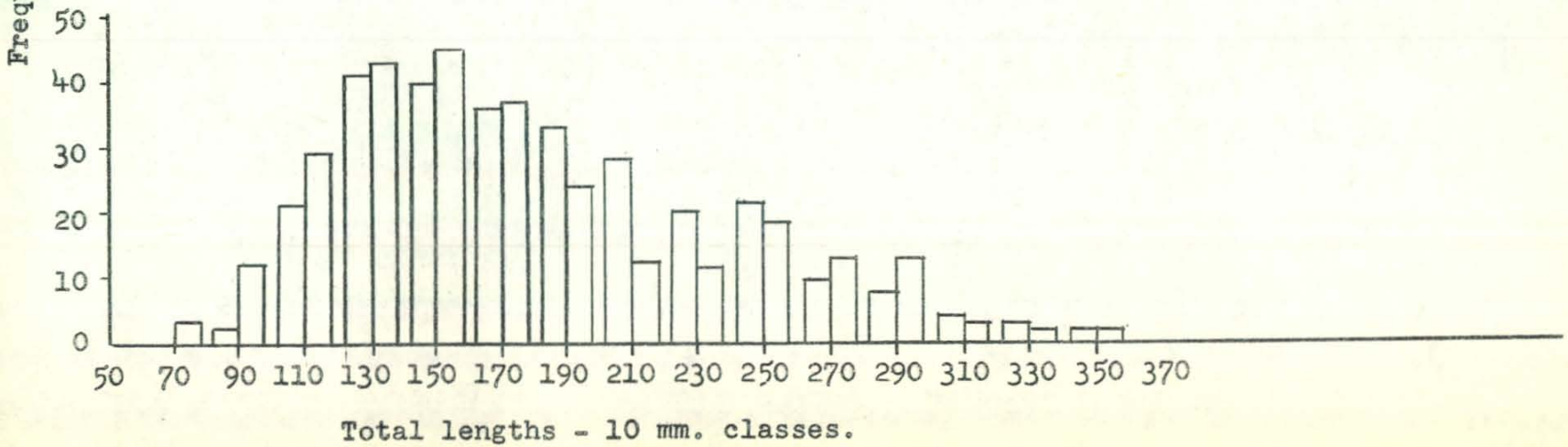
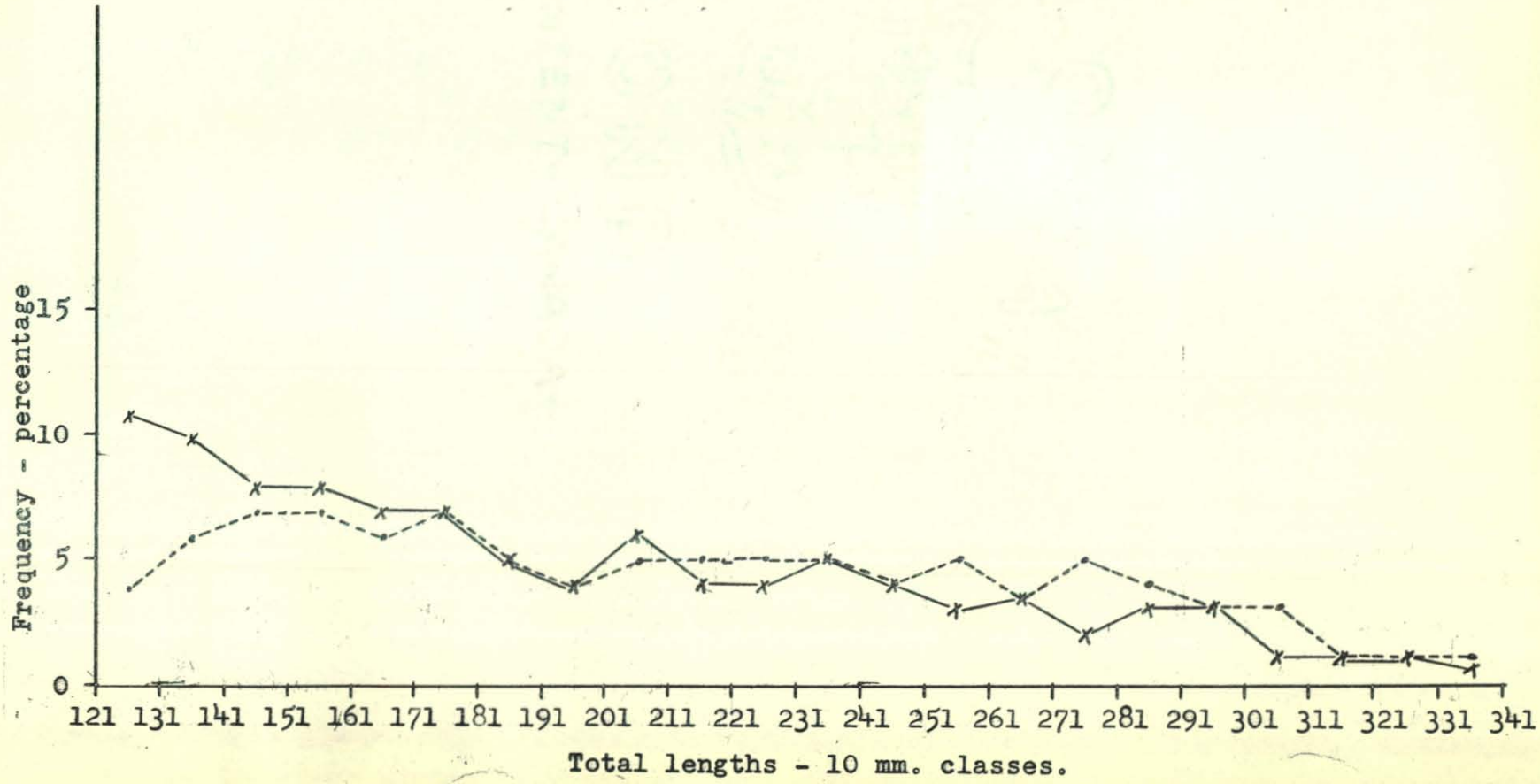


Fig. 6. Percentage occurrence of eels of size groups 121 mm. and over in a small stream (Nigus Brook), and a larger river (Pollett River).



eel-control policy. Investigators would probably rely on a knowledge of changes in the size-composition of eels as an index of the effectiveness of technique, or as an indicator of variations in other related phenomena.

Weights of eels

Wherever a collection of eels was made in these investigations usually only the total weight of the sample was determined, as well as the "total length" for each fish. About three hundred eels were weighed individually, most of these being a collection from the Holmes brook. These data are inadequate for a detailed analysis of the length-weight relationship of eels. By employing weighted averages, it has been possible to make certain comparisons between the possible potential production of eel flesh in several different streams.

The difference in the weight of the standing crop of eels that might be supported by small and large streams can be demonstrated by comparing the data of the Nigus brook and Pollett river.

The average length of eels taken in the Nigus brook was 18 cms., and that for the Pollett 20 cms. On the basis of the Holmes brook weight data, 18 cm. eels averaged 8 gms. and 20 cm. eels averaged 14½ gms. in weight. An estimated total of 5316 eels per acre on the Nigus gives a weight of 43 kilos. or 95 lbs. per acre, and an estimated 620 eels per acre on the Pollett, a weight of 9 kilos. or 20 lbs. per acre.

