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Margaree Salmon and Trout Investigation

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MARGAREE SALMON AND TROUT INVESTIGATION

VOLUME XI

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MARGAREE SALMON INVESTIGATION

1937

Report No. IX

Smolt Spring Growth of
The Salmon Scale

By Wm. S. Hoar

Studies of the smolt spring growth of the Margaree salmon in 1936 showed that:

1. Scale growth takes place during the migration to the sea.
2. The circuli formed at this time are intermediate in character between those of the parr and adult fish.
3. The circuli become broader as the season advances.
4. The amount of smolt growth is proportional to the time spent in reaching the sea.
5. Proportionally to their length parr show a more rapid growth than the smolt which have remained in the river (See M.S. Report on this subject for 1936).

Similar studies of 165 smolt and 100 parr during the present season substantiate these findings. The smolt studied this year were collected at Margaree Harbour from May 24th until June 12th, and at Forest Glen Brook from May 30 until August 7. Parr were taken throughout the river system. The detailed measurements are given in Appendices "B" and "C" of the report on "Changes in Condition of the Margaree Salmon".

With the exception of two smolts - one taken on May 24 and the other on May 29 - all scales showed that at least one circulus had been formed before reaching the sea. Since collections were made this year throughout the greater part of the migration it seems certain that growth is made in over 90 per cent of the smolt

{90+ % for the data of 1936 and 1937}, descending the Margaree. / Studies of mature salmon scales would scarcely lead us to believe that such a large percentage of fish show this growth. A careful consideration of the adult scale, however, shows that the above conclusion is probably true. These scales show that the circuli following any winter's growth are usually narrower by about one division, than the majority of the summer bands. The following table prepared from scales collected on June 16 illustrates this feature. In none of these fish was "smolt spring" growth clearly marked.

Length of Fish	Weight of Fish	Width of Circulus (divisions)			
		Following the parr winter		Following first sea winter	
		First Circulus	Outer Circulus	First Circulus	Outer Circulus
72 C.M.	8 lbs.	2	4	2	3-4
90	17½	2	5	4	4-6
96	20	3	4-5	3	4-5
78	8½	2	3-4	3	4-5
80	9½	2	3-5	3	5

Comparing this data with that in the table on page 4 (widths of Individual Circuli) shows why one is not aware of smolt growth more often when studying adult scales. Practically all the smolts do commence their spring growth with comparatively narrow bands. However, when there are but one or two of these, as in smolts 2, 4, 8, 9, 10 etc, they can scarcely be distinguished from this gradual widening, which takes place in any spring. The earliest smolts to go to sea will then show no smolt growth in their adult scales, even though a small number of circuli may have been formed. Conversely, adult salmon showing this peculiar region of scale growth were largely fish which descended the river later when smolts.

The table below illustrates the fact that the amount of scale growth is directly proportional to the time spent in reaching the sea.

Scale Growth of Margaree Harbour Smolts.

Date	No. of Specimens	Average No. of Circuli added	Average width of Circulus	Average % Growth
May 24-29	21	2.9	0.26	13
June 3-5	46	4	0.27	20
June 7-10	29	4.4	0.28	22
June 11-12	24	5	0.29	26

Not only does the number of circuli - hence also the percentage of the total scale growth - increase as the season advances, but the circuli become wider. This last feature is true only to a limited extent. The widening reflected above in the average figures is due to two factors. The bands do widen gradually for the first two or three circuli (table on page 4). Even after this, however, average figures will still tend to show an increase in width, due to the fact that more wide circuli are being formed.

In 1936 we concluded that the growth under study was characteristic of the smolt spring and not of the estuary or locality where the smolts were taken. A comparison of the Forest Glen Brook fish (table given page 3) with those taken at Margaree Harbour (table above) sheds further light on this problem.

Forest Glen Brook Smolts.

