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A Study of the Relationships Between Brown Trout and Eels in a New Zealand Stream

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A STUDY OF THE RELATIONSHIPS BETWEEN BROWN TROUT AND EELS IN A NEW ZEALAND STREAM

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SUMMARY

A mile long stretch of the south branch of the Waimakariri River, was isolated by a fish trap, and the numbers and weight of the trout and eel populations determined. Eels exceeded trout both in number and by weight.

In the spring of 1959 an effort was made to remove as many eels as possible. Eel control resulted in a marked increase in the trout population number with a consequent increase in density and an associated decrease in growth rate. As the growth rate of the trout decreased so the 'condition' of the trout declined from good to poor.

The downstream movement of trout, measured at the fish trap, accounted for only 12% of the fish which disappeared between the annual censuses.

INTRODUCTION

The acclimatisation of brown and rainbow trout in New Zealand has been very successful, and in their respective areas, both species are numerous. While both species were released in most lakes and rivers, they now have a fairly separate distribution. In the North Island rainbow trout are the principal fish south of Hamilton down to a line drawn from southern Hawkes Bay to north Taranaki. In the region of this line both species are found together, and south of the line brown trout predominate except in lakes. In the South Island brown trout predominate in nearly all rivers and streams, but rainbow trout are found in the lakes.

Most of the native freshwater fish are small compared to the trout, and are to some extent preyed upon by them. The largest of the native fish are the two species of eels. Anguilla dieffenbachii (the long finned eel) the female of which may grow to 200 cm., in length and Anguilla australis schmidtii (the short finned eel) the females of which grow to about 100 cm., in length. The short finned eel is selective in its choice of habitat, and is the exclusive inhabitant of some coastal waters. It generally prefers lakes and spring streams. The long finned eel is widely distributed, and it is found that almost every water has either one or both species present. In many cases the numbers are high and exceed those of the trout population.

Previous studies, Burnet (1952), Cairns (1942) have shown that eels are abundant, and that they prey on trout, and have similar feeding habits. However there was insufficient data to determine the effect of predation, and the extent of competition for food. Acclimatisation Societies have spent a considerable amount of effort on eel control in the hope of improving trout fisheries, and it was desirable that a more practical study of the problem be made. It was decided that the most satisfactory approach was to study a trout population in the presence of, and in the absence of, eels. This paper describes the results of such an experiment.

THE EXPERIMENT

The first problem was the choice of a stream suitable for such an experiment, and a decision on the length of stream to be used.

Christchurch, in the South Island, was chosen as a base to work from, and a number of streams in the vicinity were examined. The area chosen was in the upper reaches of the South Branch, a tributary of the Waimakariri River, and situated six miles north-west of Christchurch. The area, and its locality are shown in Figure 1.

This stream was chosen because it was spring fed, and the absence of flooding ensured that there would be no major physical changes in the environment. This was essential because physical changes could bring about trout population changes, and mask the effects which were being studied. The stream had abundant cover for eels, and a plentiful eel population. The main experimental area comprising 0.9 miles of stream was selected, and it was decided to install a fish trap at the lower end in order to isolate the population from a control section below the trap. The trap was designed to collect all fish moving downstream, and thus to determine the extent to which emigration accounted for the trout that disappeared each year.

The fish trap was constructed during 1957. It is shown in Figure 2 and had a basic timber framework which provided five 5ft wide bays. Into three of the bays horizontal screens of the type described by Whalls et al (1955) were fitted. Various types of wire mesh were tried and most satisfactory was six inch mesh stainless steel. This type of screen has been most successful and capable of handling a large amount of debris without blocking. The trap operated for up to four days without attention. Two of the bays were fitted with automatic drop gates similar to those described by Whalls et al (1956), and the water when the gates open falls on to an inclined screen of 10 inch mesh stainless steel gauze. The gates were adjusted to open when the water level rose. Further details are given by Hardy (1959).

The experimental area was divided into four sections, and tributary streams joined at the boundaries between sections one and two, and two and three; the volume of water carried thus increased downstream. The stream below the fish trap has been used as a control (section four).