The following rough estimates, similarly derived, are for the five streams:

Stream	Mean width yds.	Weight per acre-kilos.	Weight per acre-lbs.
Bennett	1	69	152
Nigus	2	43	95
Turtle	10	11	24
Coverdale	17	5	11
Pollett	23	9	20

No correction in these estimations has been made for incompleteness of count for the Pollett, Turtle and Coverdale rivers where, as previously discussed, probably only about two thirds of the eels present were taken. However, the differences are so great that they would still demonstrate the probable heavier weight of eel flesh supported by small streams as compared to large streams, effected by the former having many more, though smaller, eels per unit area.

Fish predation by eels

When the eel is referred to as a predator the fish usually involved as prey are the trout and salmon. Because these are esteemed fish, it is possible that eel depredations are sometimes exaggerated. Nevertheless, many observations

both in this and in other countries suggest that the eel may truly be a hazard to the optium production of more valued fish. Without doubt eels do feed on trout and salmon as eggs, alevins or young fish. When a knowledge of the abundance of eels in streams is added to such observations it is little wonder that those interested in the culture of salmonid fishes have been perturbed.

Several records of fish predation by eels particularly on trout and salmon have been made by Frost (1946) and Menzies (1932). Cairns (1942b) has particularly emphasized the depredations of the long-finned eel upon adult trout and upon salmon.

In Canada eel predation has been recorded in several instances. White (1935) has frequently found the remains of salmon and trout in the stomachs of eels. On one particular occasion he took an eel from a New Brunswick lake, in which a dense planting of salmon fry had been made earlier on the same day that had 429 of these fish in its stomach - a useful observation on the stomach capacity of a large eel. Elson (1941) has suggested that the loss of more than 95% of salmon fingerlings planted the previous year in two Nova Scotian streams had been due largely to predation by eels.

Eels may perhaps begin to predate upon other fish, or their eggs, during their second or third year in fresh water. White has told (in conversation) of finding eels which had fed on salmon sock-fry from redds; and Mr. James Catt of the Department of Fisheries at Saint John, N. B. has described how he has observed, at night by the aid of a light, the tails of eels protruding from the stones of newly made salmon redds.

Elson (1941) gives a length of 15 cms. for the smallest eel in which he found salmon fry remains and the writer took two eels of the same size of 15 cms. which had eaten salmon fry, in the Coverdale river last summer.

As will be described later, the eel in streams is primarily dependent upon the bottom insect fauna for its food. As it grows larger, however, it doubtless has to rely more on a heavier diet such as fish would provide. This is certainly the case with the New Zealand long-finned eel, as Cairns (loc. cit.) has described. Eels taken in the smolt traps on the Petitcodiac river during the smolt run, almost invariably had one or several of these fish in their stomachs. The occurrence of trout with eel teeth marks on their sides is common in New Zealand and has often been observed in this country (White, in conversation, and by the writer).

First-hand information on the food of eels in streams was sought last summer through a series of night collections of eels by electro-fishing. These collections were made on the upper reaches of the Kennebecasis and Coverdale rivers (the former belonging to the Saint John River system). They will, unfortunately, add little to the knowledge of the predatory activity of the eel in salmon streams for several reasons. In the first place, by the time it first became possible to make the collections, the salmon fry had probably already emerged from the redds and were dispersed throughout the stream. Thus the period of emergence (about 10 days), which might well be a critical period in the eel-salmon relationship, was probably missed. In the second place, an almost

total ignorance of what salmon spawning takes place in these waters limits any observations to being little more than qualitative. And finally, probably few salmon spawn in the areas fished, so that these territories are really unsuitable for this particular phase of enquiry.

Several hundreds of eels were collected, and all have been preserved for later examination. Detailed analyses of stomach contents have yet to be made, but to date 302 stomachs have been opened, briefly examined and their contents transferred to vials. Only a few of these stomachs (about 5%) had fish remains and fewer had the remains of either trout or salmon. The bulk of the food consisted of the immature stages of insects.

Though further observations of the food of eels in streams is desirable, a more urgent need is for quantitative determinations of the rate and magnitude of predation by eels and of the change in the survival of young salmon under conditions where the eel has been removed. To this end some suggestions for experimentation are given here.

1. (a) Select a stream where the numbers of naturally-spawning salmon are reasonably high;

(b) Where it is possible to estimate potential fry production; that is, obtain an absolute count of female spawners and estimate egg deposition and fry production on the basis of previous research;

(c) Determine by electro-fishing the numbers and sizes of eels present;

(d) Determine production and loss of fry, parr, and smolt by seining, electro-fishing and trapping.

2. Compare salmon production and loss in a similar manner in a suitable stream where there are no eels or from which they have been removed.

3. (a) Census the eel population in a suitable stream by electro-fishing;

(b) Plant salmon fry or fingerlings and follow up by a series of night collections of eels, such that the first collection would be made from stream section A on the first night, a second collection on the second night from another section B, and so on. At the same time determine by electro-fishing and/or seining the numbers of fry surviving in each section (this to be done during the daytime).

(c) Compare survival of planted fry in stream sections from which eels have been removed.

4. Over a period of several years some of these experiments could be modified to determine variations due to differences in numbers and sizes of eels present and differences in types of habitat involved.

It is important to note that these experiments call for (a) natural spawning of salmon for 1 and 2 and (b) census of the eel populations both prior to and during the experiments.

The experiments should be designed to record movements of eels into or out of the area where necessary; and while they are in progress observations should be made of predation under natural conditions, in redds and upon fry and parr.

Competition for food

The role of the eel as a competitor for the food of trout or salmon has been described by Frost (1946) for the European eel, Hobbs (1940, 1948) and Cairns (1942) for the long-finned eel of New Zealand, and by White (1935) and Elson (1940b, 1941) for the American eel.

Frost has observed that the food requirements of the eel coincide appreciably with those of the brown trout. She adds, however, that the evidence was lacking to prove that this definitely amounted to competition - a condition dependent upon the availability of food and on the population densities. Hobbs has described the similarity of the food of the long-finned eel with that of the brown trout, but hesitated to predict the effects of eel control upon the production of trout. White and Elson have recorded very similar diets for brook trout and especially salmon and eels. Elson (1941) has stated that smaller eels "compete very seriously" with salmon fingerlings for their food, and that larger eels "also compete with salmon parr for almost all their food organisms".

Later ecological research has supported Darwin's thesis that the potential rate of increase of organisms is greater than that which the resources of the environment can support, with the result many are destroyed by the action and inter-action of a variety of physical and biological factors. Biological factors are usually density-dependent; that is, the moment and degree of their action depends partly upon the density of the organisms they affect. Crombie (1947) has defined competition as "the demand at the same time by more than one organism for the same resources of the environment in excess of the immediate supply". It may be assumed that the terms "at the same time" and "immediate" are relative, since situations exist where one organism may feed at a different time from the other, upon a supply of food that is for both to share.

It is a biological principle that two distinct groups of animals, whose environmental needs are identical, cannot survive together in the same place. From this it follows that the degree of competition for the resources of the environment will increase as the similarity of the needs of the two groups coincide.

In the case of the eel and salmon in streams, the following facts suggest that competition for food between the two constitutes a biological factor which limits their survival: (a) the potential increase for both species is great, (b) they live together, which suggests (c) that they have certain physiological needs and characteristics in common and (d) they eat the same, or almost the same, food. Now it is also possible that these relationships may be either intensified or alleviated by the simultaneous action of other factors of the environment, such as intra-specific competition, or the predatory activity of the eel upon salmon. Nevertheless, the question is posed as to whether, because of certain similarities of needs and function, the eel competes for the food of the salmon on a level which limits its optimum production.