Date	No. of Specimens	Average No. of Circuli added	Average width of Circulus	Average % Growth
May 30	6	1.4	0.29	8
June 10	5	2.7	0.19(?)	12
July 6	10	3.1	0.24	16
July 15	9	5.3	0.22	21
July 22	5	7.1	0.19	25
Aug. 7	3	8.5	0.19	29

In considering this table it must be remembered that the fish of Forest Glen Brook grow more slowly than at many other places on the river system. This is evident from the fact that 73 per cent of the fish are 3 year smolts, as compared to 27 per cent of 3 year smolts taken at the Harbour Mouth. Moreover, fry collected at Forest Glen Brook in the first week of August averaged 4.0 c.m. in length, as compared to the 4.9 c.m. fry from Widow Lord's Brook or 6.1 c.m. fry from North West Margaree (Doyle's Bridge) collected at the same time.

Although growth is slower in this river the smolt adds circuli to its scale in the same manner. The table shows that the number of circuli added, and the percentage growth made increases as the season advances in the same manner here as at the Harbour Mouth. The figures seem to show that the average width of the circulus is less in the Forest Glen fish. The table given below, nevertheless shows that circuli formed here are of the same general width as those formed at other places. However, the bands tend to form somewhat later or more slowly; for example, fish taken on June 10 at Forest Glen had added 2.7 circuli, while those at the Harbour had added 4.4 circuli. This is the difference which is reflected in the average figures for the width of the circulus.

Widths of Individual Circuli

Specimen Number	Date	Place of Collection	Width (in divisions) of the Individual Circuli Formed During Current Year.
2	May 24	Harbour	3, - 2 $\frac{1}{2}$, - 3 $\frac{1}{2}$, 5, - 4
3			3
5			2 -, 3
8	May 26	Harbour	3 - 3
9	May 28		2 - 4 } Parr marks evident.
10			2 - 4 }
57	June 5	Harbour	2 - 2 - 2
60	"	"	2 - 3 - 4 - 4
55	"	"	2 - 3 - 3
57	"	"	2, 4, 4, 4, 3 $\frac{1}{2}$, 3 $\frac{1}{2}$
63	"	"	2, 2, 2

Specimen Number	Date	Place of Collection	Width (in divisions) of the Individual Circuli Formed During Current Year.
129	June 10	Harbour	3, 3, 3, 3, 3,
130	"	"	2, 2, 3, 3, 3, 3
132	"	"	3, 4, 3, 2 $\frac{1}{2}$, 3
133	"	"	2, 2, 3, 4
138	"	"	.3 (From Forest Glen)?
124	June 12	Harbour	2, 2 $\frac{1}{2}$, 3, 5
120	"	"	3, 3, 5, (11 $\frac{1}{2}$)
101	June 16	Harbour	2 $\frac{1}{2}$, 2 $\frac{1}{2}$, 2, 2, 1, 1 $\frac{1}{2}$, 2, 2
103	June 15	Chapel Bridge	1, 2, 2, 2, 2, 2
103a	June 19	Margaree Ford	2, 3, 3, 2, 2 $\frac{1}{2}$, 2 $\frac{1}{2}$, 2 $\frac{1}{2}$
102	June 29	Marg. Estuary	2 $\frac{1}{2}$, 2 $\frac{1}{2}$, 2 $\frac{1}{2}$, 2, 1 $\frac{1}{2}$, 2, 1 $\frac{1}{2}$, 1 $\frac{1}{2}$, 1 $\frac{1}{2}$
110	Aug. 2.	Trout Brook	Bands uniformly 2 (17 in number)
104	July 4	Glen Brook	2, 5 $\frac{1}{2}$, 1 $\frac{1}{2}$, 1 $\frac{1}{2}$,
	May 30	Glen Brook	2, 1
	"	"	2, 3
	"	"	1 $\frac{1}{2}$, 2 $\frac{1}{2}$, 1
156	July 6	" "	1, 2, 1
160	"	" "	3, 3, 5
144	July 15	" "	.3, 3, 2, 2
150	"	"	3, 2 $\frac{1}{2}$, 3, 2, 1 $\frac{1}{2}$, 1 $\frac{1}{2}$
162	July 22	"	4, 3, 3, 2, 2, 1 $\frac{1}{2}$, 1
163	"	"	3, 2, 2, 2, 2, 1 $\frac{1}{2}$, 1 $\frac{1}{2}$, 1 $\frac{1}{2}$, 1 $\frac{1}{2}$
165	"	"	2, 2, 1 $\frac{1}{2}$, 1, 1
	Aug. 7	"	3, 3, 2, 1, 1, 1, 1
	"	"	2, 2 $\frac{1}{2}$, 2 $\frac{1}{2}$, 2, 1 $\frac{1}{2}$, 1 $\frac{1}{2}$, 1 $\frac{1}{2}$, 1
	"	"	2, 3, 3, 2, 2, 1 $\frac{1}{2}$, 1 $\frac{1}{2}$, 1, 1