The area measured was the open channel and there was in each section a varying width of weed bed on either side; this weed bed comprised the main cover for the eels.

Section one was 506 yards long, had an average width of 7.7ft, and an average depth of 1.3ft; Section two was 429 yards long, had an average width of 8.2ft, and an average depth of 1.4ft. Sections one and two were similar in area and in depth, but different in that section two was much more open with little bank cover or shade. In general, both sections consisted of a uniform channel with no definite pools.

Section three was 653 yards long, had an average width of 14.4ft and an average depth of 3.0ft. Itdiffered from sections one and two being wider and deeper and having six pools up to 7ft deep; thus there was a great deal more cover, especially for the larger fish.

Section four was 594 yards long, had an average width of 20.6ft and an average depth of 1.8ft. It was similar to section three, but was wider and not so deep.

Typical views of the four sections are given in Figures 3, 4, 5 and 6.

In the work of preparing the stream for the experiment, it was necessary to remove water weeds, and willow trees both of which provided some of the eel cover. Thus the eel population was probably reduced to some extent by physical changes in the environment. Also the data suggested that frequent sampling by electric fishing disturbs eels and so reduces the population.

In the spring of 1959 an effort was made to remove as many eels as possible both from the experimental area, and from some of the tributaries.

METHODS

TEMPERATURE

Water temperatures were recorded using a maximum and minimum thermometer sited at the fish trap. The thermometer was read twice a week.

TRAP

In 1957 a two-way trap was installed, as detailed in Hardy (1959).

ELECTRIC FISHING

The execution of the experiment was dependent on the development of suitable methods of electric fishing (Burnet 1959A and 1967). An annual census of the trout population was carried out about the 1st of September each year. This date was close to the hatching date of the fry and was taken as the beginning of the year. Additional samples were taken to give more detail of the growth rates.

The population estimates were made using both the diminishing returns and the mark and recapture methods.

MARKING

The adipose fin was removed on all fish handled in sections one, two and three, and this served as a guide to look for other markings.

In addition, the trout were individually tagged using a preformed wire loop and disc tag described by Hardy (In Press).

The eels were tagged with numbered stainless steel subcutaneous tags.

TROUT POPULATION

The trout population numbers were studied for three years in sections one and two, and for two years in sections three and four, and then the eel population was reduced as much as possible. The consequences of this reduction appeared in the following four years of the study.

During the first part of the programme the numbers of yearlings, and two year old fish were determined by polymodal analysis of the length frequency distribution, confirmed by data from tagged fish. It was found that the yearling fish could be distinguished from the older fish by size, and to some extent by colour. In recent years all yearling fish were fin clipped with a distinctive mark by the method described by Stuart (1958). In this method half of the fin is clipped off, and when it regenerates there is a mark where the cut was made. The paired fins were clipped in a four year cycle of, left pelvic, right pelvic, left pectoral, and the right pectoral. The Caudal, dorsal, and anal fins were clipped to indicate residence in sections one, two or three. Thus a clipped fish could be aged and its place of origin determined, and this simplified the analysis of the results.

The total numbers of fish were determined by the method of diminishing returns in sections one and two up to and including 1961. In this method the area was fished twice with electric fishing equipment described by Burnet (1967), and the fish caught were held in live boxes until the operation was completed. The total population was then estimated by the graphical method, Du Lury (1947), or from the formula. Estimated total = $\frac{(\text{1st Catch})^2}{\text{1st Catch} - \text{2nd Catch}}$.

The mark and recapture method was used in 1962 and 1963, because with the increase of fish it was not practicable to complete two runs of a section in a day. In sections three and four, the mark and recapture method was the most suitable one to use.

Fork length was used for all measurements of trout during the study.

RESULTS

PHYSICAL

Water temperatures recorded on a maximum and minimum thermometer from June 1960 to June 1961 (inclusive) are shown in Figure 7. There was comparatively little seasonal variation in temperature, and the difference between the mean summer, and mean winter temperatures was of the same order as the difference between summer maxima and minima. The minimum temperatures ranged from 7.8°C in the winter to 14.4°C in the summer, and similarly the maximum temperatures ranged from 10°C to 19.4°C.