Competitive relationships between organisms are usually highly complex and difficult to determine. The practical needs of this investigation, at least in its early stages, would perhaps be satisfied by defining the new status of salmon in an environment where the actions of the eel, both as a competitor and a predator, have been controlled. To this end the experimentation suggested for a study of eel predation would suffice. Additional observations would be necessary to obtain some distinction between the effects of both factors. In the event of increased numerical survival, which might be anticipated as resulting from the removal of the predator, it would be necessary to observe at the same time whether loss in weight and reduction in growth rate had followed as a result of the intensification of intra-specific competition. If a slow-growing fish remains smaller throughout its sea, as well as its fresh-water life, a relative loss in the ultimate production of salmon flesh will have been effected. It would be necessary, therefore, for the investigation to determine whether by increasing the numbers of young salmon surviving in the streams, the total production of adult fish had been increased, or to define a new balance at which this might be attained.

The night collections referred to in an earlier section will provide some additional data on the food of eels when they have been analysed. From the 300 stomachs opened to date (from these collections) the food of eels in some Petitcodiac streams was found to consist mostly of the immature stages of several groups of insects, mayfly nymphs (Ephemerida), stone-fly nymphs (Plecoptera) true flies (Diptera) and caddis worms (Trichoptera) and of the common earthworm (Lumbricus).

Predation upon eels

By trout and salmon

Though there have been various records of salmon and trout feeding on eels, the general opinion is that the effects upon eel populations are negligible. Frost (1946) has described heavy feeding by trout upon ascending elvers, and predation of insignificant consequence by trout upon small and adult eels. Hobbs (1948) and Cairns (1942b) consider the predation by brown trout upon long-finned eels to be of no importance.

By eels

The most important fish predator upon eels is perhaps the larger eel. Eels apparently feed heavily upon the elvers during their ascent into fresh water (Day, 1941, and White, in conversation). It is of interest to note that though the eel is primarily a nocturnal feeder, they may feed actively in broad daylight upon the abundant supply of migrating elvers, even though the waters, at that time of year (spring), are relatively cold.

By birds

White has stated, in conversation with the writer, that the occurrence of eels in the stomach contents of many mergansers and kingfishers which he has examined was, with occasional exceptions, of minor importance.

Significance

Though quite a variety of animals may at times feed conveniently upon eels, and especially the elvers, (Menzies, 1936 even mentions rats) no importance is attached to such predation in terms of its possibly limiting the sizes of eel populations below that which their environments could support.

Movements of eels

Elvers

In the spring these tiny fish enter fresh water from the estuaries to ascend the coastal rivers in countless thousands. In certain parts of Europe they are regularly fished for food and in some cases for transplanting to inland waters to provide for important freshwater eel fisheries (e.g. the River Bann, Northern Ireland. Menzies, 1936). The entrance of elvers into the Moser river in Nova Scotia has been described by Day (1941).

Characteristics often typical of elver runs are as follows: (a) they usually enter with the tide and at times of spring rather than neap tides, (b) they run in dense masses, generally near the water surface and close to the river banks, (c) in certain places night runs predominate whilst in others runs occur as much during daylight, (d) elvers in a run exhibit almost complete disregard for disturbances, a pattern of behaviour which soon changes after they enter the fresh water, (e) they are able to surmount or to by-pass most obstacles.

In certain localities elver runs are less distinct than has just been described, and they arrive in a state of dispersal rather than in a great concentration. Though the earliest entry of elvers into the Petitcodiac was not observed last summer, later entries were rather of this type. Heldt and Heldt (1929a) have observed that the arrival of the elvers at the Lac de Tunis in North Africa is in a dispersed state ("arrivée en ordre dispersé") and contrast it with the entrance of elvers into the River Sidi-Daoud (1929b), which lies to the eastward of the Lac de Tunis, on the coast ("montées en masses......"). These writers attribute the differences in the character of the elver runs to the influence of fresh water in the coastal waters.

In the Petitcodiac river, though elvers were first reported in late May, they were not observed by the writer until in early June. During these observations they were never seen to ascend at a rate greater than 5 per minute. They were usually seen resting on flat stones, partly buried in the mud or swimming up-stream. They were easily disturbed and would respond by quickly hiding under stones or weeds or by swimming out and down into deeper water. Though such observations were made immediately above tide level, as well as higher up the river, they can hardly refer to elver "runs" as the term is usually employed (for example by Frost, 1950).

Recently-entered elvers in the Petitcodiac were partially transparent, and were pigmented along the back. The process of pigmentation in elvers is influenced by a variety of factors, a topic which is discussed in some detail by Bertin (1951).

Though records of actual distances have not yet been encountered in the literature, the inference gained from several accounts (Menzies, 1936, Frost, 1950, Bertin, 1951) is that elvers can travel far up-stream during their first summer. In the Petitcodiac rivers the year's elvers have been taken up to 15-20 miles above tidal waters. That these small fish were probably elvers is based upon the following observations:

(1) The otoliths of 23 elvers recently entered into the Petitcodiac showed two very distinct opaque rings (either or both of which may or may not have been annual rings). These elvers ranged in total length from 54-105 mm.

(2) Small eels, less than 100 mm. and having but the two opaque rings in their otoliths were taken at points up to 15-25 miles above tidal water in the Petitcodiac River.

(3) The variation in total lengths among elvers of a particular run is great. Furthermore, the period over which they enter from the sea into the main river, and thence into tributary streams is prolonged (probably several months). Again, as the season progresses, the average length of elvers in a run decreases, a phenomenon described by Menzies (1936), and attributed by him to prolongation of the metamorphic processes; and illustrated also by Heldt and Heldt (1929a), who employ the term "réduction de métamorphose".

These conditions must account for particularly great variation in the sizes of the year's eels that may be present in certain streams. It might even be that certain large, new elvers equal the lengths of small, late-entered elvers of the previous year.

(4) Total lengths of small eels, most of which were probably elvers, that were taken in different streams at various distances above tidal water, are given in Table IV.

Table IV Records of small eels taken at various distances above tidal waters

Date	River	Miles above Tide	Sizes of smallest eels taken (mm.)	Elvers Yes	Elvers No.	Elvers Uncertain
June 3	Petitcodiac	0	N=10, 54-65 ($\bar{x}$=58.2)	x		
10	Petitcodiac	9	N=23, 53-79 ($\bar{x}$=61.0)	x		
13	Up. Coverdale	25	63, 86, 96	x		
14	Lwr. Coverdale	3	72, 77 (others seen)	x		
15	Lwr. Turtle	4	76, 77, 79	x		
15	Up. Turtle	15	111, 112			x
15	Pollett	20	96, 108	x		
July 5	Lwr. Bennett	15	N=7, 63-72 ($\bar{x}$=63.9)	x		
28	Pollett	13	62, 69, 78, 85	x		
29	Pollett	23	90, 92, 97	x		
31	Pollett	25	87, 91, 93, 94	x		
Aug. 22	Nigus	3-4	Numerous, from 56 up	x		
23	Up. Bennett	25	91, 95, 98	x (?)		
Sept. 6	Nigus	3-4	Numerous, from 57 up	x		

Small eels

Cairns (1942a) and Hobbs (1948) have observed that small, "long-finned" eels make regular secondary, up-stream movements during late summer or autumn. Cairns has suggested that these movements of small eels from the lower to the upper reaches of a river, which occur in January and February (i.e. summer) are correlated with the entrance of elvers into the fresh water in October, November and December (i.e. spring). He has described the secondary movement as a well-defined migration, which in certain localities, being anticipated annually, is observed with constant regularity.

The writer witnessed a similar movement of small eels in the Pollett river last mid-August. Numerous small eels were swimming up stream at various depths across the width of the river during a hot, summer afternoon. As far as could be judged, the sizes of these eels ranged from about 15 to 25 cms.