It is evident, then, that the rate of widening of the circulus and the width of the ridge formed is unrelated to the estuary. A careful study of the scales of four parr, seined from the estuary in company with a smolt failed, moreover, to show any growth that might be characteristic of the estuary. Three of these parr were two years old, and hence of the same age as the smolt taken with them.

The scale growth of the smolt is, like all scale growth, definitely influenced by the environmental conditions. This is shown in fish which because of natural or artificial barriers have been prevented from reaching the sea. Thus a smolt - 22.6 c.m. in length - taken at the mouth of Trout Brook on August 2nd had added 17 bands of almost uniform width during the season. This fish was apparently

returning from a summer of good feeding in Lake Ainslie. The circuli were considerably narrower than those formed in the sea (0.2 as compared to 0.4 or 0.6). This growth is very similar to that of the last smolts to leave the estuary (Nos. 101, 102, 103 and 103a of the table on page 5). Feeding conditions here might be expected to be good, and comparatively narrow circuli tend to form rapidly. This is in contrast to the growth of fish forced to stay in Forest Glen pool because of an artificial barrier to their descent. The fish here after the first of July form the narrow bands characteristic of a winter's growth, and presumably of poor feeding - (Table page 3). Thus it seems that although smolt growth is typical of the smolt, and more nearly that shown by the adult salmon than that of the parr, the exact character of this growth depends on the local conditions. Under favourable conditions growth is rapid, the circuli being wider than those of the parr, but narrower than ridges formed in the sea. Under adverse conditions narrow ridges characteristic of winter growth are formed. The formation of the bold wide bands characteristic of sea growth is evidently dependent upon the fish's reaching the sea.

A check is often found on the salmon scale in the first year of sea growth. This frequently appears at a point which might very well be formed when the smolt reached the sea. It would be interesting to know whether this was due to a prolonged stay in the river, or to other adverse conditions.

Proportionally to their lengths parr show a more rapid growth than smolts under similar conditions. As any fish becomes longer the percentage of its total length which it can add in any given time

must become less. For example, yearling parr show a greater percentage increase of growth than two year parr at the same time in the season (47% for yearling parr as against 31% for the two year olds). Similarly, two year smolts grow more, comparatively speaking, than the three year fish (25% as compared to 11%). Remembering this, however, and comparing parr and smolt of the same age, we find that the parr grow more rapidly. The table below shows this. Parr tend to add a greater percentage of their length during the same time, and to add a greater number of circuli, but these are narrower.

Comparison of Parr and Smolt Scales

Date	Place of Collection	Age of Fish	Specimens Studied	Average No. of Circuli	Average Width of Circulus	Average % Growth
June 29	Margaree Estuary	2	2 Parr	10	0.21	47
			1 Smolt	11	0.21	35
July 4	Forest Glen Brook	2	4 Parr	6	0.19	25
			4 Smolt	3½	0.26	21
		3	1 Parr	9	0.19	31
			4 Smolt	7	0.20	26

Summary

1. The majority of the Margaree salmon show a smolt spring growth.
2. The amount of this is proportional to the time spent in reaching the sea.
3. The first two or three circuli often show a gradual widening out. This probably indicates that the smolt metamorphosis is gradual.
4. In early smolts the spring growth passes into the sea growth without leaving any obvious record. In the later fish the spring descent will be clearly marked by circuli narrower than those formed

in the sea, but more nearly similar to the latter than the narrow parr ridges.

5. The growth studied is not typical of the estuary but of the smolt.

6. A prolonged stay in the river after metamorphosis is reflected on the scale according to the environmental conditions. With favourable conditions, such as found in Lake Ainslie or the Margaree Estuary, rapid growth will continue. Under adverse conditions growth almost ceases.