The pH of the water was 7.4.

The resistance of the water measured at 25°C was 11,700ohms per cu.cm.

A number of measurements of the soluble phosphate were made and the concentration ranged from 1.3 to 1.8 microgramms P per litre.

EELS

The growth of eels in the South Branch, and two other streams studied will be given in a separate paper. Growth in the South Branch was found to be considerably less than in the other two streams.

The downstream migration of mature and immature eels was recorded at a fish trap, and the results of this study will be presented in a separate paper. The average size of the migrants were less than those recorded by Hobbs (1947) for migrants at Lake Ellesmere. This supported the observation that the growth rate in the South Branch was comparatively slow.

Eel control was begun in 1959. A total of 2,215 eels weighing 320Kg., was removed from the three experimental areas and comprised 53%, A. dieffenbachii and 47% A. australis by number.

During the 1960 census a further 489 eels weighing 68Kg. were removed, and since then smaller quantities have been caught each year. The numbers from each section are shown in Table 1. The number and weight of eels was considerably in excess of the number and weight of trout present.

TROUT

With all the data it has been found that the rate of catch increases as the size of the fish increases, therefore the yearling fish have been treated as a separate group.

Where the mark and recapture method was used the total population was estimated using the formula given by Ricker (1958).

$$N = \frac{M(C + 1)}{R + 1}$$

Where N = Size of the population at the time of marking
M = Number of fish marked
C = Number of fish caught in 2nd Census
R = Number of marked fish caught in 2nd Census

The range of the 95% confidence limits have been determined using Clopper and Pearson's (1934) chart. This chart is calculated for large populations and, it overestimates the range of the confidence limits for this data because the total population was small, and the proportion marked high. The effect shows up, especially in the case of the larger fish, in sections one and two in 1962 and 1963, and in section four in 1964, when the number caught (M + C - R) is greater than the lower range of the confidence limit.

The relevant data for the yearling fish giving the rate of catch, the estimated total population numbers, and the range of the 95% confidence limits of the estimate is given in Table 2.

Confidence limits are not given for the period when the method of diminishing returns was used in section one.

The value for the rate of Catch P, for sections one and two was consistent from year to year. The low figure for 1963 was probably due to unfavourable weather conditions during the sampling.

In section three the results were much more variable, due in some degree to unavoidable variations in the time available for the census. The high value for 1962 was certainly due to the longer time spent sampling. The 1958 figures for sections three and four were low due to the lower efficiency of the equipment. Apart from this section four results are consistent.

From the examination of the successive estimates in each section it can be seen that in most cases the 95% confidence limits do not overlap. This indicates that in respect to random sampling errors, the changes in the numbers of yearling fish are significant.

Similar data for the two year old and older fish are given in Table 3. A figure for the rate of catch has not been given where the numbers of fish caught were small. There was a significant increase in the numbers of older fish in section three from 1959 to 1961, since when the level remained fairly constant. In section four there have been significant changes in the number of larger fish, mainly due to the effect of two strong year classes.

Comparing the rates of catch for these larger fish (Table 3) with those of the smaller fish (Table 2) it can be seen that there was a consistent difference with the larger fish having the higher rate of catch.

Taking the years 1961, 62, and 63 the average value of P (the rate of catch) in section one was 0.79 for the larger fish and 0.64 for the smaller fish, a difference of 0.15. Similarly, in section two the rate of catch for the larger fish was 0.78 and for the smaller fish 0.56, a difference of 0.22. In section three the average rate of catch for the larger fish was 0.66 and for the smaller fish 0.47, a difference of 0.19. In section four the average rate of catch for the larger fish was 0.64, and for the smaller fish 0.56, a difference of 0.08.

In general the rates of catch were highest in section one, then came section two, followed by section 4, and the lowest values were recorded in section three (despite a greater effort put into the sampling of this section). This order was the same as that of the average depths of the stream, and it is thus clear that the deeper the water the more difficult is electric fishing.

Thus, examination of the rates of catch for the four test sections showed that when a population was estimated by electric fishing, the rate of catch can vary with the size of the fish being caught, the output of the equipment, the weather, and the depth of the water.