These movements may prove useful to the devising of methods for the control or elimination of eels. Cairns and Hobbs were able to observe these migrations through the action of natural barriers across streams, which so temporarily halted the movements of these fish, that they could be seen in concentrations below them. In the absence of suitable natural barriers, it should be possible to erect temporary barriers across streams to allow periodic observations in changes in the numbers of eels below them or even to create convenient conditions for destroying them.

Down-stream migrations

Down-stream migrations of eels, usually in the fall of the year, occur annually in many countries. They are generally termed spawning migrations, since most of the eels are silvered, are presumably maturing, and are considered to be making the initial stage of their journey to the south Atlantic spawning grounds.

Smith (1951) has operated traps at the exits of certain New Brunswick lakes and over a period of several years has been able to record annual movements down-stream from the lakes each spring. The runs were made up of small and large fish and, to the writer's knowledge, none were silvered.

Though in this investigation there has been opportunity to make only a few observations on these migrations, it has been noted that they involve not only silvered eels, but yellow eels, many of them quite small and certainly far from mature. This fact has also been noted by Smith (loc. cit.).

What the destination of these eels is and whether they all enter the estuaries is not known.

In mid-September last year a trap was erected on the Anagance river at Petitcodiac, with the intention of capturing seaward migrating silver eels. It was designed after the description given by Day (1948) but included some modifications. The trap operated from September 19 to November 17 except for several days during very high water. It was examined nightly and on several occasions hourly for several consecutive hours. Day visits were made frequently but almost invariably fish entered only during darkness.

The following fish were taken

Eels - 79 Range in size, 153-550 mm. $\bar{x}$ = 260 mm.
Greatest number in one 24-hour period - 11
Average number per day - 1.5
Number distinctly silvered - ca. 10
Taken first on first day of operation

Lampreys - 1509 All distinctly silvered
Greatest number in one 24-hour period - 321
Average number per day (while they ran) - 60.4
Duration of run, October 12 to November 5

Lampreys were frequently observed entering the trap. They invariably entered it after dark and none were observed migrating during the daytime. They usually swam within 6 to 8 inches of the surface of the water, in mid-stream, and were always headed down-stream.

The trap was not designed to take fish other than eels, having wings only 18 inches high off the stream bottom. That so many lampreys were taken would suggest that the run was at least well sampled.

Salmon parr - 72 All ripe males
Size range, 87-187 mm., $\bar{x}$ = 122 mm.
Greatest number in trap, 24-hour period - 11
Appeared in trap October 15 to end of operation

A single examination of scales from these fish showed that one third were in the 2+ and the remaining in the 1+ age groups. One fish of 87 mm. was in its first year and was ripe.

Other fish - Besides small numbers of several species of minnows and many suckers, 10 trout were also taken, 2 of which were ripe males and 2 ripe females.

It is possible that the trap did not fish successfully for eels, though this is unlikely for the following reasons - on many occasions it was examined hourly for several hours during the night; it operated after rain and during all but the highest water; it took a large number of lampreys and other fish for which it was not designed, and which had every opportunity to avoid entering it. The trap may have been set after the peak of the run had passed and it is also a possibility that few eels ran there last year.

Movement of eels into a cleared section of stream

Eels were systematically removed by repeated electro-fishing in sections of two streams and subsequent periodic checks were made to determine what replacement had occurred.

Bennett brook. The first experiment was conducted on the upper Bennett brook and was designed also to make observations on the feasibility of marking eels by branding them.

All possible eels were removed from a 100- yard section of the stream by repeated electro-fishing. At the same time 50 eels were branded and returned to the same water from which they were taken, from stream sections 50 yards above and 50 yards below the cleared section.

Subsequent checks by electro-fishing in the cleared area and adjacent to it over a period of two months indicated that only a few of the marked eels had wandered out of their area and that there had been very little movement of eels into the cleared 100 yards. A summary of the results of these tests is given below.

DOWN STREAM →

Date	A Upper marking area	B 50 yd. interval	C Cleared 100 yds.	D 50 yd. interval	E Lower marking area
23 Aug.			178 removed		
24 Aug.	50 marked (left side)		40 removed		50 marked (right side)
29 Aug.	21 recovered (returned)	No marked eels	26 removed		
6 Sept.				4 from E recovered and returned	25 recovered (returned)
25 Sept.					25 recovered (returned)
2 Nov.			7 eels taken; 2 of which were marked from A; 1 from E		Seen but not collected

Nigus brook. By repeated electro-fishing, the attempt was made to remove all eels from the lowermost 625 yards of this stream (excepting eels less than 90 mm.). The numbers of eels taken in each attempt have been summarized in Table 1, shown earlier in this report.

The final treatment to the experimental 625 yards was given on November 23 when only 7 eels were taken from the upper 225 yards. When an additional and adjacent 50 yards was electro-fished for the first time on this day, 45 eels were taken, and a further 16 on the following day.

A summary of the different collections is as follows:

Collection No.			
1	mid-August	625 yds.	890 eels, 64% of total of 1395
2	mid-August	"	307
3	mid-Sept.	"	168
4	mid-October	"	30
			1395
5	23 November	upper 200 yds.	7
1	23 November	next 50 yds. above 625th.	45
2	24 November	"	16

The contrasting abundance of eels in the 625 - 675 yard section fished for the first time on November 23 demonstrated that during the period concerned (mid-August to late November), there had been little or no movement of eels into the cleared area.

Of course, these observations are good only for the period they refer to. Eels not only make the periodic migrations already mentioned, but they may also make less defined movements in streams, particularly, no doubt, during times of flood (as Elson's trap records in Nova Scotian streams would suggest, Elson, 1940c, 1941).

In mid-January of this year, when ice had formed along the banks of the Nigus, it was again electro-fished for eels. None were even seen in 275 yards of the cleared section; and none were seen in the next, previously unfished 250 yards. The small generator was used which delivered approximately 125 volts at half an ampere. Whether no eels were then present in the area or whether they were there but could not exhibit galvanotropic response is not known. But in the same month and in water of similar temperature, eels were readily electro-fished from the deep mud of a pool in the river at the St. John hatchery. This pool, however, was

fed by a sewage pipe which carried considerable organic matter and such refuse as pieces of liver left over from the trout feed. Furthermore, at the St. John hatchery the large generator was used which delivered 575 volts at about 1.7 amperes.

Several years of observations would be necessary before the complexities of the movements of eels in streams could be explained. The information provided here, however, may prove useful, as for example, when optimum conditions are being sought for the planting of young salmon and trout. At the right time of year a stream cleared of eels would probably remain relatively free of them over a period critical to the planted fish.

Up-stream autumn movements of eels from salt water

The writer has no first-hand observations to record here, but the matter is of sufficient interest to the investigation to warrant some discussion.

Under certain conditions, apparently, yellow eels leave the estuaries or the sea and enter into fresh water. They do this during the fall of the year and presumably hibernate in fresh water throughout the winter months. Menzies (1932) referring to his observations of the eel in United Kingdom waters, has said that "considerable numbers of eels feed either in estuarial or in salt water and as winter approaches, some move up stream to hibernate in fresh water".

This type of movement has been observed in certain Nova Scotia streams by White (in conversation with the writer) and also, according to a first-hand report given to him, such a movement occurred last November in a stream of Albert County, N. B.

In a reply to a recent letter from Dr. J. C. Medcof of this Station, the Fisheries Inspector at Arichat, N.S. has stated that regular runs take place each autumn from the sea into the River Moulin, the River Habitants and the Grand Lake brook of the south shore of the province. These eels are trapped by local fishermen for food.