7. Parr grow more rapidly than the smolts remaining in the river. They are probably better adapted to life in the fresh water (?)

MARGAREE SALMON INVESTIGATION

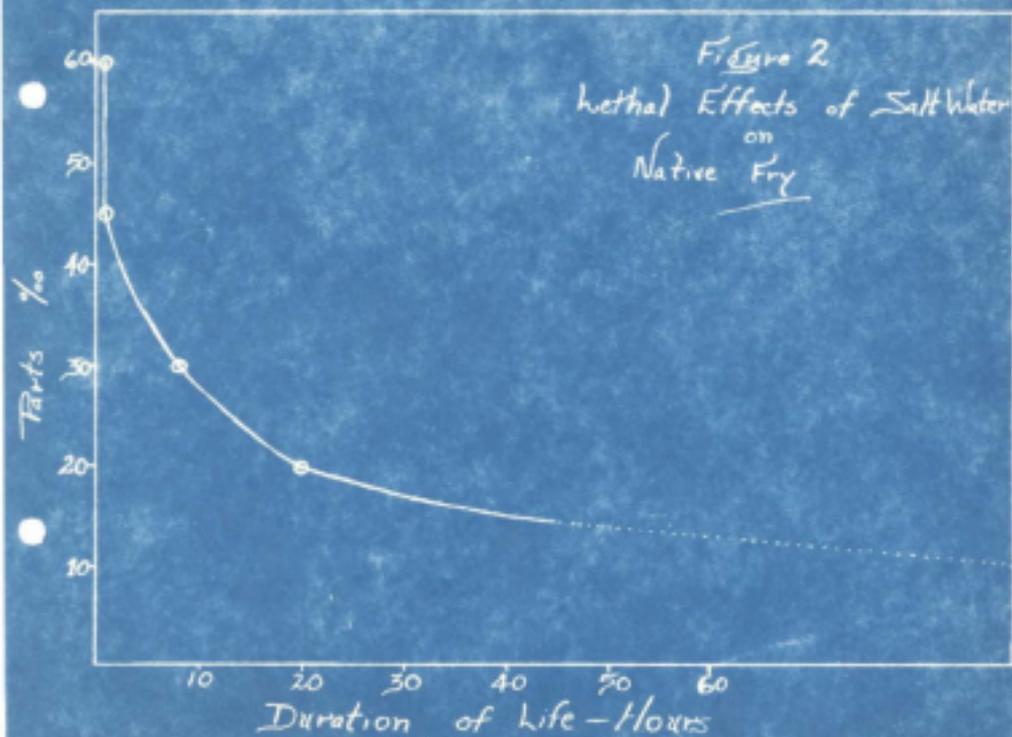
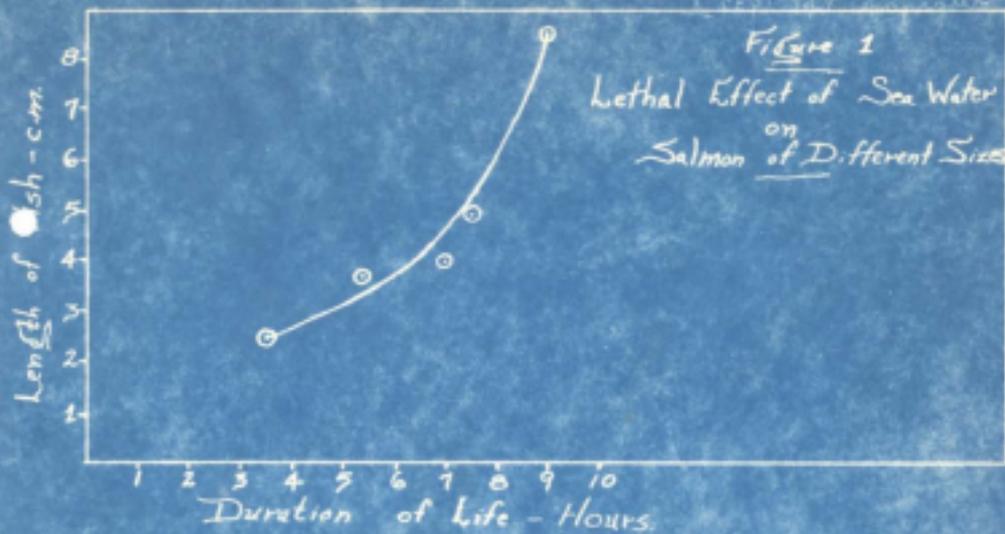
1937

Report No. X. The Reactions of Young Salmon
to Salt Water

By Wm. S. Hoar.