A further check on the accuracy of the estimates is possible by comparing successive years' figures. The estimated percentage of the total population marked was calculated from the proportion of marked fish in the catch, the number of fish marked during the census, and the estimated total population. These fish would then comprise the two year old, and older fish in the following year, and the percentage of marked fish in this group should agree, within the limits of the experimental error, with the percentage marked as calculated above. The results of these calculations are given in Table 4.

The results for sections one and three were fairly consistent, but section 2 showed considerable variability. In all cases, except one which involved only a few fish, there was an apparent decline in the percentage marked in the population. There must therefore be a systematic error in the method, and this could be due to the following

1. Non recognition of marks.
2. Higher mortality of the fish handled.
3. Immigration into the test areas of unmarked fish from the tributaries.
4. Underestimation of the total population due to incomplete random mixing between mark and recapture.

As mark recognition is based on the adipose fin being clipped in addition to the other marks, it was considered that non recognition was not significant. Trials have been carried out to measure the mortalities resulting from electric fishing, handling of the fish, tagging, measuring, and the use of M.S.222 as an anaesthetic. (N.B. M.S.222 was used throughout most of the experiment as an aid to the handling of the fish). In the tests described by C.J. Hardy in a paper to be published, 282 fingerling fish, and 83 yearling and older fish were caught by electric fishing, and transferred to hatchery ponds for observation. The larger fish were anaesthetised, and tagged before release in the ponds. Excluding the fish found dead immediately after capture, the post handling mortalities amounted to three fingerlings (1%), and no larger fish.

Fifty eight fingerlings were held in a 1in 15,000 solution of M.S.222 for periods of up to 43 minutes with no resulting mortalities. In practice the fish are held in live boxes in the stream for at least ½ an hour before release, and any dead fish noted. It would appear from the tests that unseen post handling mortalities were not significant.

Immigration could account for part of the difference between the estimate of the percentage marked, and the actual number found to be marked one year later. It will be shown later that there is a downstream movement of fish from outside the experimental area.

However, if immigration was significant its effect should decrease when the numbers of fish in the experimental area increased. There is no definite evidence that this occurs.

It therefore appears that the total population was consistently underestimated. It was realised from the start that electric fishing did not sample the whole of the population, as it was not practicable to cover the weed bed areas. Owing to the strong territorial behaviour of trout it is unlikely that a completely random mixing occurred between marking and recapture. However, to minimise this effect an effort was made to cover the same areas from year to year.

A summary of the estimated total population numbers, weights, and the average lengths for one year old, two year old, and older trout is given in Tables 5 and 6.

The four sections were treated separately as there were physical differences between the sections, and marking experiments have shown that there is little movement of trout between sections. Eel control, begun in the spring of 1959, was effective for the yearlings caught in 1960. There were three years of observations of the population of sections one and two prior to eel control, and two years in section three.

In section one eel control resulted in a marked increase in the trout population numbers, an average increase of 4.9 times for the yearling fish. In section two the average increase was 9.9 times, and in section three, 2.7 times. In contrast there has been no change in the control section (0.9 times).

The increases in the numbers of yearlings have been followed by increases in the numbers of older fish, and a build up in population numbers and weight, with associated decreases in the growth rates.

OVA PRODUCTIONS

Data on the numbers, and sizes of mature fish were collected in 1962. Previous measurements were not made because of the risk of damage to the fish by electric fishing during the spawning season, and possible effects on the spawning behaviour.

It was planned to estimate the number of ova deposited from proportion of fish which were mature. The proportion of mature one year + fish was higher in sections one and two (39%) (mainly males), than in section three (21%), and this correlates with the slightly higher growth rate in sections one and two. Of the two year + and older fish the majority were mature, 86% in sections one and two, and 88% in section three. From this data, and the estimated population numbers during the spawning season, it was calculated that there was a total of 118 female fish in sections, one,two and three, and the average length was 23.3 cm. The average length of the males was 24.0 cm.