Several years ago a fisherman of Musquodoboit Harbour, Halifax County, N.S., Mr. Charles T. Young, described to Dr. Medcof his having observed one night the crossing of eels from the sea over a bar which separated a freshwater lake from the sea. In a recent letter to Dr. Medcof, Mr. Young has stated, as best he could remember, some of the features of this incident. It took place during the autumn and on "a foggy, wet night". The bar was stony and grassy, was about 50 yards wide, and at its highest point was about 10 feet above the level of the salt water. He recollects that there were "dozens" of eels both large and small, and that he saw several actually enter the pond. This pond has no outlet to the sea at this locality and is a muddy pond of about 3 acres.

Hibernation

The hibernation of eels during winter is a commonly-known phenomenon. In estuaries, for example, at the approach of winter they bury themselves in groups in mud which will not be exposed at low tide. These "eel holes" can be seen and recognized and are fished in some localities by spearing the eels. Cairns (1942) has stated that besides commonly finding

eels buried in the mud of rivers during the winter, other evidence of their hibernation is in the fact that they are no longer to be seen actively feeding in the rivers and that the catch of eels in pots set in streams ceases during the winter. According to him, also, a few eels do continue to feed throughout the winter.

Japanese workers have correlated the reduced feeding activity of eels with lower water temperatures (Cairns, loc. cit.) and the hibernating act may be a survival response on the part of the eel against starvation. The slowing down of metabolic activity in response to certain unfavourable conditions of the environment seems to enable the organism affected to resist such conditions.

The responses of the eel to cold water temperatures are in keeping with the view that the genus is of tropical origin, (Schmidt, 1932). The eel has also, apparently, a high thermal tolerance, for according to White (in conversation) he has observed them actively feeding in warm waters that were almost lethal to Atlantic salmon. The adaptive capacity of the eel to the cold temperatures of northern climates has doubtless contributed to its abundance there.

Sex studies

The sex of eels inhabiting fresh water has been a matter of controversy for many years, and for this reason the writer was attracted to attempt the identification of the sex of eels in New Brunswick streams. The study is still in progress and the results to date are not suitable for presentation here. However, the writer feels confident that the presence of male eels in streams can be identified.

An excellent summary of the history of sex studies of the eel is given by Bertin (1951). The most thorough research, employing cytological and histological techniques is that by d'Ancona (1943). This work is in Italian, but has an English summary and a large number of excellent photomicrographs.

Age studies

Age determinations from scales of the eel are ambiguous and uncertain (Hornyold, 1937; Frost, 1945; Smith, 1951). The use of otoliths has been especially recommended by Hornyold (opp. cit), though the method is rather tedious. The writer has removed and prepared otoliths from a little over 200 eels. Most of these have still to be read.

Every otolith that the writer has so far examined has around its central nucleus two distinct, opaque rings. This is the condition of elvers, whose otoliths show only these two rings. Now according to Schmidt (1922) the American elver is in its second year when it enters fresh water. Perhaps, therefore, if one of these rings is an annulus the other may represent a period of retarded growth, such as might occur during the non-feeding process of metamorphosis, from Leptocephalus to small eel.

Electro-fishing in the vicinity of developing fish eggs

Foreword

In view of the increasing use of the electro-fishing technique in streams it has seemed desirable to determine whether the electric shock generated might be harmful to developing fish eggs. For this reason a series of experiments has been carried out during the winter, in which observations were made of the effects upon salmon and trout eggs in different stages of development when the two D.C. electro-fishing generators were used in their vicinity. The output of the larger of these machines when used was about 500 volts at 2 amperes, and that of the smaller, about 125 volts at half an ampere. These two machines and their use have been described by Smith and Elson (1951).

The scope of the experiments has had to be modest since neither the assistance nor facilities for very detailed technique could be spared. The emphasis of investigation has been on the practical, and although experimental precautions and controls were adopted, the tests were designed to define limits of safety in electro-fishing, rather than as a study of electronarcosis.

Most of the tests were made at the Saint John fish hatchery where outdoor concrete troughs were available and were suitable. Eggs available at the hatchery were trout (Salvelinus fontinalis) salmon (land-locked Salmo salar) including stages from early cleavage to near-hatching.

A few preliminary tests were made at Petitcodiac, using eggs obtained from a single female salmon trapped in the Pollett river, which had been fertilized by a male from the same trap.

Methods

The Petitcodiac eggs were placed in perforated celluloid cylinders which were then set on the stream bottom in 6 to 8 inches of water. The positive electrode was held at the surface of the water, at the required distance, and the switch closed for the required duration of shock. One set of eggs was buried in the gravel of the stream bed and then shocked, the intention being to simulate eggs in a redd.

At the Saint John hatchery, samples of eggs were placed in shallow glass stendors which were then set on the bottom of the trough in about 7 to 8 inches of water. They were arranged at various horizontol distances from the positive electrode.

After treatment most of the eggs were retained for observation in the indoors running-water troughs.

Determination of the effect of electric shock

The "death" of a salmon or trout egg is frequently followed by the appearance of a characteristic opaque, white spot, which spreads until the whole egg is white. This is presumably due to coagulation of the yolk. When the recently-fertilized Petitcodiac eggs were shocked, the white spot developed within a few minutes, up to an hour or more, depending apparently upon the severity of the shock. For this reason it was originally thought possible to use the appearance

of the white spot as a criterion of the death of an egg. In the case of eggs recently fertilized this test is probably reliable. However, the criterion is less valid as eggs proceed in development, since apparently the time of appearance of the opaqueness will vary with the stage of development of the egg. With "eyed" eggs, for example, Mr. K. S. Shellington, Manager of the Saint John hatchery has stated that these may be dead for a week or more before they begin to turn white.

For these reasons most of the eggs were retained at the hatchery after treatment. Though it was not possible to check these eggs as carefully as an ideal experiment would warrant, arrangements were made for one of the hatchery employees to pick out and record the obviously dead (white) eggs from the samples once a week.

An attempt was made to get some idea of the time of appearance of the white spot in dead eggs. Samples of eggs in different stages of development were dropped to the concrete floor from a height of about 8 feet and these eggs were then held in running water for observation. The tests were unsatisfactory since most of the eggs were not killed by the fall.

Probably the only sure and reliable means of determining if an egg has been killed by electric shock would be by microscopical examination for cessation of circulatory movement. It was suggested to the writer by Dr. H. I. Battle that by this means a chart could be drawn up demonstrating the average time of appearance of the white spot in dead eggs of different developmental condition. However, it was not convenient to carry out such a programme at this time.

The effects of electric shock have therefore been described on the basis of comparing the number of dead eggs in treated samples with controls. Though dead eggs were recognized by their whiteness, the first appearance of the white spot could not be used to indicate the time of death, for the reasons given.

Some of the eggs treated have already hatched, and those still living and unhatched are held at the hatchery. In terms of the practical objective originally desired, the results to date are sufficient to indicate certain conditions under which it is probably safe or not safe to use electric shockers, giving an electrical output similar to that of these tests, in the vicinity of developing trout and salmon eggs.

Petitcodiac tests - Results

All tests were made with the Wolf machine, which delivered 550 volts at 1.7 amperes.

Test #1. November 27th, 1950. Holmes Brook. Salmon eggs.
Incubation period, 5-6 hours (pre-cleavage)
Distance, 6 inches
Duration, 25 seconds
Sample size, 50 eggs
Results: At the end of 1 hour no eggs had died (i.e. no white spot). In eggs at this stage, the white spot can appear very rapidly after death.

Test #2. November 27th, 1950. Holmes Brook. Salmon eggs.
Incubation period, 5-6 hours (pre-cleavage)
Distance, 6 inches
Duration, 2 minutes
Sample size, 48 eggs
Results: Several eggs showed white in less than 10 minutes. At end of 1 hour 39 or 81% had died.

Test #3. November 27th, 1950. Holmes Brook. Salmon eggs.
Incubation period, 5-6 hours (pre-cleavage)
Distance, 6 inches
Duration, 2 minutes
Sample size, 50 eggs
Eggs buried in 6 to 8 inches of gravel
Results: After 1 hour 5 or 10% of the eggs had died (i.e. were white).

Tests #4, #5, #6. November 28th, 1950. Holmes Brook. Salmon eggs.
Incubation period, 28-30 hours (early cleavage)
Results: see below

Test No.	Duration	Distance	Sample Size	No. dead after 1 hour	% Mortality
4A	30 secs.	6 ins.	50	45	90
4B	"	"	51	49	97
5A	1 min.	6 ins.	50	50	100
5B	"	"	50	50	100
6A	2 min.	6 ins.	50	50	100
6B	"	"	50	50	100
Controls			50	0	0

Petitcodiac tests - Discussion

The results of these preliminary tests with recently-fertilized salmon eggs may be summarized as follows:

(a) Pre-cleavage eggs may be killed by severe electric shock, but are less susceptible than eggs in early cleavage.

(b) Eggs buried in gravel may be somewhat "protected" from electric shock.

(c) Samples of eggs in early cleavage given a severe shock suffered total mortality.

Saint John hatchery tests

Considerable delays and difficulties interfered with these tests. In the first place, as the large generator was about to be used for the first tests, it was found to have lost its magnetism and had to be taken in for repairs. On the following days rain fell heavily throughout the operations which delayed the

work and caused breakdowns in both machines. The large generator again lost its magnetism after running for part of the day and on this occasion had to be left for an extensive overhaul.

It became evident that the original plans for the experiments would have to be simplified. Since the counting, placing and removing of eggs was a slow process, it was decided to reduce the number of eggs per sample (from 50 to 20), and to dispense with repetition and replication of tests and samples and to rely more on a general, overall comparison of treated samples with controls. Furthermore, it was hoped that later tests would supplement the earlier observations and this has, for the most part, been realized.

Types of eggs used

The different types of eggs used were as follows:

December 9th-11th.	Type A.	Trout. Early cleavage. Incubation period, 6 days.
	Type B.	Trout. Late cleavage. Incubation period, 27 days.
	Type C.	Trout. Late eyed; about 60 somites. Incubation period, 44 days.
	Type D.	Salmon. Eyed; about 40 somites. Incubation period 27+ days.
February 12th-13th.	Type A^1.	Salmon. Body almost completely formed.
	Type B^1.	Trout. About to hatch.
	Type C^1.	Trout. Early eyed.
	Type D^1.	Trout. Similar to Salmon A^1.

Tests made

A description of the tests made is given in the following summary:

Series A. December 9th, 10th. 550 volts, 1.7 amperes.
Egg types used, A, B, C, D.
Distances employed, 1, 3, 6, 12 feet.
Durations employed, 30 sec., 1 min., 3 min., 5 min., 30 sec. repeated 6 times at 10-sec. intervals.
Total number of tests, 48.
Sample sizes, 20 eggs.

Series B. December 10th, 11th. 150 volts, 0.6 amperes.
Egg types used, A, B, C, D.
Distances employed, 1, 3, 6 feet.
Durations employed, 1 min., 3 min., 30 sec. repeated 6 times at 10-sec. intervals.

Total number of tests, 28.
Sample sizes, 20 eggs.

Series C. February 12th. 550 volts, 1.7 amperes.
Egg type used, A^1, B^1, C^1, D^1.
Distances employed, 1, 3, 6, 12, 21 feet.
Durations employed, 1 min., 5 min.
Total number of tests, 40.
Sample sizes, 50 eggs.

Series D. February 13th.
Egg types used, Alevins (trout).
Distances employed, 1, 3 feet.
Durations employed, 1 min., 5 min.
Total number of tests, 5.
Sample sizes, 20 alevins.

Saint John Hatchery tests - Results

Series A. 550 volts, 1.7 amperes.

Controls. 50% mortality within 26 days. No further mortality.

Type A. Duration, 30 sec. 50% mortality within 24-48 hours at 1, 3, 6 feet.

1 min. 50% mortality within 24-48 hours at 1 foot. Total mortality within 26 days at 1, 3, 6 feet.

3 min. 50% mortality within 50 min. at 1 foot. Total mortality within 24 hours at 1 foot. Total mortality within 46 days at 3, 6 feet.

5 min. at 12 feet only. 50% mortality within 8 days. Total mortality within 75 days.

30 sec. repeated 6 times at 10-sec. intervals. 50% mortality within 18 days. Total mortality within 56 days.

Comments

Eggs of Type A (in early cleavage) were apparently killed during the processes of counting and moving them since mortality in the controls was high. They were perhaps killed by electric shock up to a distance of 12 feet, the maximum employed. It is impossible to distinguish clearly between the effects of electric shock and of handling, but the results do suggest that such eggs may be highly susceptible to any form of shock.

Controls. 25% mortality within 26 days. 50% within 56 days.

Type B. Duration, 30 sec. Total mortality within 24-48 hours at 1 foot. 50% mortality within 24-48 hours at 3, 6 feet.

1 min. 50% mortality within < 24 hours at 1, 3 feet. 50% mortality within 24-48 hours at 6, 12 feet.

3 min. 50% mortality within 50 min. at 1 foot. Total mortality within 46 days at 3 feet. 50% mortality within 24-48 hours at 6 feet.

5 min, at 12 feet only. 50% mortality within 8 days.

30 sec. repeated 6 times at 10-sec. intervals, 6 feet only. 50% mortality within 46 days.

Comments

Type B eggs (late cleavage) may also have been injured during handling. They were killed by severe electric shock up to the maximum distance tested of 12 feet, the mortality being higher the longer the shock and the shorter the distance.

Controls. No mortalities, all finally hatched.

Type C. Duration, 30 sec. 1 dead only in 3 months at 1, 3, 6 feet.

1 min. < 50% mortality within 26 days at 1, 3, 6 feet. At 12 feet 1 dead only.

3 min. < 50% mortality within 26 days at 1, 3, 6 feet.

5 min. at 12 feet only. < 50% mortality within 26 days.

30 sec. repeated 6 times at 10-sec. intervals. < 50% mortality within 26 days.

Comments

Type C eggs (eyed trout) were susceptible to very severe shock, but mortalities were relatively light.

Controls. Only 1 dead after 3 months (5% mortality)

Type D. Duration, 30 sec. < 50% mortality in 3 months at 1 foot. 50% mortality in 3 months at 3, 6 feet.

1 min. 50% mortality within 24 hours at 1 foot. < 50% mortality in 3 months at 3, 6, 12 feet.

3 min. Total mortality within 24 hours at 1 foot. 10-20% mortality in 3 months at 3, 6 feet.

5 min. at 12 feet only. 20% mortality in 3 months.

30 sec. repeated 6 times at 10-sec. intervals - 5% mortality in 3 months at 6 feet.

Comments

Type D eggs (eyed salmon) were killed by severe shock at short distances but were not seriously affected at distances of 6 feet or more.

Series B. 150 volts, 0.6 amperes.

Types A, B, C, D - mortalities during 3 months were either less than or approximately equal to those in controls. Thus it cannot be stated definitely that eggs were killed by the electrical shock. This applies to distances of 1, 3 and 6 feet for durations of shock of 1 min., 3 min., and 30 sec. repeated 6 times at 10-sec. intervals.