Data on the fecundity of the brown trout of this stream has been presented by Hardy (1967). The total number of ova for the 118 mature fish was calculated to be 47,000. In the following year, 1963, the number of yearlings was estimated at 1,109, giving a survival of 2.4%. In comparison the result obtained by Allen (1951) for the Horokiwi River indicated a survival of 0.5% from ova to yearling stage. Examination of Tables 5, 6, and 7 showed that the 1962/3 data was for a comparatively high ova production, and a low number of yearlings. When the 1959/60 results were considered (0.22 times the number of redds, and 1.6 times the number of yearlings), the survival must be many times that calculated above. (Could be of the order 17%.) There was thus, if anything, a negative correlation between the numbers of ova, and the numbers of yearlings surviving.

That survival rates from ova to yearling stage can vary substantially was supported by the section four data, and agrees with conclusion reached by the author (1959b) in a study of two other brown trout populations.

The 118 mature females in 1962 were in excess of the number of redds counted in the experimental area (77). Observations were not detailed enough to determine whether superimposition of redds occurred, or whether the larger redds were the results of more than one pair of fish. These two factors, together with the possibility that some of the experimental area fish spawned outside the observed area would account for the discrepancy between the estimate of the number of mature females and the number of redds observed. The results support the conclusion that when conditions are suitable a fish will deposit all its ova in one redd.

SURVIVAL RATES AND EMIGRATION

The survival rates for sections one and two are shown in Figures 8 and 9. These graphs include population estimates made when the fish were about six months old. There was no definite change in survival rates following eel control; certainly not sufficient to account for the marked increase in the number of yearlings. Survival rates, one year to two year old, for sections three and the control (section 4) are shown in Table 8. There was a significantly higher survival rate in section three when the eels were controlled.

The average survival rate for section one (16%) and section two (18%) are similar to the rates measured by Allen (1951) in the Horokiwi River. Survival rates in sections three and four are over twice the Horokiwi River rates. In section three, since eel control, there has been a negative correlation between the number of yearlings and the percentage surviving to two years old. There was only a slight indication of a similar relationship in section four.

It is clear from the results that the major increase in survival rates brought about by eel control occurred at some time between the ova and the fingerling stage.

The fish trap was installed to measure the downstream movement of trout so that it could be compared with the survival rates. The numbers of trout moving downstream are shown in Table 9. The trap was examined twice a week for most of the experiment, and this meant that at times there would be both eels and trout in the ponds together. It is known that there was some predation by eels on the smaller trout, but a satisfactory correction has not been devised.

The downstream movement of fry (September to December inclusive) has been compared with the area of the redds in section three. There was a significant positive correlation (r = 0.91) between the numbers of fry moving downstream, and the area of the redds, which is presumably a function of the number of ova deposited.

The comparison of the numbers of fish moving downstream with the numbers surviving was best made using recaptures of fin clipped fish. Table 10 gives for 1962 and 1963 the survival over the latter part of the first year of life for marked fingerling fish in sections one and two.

The estimated annual survival rates are, 1962, 17.5% and 1963 18.6%. Only a small proportion of the marked fish appear at the trap, or in section three. (The trap catch is also expressed as a percentage of the geometric mean of the number of marked fish present in both areas over a period.) The numbers appearing at the trap, and in section three are much smaller in 1963 for some unknown reason. Of the total number of fish in their first year, caught during this period, only a small proportion were marked (9.5%), and it was concluded that the majority, comprising unmarked fingerlings, came from section three. It is suggested that the downstream movement of fingerlings is a general drift rather than a definite migration.

The one year old and older fish have a definite spring migration with the peak run in October and decreasing over the summer. During the period a proportion of the fish caught had a silver appearance. After the population numbers had built up there were also winter runs, usually associated with rainfall.

There was some trout water above the trap, and not included in the experimental sections. A proportion of this water has had the eel population reduced. The trap is thus catching trout from the experimental areas, and from unchecked areas. For each year a correction has been calculated by comparing the mean proportion of marked fish in the population with the proportion caught in the trap. The results are shown in Table 11. There is, as would be expected, an increase in the numbers of fish moving downstream, as the fish population of the experimental areas increased. The increase in numbers from the experimental area is much greater than the increase in number of fish originating outside the experimental areas. This would be expected as only a proportion of the outside area was affected by eel control.