Series C. 550 volts, 1.7 amperes.

Mortalities occurring during the period of observation to date (25 days) were as follows:

Controls. One dead in 2 lots of 50 eggs. (1% mortality)

Type A^1. Duration, 1 min. 2% mortality at 1, 6, 12 feet. Zero mortality at 3, 21 feet.

5 min. 2% mortality at 6, 12 feet. Zero mortality at 1, 3, 21 feet.

Comments

Following the tests, several eggs in different samples were seen to be still alive. There is no sure indication that any deaths occurred as a direct result of electric shock with these salmon eggs of an advanced stage of development.

Controls. Two dead in 2 lots of 50 eggs. (2% mortality)

Type B^1. Duration, 1 min. 2% mortality at 1 foot. Zero mortality at 3, 6, 12 feet. 4% mortality at 21 feet.

5 min. Zero mortality at 1, 3, 6, 12 feet. 2% mortality at 21 feet.

Comments

With Type B^1 eggs (trout, about to hatch) no mortalities can be attributed directly to electric shock. In each sample, most of the eggs have since hatched and alevins appear normal.

Controls. One dead in 2 lots of 50 eggs. (1% mortality)

Type C^1. Duration, 1 min. 6% mortality at 1, 6, 21 feet. 2% mortality at 3 feet. Zero mortality at 12 feet.

5 min. 14% mortality at 1 foot. 10% mortality at 6 feet. 4% mortality at 12 feet. 2% mortality at 3, 21 feet.

Comments

The results for Type C^1 eggs (trout, early eyed) are somewhat ambiguous. However, it seems that severe shock at short distances may have killed eggs. These eggs are perhaps relatively safe from severe shock at distances beyond 6 feet.

Controls. Five dead in two lots of 50 eggs. (5% mortality)

Type D^1. Duration, 1 min. 2% mortality at 3, 12 feet. 6% mortality at 1, 21 feet. 10% mortality at 6 feet.

5 min. 4% mortality at 3 feet. 6% mortality at 12 feet. 8% mortality at 1, 6 feet. 16% mortality at 21 feet.

Comments

With Type D^1 eggs (trout in advance development) the results do not clearly indicate mortality due to electric shock.

Series D. 550 volts, 1.7 amperes.

Alevins

Controls. Zero mortality during comparable period.

Duration, 1 min. zero mortality at 1, 3 feet.

5 min. Total mortality, probably within several hours at 1 foot. (All were long since dead when first examined on 6th day.) Zero mortality at 3 feet.

Comments

In each test the response of the alevins to electric shock was immediate. They contorted violently and swam sporadically about the dish. None were seen either to orient in relation to the direction of the source of the shock nor to move distinctly towards or away from the electrode. After the first few seconds of the shock they would generally cease moving and rest, but this would again be followed by further swimming, contortions and periods of rest.

The only deaths that occurred were with the 5 min., 1 foot shock, and these alevins were still alive, though rather feeble, up to at least an hour after the shock. When next examined on the 6th day, all had been dead for some time.

Saint John Hatchery tests - Summary

The following statements are based upon a consideration of the results of the entire series of tests and are intended to indicate the probable effect upon developing salmon and trout eggs, of electro-fishing in their vicinity with D.C. apparatus of similar output to that used.

1. The effects of using a small machine (about 150 volts at ½ ampere) will probably not be serious except perhaps in the case of eggs in cleavage or if used very close to eggs in more advanced stages for prolonged periods.

2. Eggs in early stages of development, particularly during cleavage, will probably suffer high mortalities from severe shock, such as would be generated by machines comparable to the Wolf machine (500 volts at 2 amperes), in waters of similar electrical conductivity.

3. Eyed eggs and eggs in later stages of development are more resistant to electric shock, but may be killed by very severe shock.

4. Eggs that were about to hatch were not obviously harmed even by fairly severe shock. Very severe shock would be expected to kill the embryos, however, since alevins were killed when the larger machine was used at 1-foot distance for a 5-minute shock.

5. Alevins, though killed by very severe shock (see 4) suffered no apparent lasting harm from less severe shock.

6. Certain observations, not recorded here, would seem to indicate that premature hatching might follow electric shock which did not kill.

Significance

D.C. electro-fishing apparatus with a power output similar to that of the Wolf machine (about 500 volts at 2 amperes) should not be used in streams in the vicinity of eggs of valued fish, in the pre-eyed stages of development. During later development the risk to eggs is considerably less, but close proximity to redds should be avoided.

Smaller machines (about 150 volts at ½ amperes) can perhaps be used with comparatively little risk to the eggs, but again, their use during the early stages of development of the egg should be avoided.

It is probably quite impractical to use electro-fishing apparatus in an attempt to attract alevins out of their redds.

Nigus Brook experiment - Eel predation on salmon eggs in artificial redds

As has already been mentioned, last autumn the lowermost 675 yards of the Nigus Brook had all its eels removed by repeated electro-fishing. Following these removals, artificial salmon redds were built in this section of the stream

and in the upper adjacent section from which the eels were not removed. Five redds were built in each section, and 1,000 recently fertilized salmon eggs were planted in each.

If water conditions permit a further 10 redds will be built this spring in which late-eyed salmon eggs will be planted.

It is the purpose of this experiment to attempt to assess the fry production from each redd to determine what losses of salmon eggs or alevins may have occurred, that could be attributed to predation by eels in the redds. Attempts will be made to build suitable traps over each redd so that emerging fry will be taken by them.

If successful, the experiment should provide interesting data pertaining to such predation. However, its value is admittedly limited, first because of the artificial factors involved, and secondly because of the practical limitations which the design of the experiment calls for.

The artificial redds were built by Mr. H. C. White of the Station and the writer is pleased to take this opportunity to thank him for his assistance.

Control of eels

Foreword

A consideration of means of controlling eels should really have in mind exactly where they are to be controlled and for what specific purpose. This would be desirable because of such governing factors as their abundance, the range and variety of their distribution both geographical and ecological, the complexities of their movements and the diversity of their relationship towards other fish. A means of controlling eels in the headwaters of a river for example might be quite different to one suitable for their control in the lower reaches of a river.

In the case of control methods for salmon streams, eels may be considered in terms of certain relatively distinct groups (a) elvers, entering fresh water in the spring, (b) small resident eels, that presumably make regular secondary up-stream migrations, (c) resident eels whose movements may be restricted to some wandering and (d) seaward migrating eels, considered to consist for the most part of silvered eels on their spawning run.

As they are most suitable for each of these groups of eels, either or both of two general methods of control might prove effective - denial of access and systematic destruction or removal.

Denial of access

Elvers

The distinct advantage of preventing the access of elvers into streams, lies in the fact that the continued existence of eels in streams depends upon the annual recruitment by elvers. Since the eel is catadromous it can be assumed that in streams which they can no longer enter the remaining population of eels will disappear eventually, either by death or by movement out of the stream.

The ultimate elimination of eels would doubtless depend upon the movement of eels out of the stream rather than through natural mortality in it. The dominant exodus of eels from fresh waters is probably in the seaward movement of silvered eels, which are assumed to be making the initial stage of their spawning migration. Therefore, how many years will lapse between the time of first denying access to elvers and that when the river is free of eels will depend upon the age or size at which eels descend to the sea. In practical terms, obviously, the desired control may be achieved sooner, when particularly undesirable size groups of eels have been eliminated either by growth, exodus or destruction.

The ability of elvers to surmount or by-pass most obstacles is proverbial. Yet there are both natural and man-made barriers which have been successful in either completely denying them further access or in reducing the numbers that successfully pass (Menzies, 1936, Cairns, 1942c, Hobbs, 1948). Dams and artificial or natural falls whose faces are either too steep, or which overhang, or down which the water flows too swiftly for elvers, have hindered or stopped their ascent in certain places.

Electric fences placed across a stream at strategic sites may prove to be an efficient means for barring the ascent of elvers. The Fish and Wildlife Service of the United States has recently awarded contracts to engineering firms for research on electric, electronic and electromagnetic devices for control of the destruction of the sea lamprey. An electric fish screen (the Burkey electric fish screen) is also being tested by that department.

Electric fences may have the distinct advantage of easy construction and operation, especially in out-of-the-way places, and of economy of operation. Furthermore, they may perhaps be conveniently erected at sites where dams would be either unwanted or too expensive an undertaking. An historical summary and critique of the use of electric fish-screens has been given by Holmes (1948).

Control methods designed to deny access to elvers must take into consideration that (a) their penetration into the main river and thence into and up its tributaries may cover a period of several months and (b) that they can ascend a considerable distance during their first summer.

Small eels

The regular secondary up-stream movements of small eels may provide a most convenient opportunity to control them. Such movements need more extensive observation in this country but it is likely that methods of control similar to those described for elvers would be applicable.

Destruction or removal

Resident eels

Possible means of destroying resident eels in streams would include electro-fishing, trapping (baited pots) and poisoning.

Regardless of what methods might prove most efficient, none will achieve the permanent removal of eels from a stream unless barriers are erected to prevent recruitment.

When the abundance of eels in streams is considered, it is probably most unlikely that trapping eels would prove a practical method for control. Electro-fishing might be useful in small streams or in small sections of larger rivers if sufficient time and effort were devoted. The repeated use of a fish poison in a section of stream might prove to be a cheaper method and sufficiently effective. Since the eel is primarily active after dark, that would seem to be the logical time at which to distribute the poison. The main objection to the method is, of course, that it destroys other fish.

Seaward migrants

Seaward migrants can be readily trapped, but as a control method nothing would be effected, since the eel presumably does not return after spawning but dies, and there has been nothing to indicate that their progeny return to "home" streams.

Summary

The only truly effective means of controlling eels would appear to be by denying them access to important streams or sections of such streams. The method might be by permanent dams or by electric fences and would be particularly applicable to elvers and to small eels during their secondary migrations up-stream. Once further recruitment of eels in a stream had been prevented, the elimination of resident eels could either depend on natural mortality (probably very small) or movement out of the stream, or on such methods of destruction as extensive electro-fishing and poisoning.

There should be awareness of the possibility of including in the design of proposed power dams modifications for barring eels from streams or for fishing down stream migrants. The same might also apply to more permanent salmon traps in the event of their construction for long-term investigation.

Acknowledgments

I would like to express my sincere thanks to the following: to Dr. P. F. Elson and Mr. H. C. White of this Station for their advice and assistance in the field, and to the latter also for his help in the Nigus brook experiments: to Mr. James Catt, Regional Supervisor of Fish Culture in Saint John, and Mr. K. G. Shellington, Manager of the Saint John Fish Hatchery for their very kind cooperation in providing the eggs and facilities for the egg-shocking tests: and generally to members of the Staff of the Station who have been generous with suggestions and advice pertaining to this investigation.

Literature Cited

d'Ancona, U. 1943. Nuove ricerche sulla determinazione sessuale dell' Anguilla. Archiv di Oceanograf. e Limn., Ann. III, Fasc. 3 (Mem. 308): 159-269.

Bertin, L. 1951. Les Anguilles; Payot, Paris.

Cairns, D. 1942(a). Life history of the two species of New Zealand fresh-water eel. Part 1: Taxonomy, Age, Growth, Migration and Distribution. N.Z. Journ. Sci. Tech. XXIII; 2B: 53B-72B.

1942(b). Life history of the two species of the fresh-water eel in New Zealand. Part II: Food and inter-relationship with trout. N.Z. Journ. Sci. Tech. XXIII; 4B: 132B-148B.

1942(c). Life history of the two species of fresh-water eel in New Zealand. Part III. Development of sex. Campaign of eel destruction. N.Z. Journ. Sci. Tech. XXIII; 5B: 173B-178B.

Crombie, A. C. 1947. Introspecific competition. Journ. Animal Ecol. XVI: 44-73.

Day, L. R. 1941. A preliminary report on elver migrations into Moser River, N.S. Mss. Rept. Biol. Sta., No. 213.

1948. Fishing eels - a profitable sideline. Fish. Res. Bd. Canad. G.S. 13. Circular: 1-3.

Elson, P. F. 1940(a) Predators of salmon fingerlings in Goldmine brook. Mss. Rept. Biol. Sta., No. 210.

1940(b) Food of salmon, trout and eels in Goldmine brook. Mss. Rept. Biol. Sta., No. 210.

1940(c) Fish population in Goldmine brook in relation to smolt production. Mss. Rept. Biol. Sta., No. 211.

1941. Eels as a limiting factor in smolt production. Mss. Rept. Biol. Sta., No. 213.

Frost, W. E. 1945. The age and growth of eels (Anguilla anguilla) from the Windermere catchment area. Journ. Animal Ecol. XIV, 1: 26-36.

1946. Observations on the food of eels (Anguilla anguilla) from the Windermere catchment area. Journ. Animal Ecol. XIV, 1: 43-53.

1950. The eel fisheries of the River Bann, Northern Ireland, and observations on the age of silver eels. Journ. Cons. Perm. Inter. Explor. Mer XVI; 3: 358-383.

Greely, J. R. 1935. A biological survey of the Mohawk-Hudson watershed. Suppl. 24th Ann. Rept. N.Y. Conserv. Dept., 1934: 1-379.

Heldt, H. and H. Heldt, 1929(a) Les civelles du lac de Tunis. Stat. Oceanograf. Salammbo, Bull. 14: 1-39.

1929(b) Etudes sur les civelles de Sidi-Daoud Stat. Oceanograf. Salammbo, Bull. 16: 1-23.

Hobbs, D. F. 1940. Natural reproduction of trout in New Zealand. N.Z. Mar. Dept., Fish. Bull. 8: 1-93

1948. Trout fisheries in New Zealand. N.Z. Mar. Dept., Fish. Bull. 9: 1-175.

Holmes, H. B. 1948. History, development, and problems of electric fish screen. U.S. Fish and Wildlife Service; Spec. Sci. Rept., 53: 1-62.

Hornyold, A. G. 1937. Les ecailles et les otolithes d'une Anguille de 106 cms. de l'Etang de Berre. Bull. Inst. Oceanograph., 734: 1-8.

Menzies, W. J. M. 1932. The common eel and its capture. Fish. Board. Scot., Salmon Fish., VI: 3-15.

1936. The run of elvers in the river Bann, Northern Ireland. Journ. Cons. Perm. Inter. Explor. Mer 11(2): 249-259.

Schmidt, J. 1922. The breeding places of the eel. Phil. Trans. Roy. Soc. London., 211 : 179-208.

1932. Danish eel investigations during 25 years. Carlsburg Foundation: 1-16.

Smith, G. F. M. and P. F. Elson 1951. A direct-current electrical fishing apparatus. Canad. Fish. Cult., No. 9: 34-46.

Smith, M. W. 1951. The American eel in waters of the Maritime provinces of Canada. Atl. Biol. Sta., (Mss. in preparation).

White, H. C. 1935. Aquatic enemies of planted salmon fry. Mss. Rept. Biol. Sta., No. 119.