As yet little is known of the mechanism whereby some fish may pass from fresh to salt water and back again. This problem is especially pertinent in the case of an anadromous fish such as the salmon, spending the early part of its life in fresh water, maturing in the sea and returning to some river to spawn. In many rivers fish have a long estuary, with waters of gradually changing salinities, to pass through in their journeys to and from the sea. Such an estuary - for example the Margaree - may contain on occasion all stages of salmon parr, smolt and river mature fish. The fish might then in such cases become gradually adjusted to these changes of salinity. These conditions, however, do not hold for every river. There are rivers where the passage from fresh to salt waters is most abrupt, leaving no room for an adjustment. Yet smolt descend these rivers and mature salmon return to spawn. There is evidence that parr, however, in these places may be washed out to sea and killed. It would be valuable, then, to know under just what conditions salmon may pass safely from fresh to salt water and back again. Is it a matter of size? Do they tend to be climatized to waters of different salinities? What effect do changing salinities, such experienced in an estuary, have on the fish?

With these questions in mind the following three sets of



experiments were designed in an attempt to clarify the situation. The effect of (a) different salinities on fish of different ages - (b) changing salinities on young salmon - (c) increasing salinity on the fish.

Materials and Methods.

Salmon of four different sizes were studied:

1. Parr seined from Widow Lord's Brook, Margaree River - average length 8.5 cm.
2. Fry from the same locality - average length 4.9 cm.
3. Hatchery Fry - average length 5.6 cm.
4. Hatchery Fry (starved for more than a month) average length 2.7cm.

Assuming that age, in this case, is proportioned to size, we have four differently aged fish on trial. All were in excellent condition except the small hatchery fry which became weakened toward the end.

Pint fruit jars containing 300 cc solution were used as containers for the fry, and enamel pans - 2 litre capacity - containing 1800 cc for the parr. Quart fruit jars were tried and found to be too small for the parr.

The containers were placed in a stream to keep the temperature comparable, and a shade was constructed over them to ward off the strong light.

Sea water was obtained fresh before each experiment to insure good aeration. Water of the required salinity was prepared from the following formula -

IF A - quantity of water in use.

S - actual salinity.

S'- desired salinity.

S^F- salinity of water used in replacing.

A^F- Amount of water to be replaced.

General Formulae

Going to a higher salinity.

$$A^F = \left(\frac{S' - S}{S^F - S} \right) A$$

Going to a lower salinity

$$A^F = \left(\frac{S - S'}{S - S^F} \right) A$$

Water of salinities higher than the sea water was obtained through a slow evaporation of the latter over an open flame and subsequent aeration by shaking small amounts in gallon jugs. All water was kept either in gallon jugs or a wooden keg.

Preliminary Experiments.

To determine the effect of salinity alone all other factors must be constant. Temperature, light and oxygen supply are the factors most likely to enter into the following experiments. The first two were governed as described above, while the following experiments showed the conditions necessary to insure an adequate supply of oxygen. This could be governed in two ways, by frequent changes of solution or by increasing the volume of solution for the given mass of fish. Since salmon tend to live for rather long periods at the lower salinities, it was necessary to arrange for an oxygen supply sufficient to last for, at least, two hours during the day and for twelve hours at night.

The first set of experiments carried out with 6 fry in pint

jars and 3 parr in quart jars showed that fish live longer in jars containing air above the water than in jars completely filled with water.

The other sets of experiments were necessary to show that but one large fry could be placed in a pint jar - 300 cc solution - with impunity, and that quart jars were too small for the parr. The parr weigh about 6X as much as the fry, and it was found that enamel pans containing 1800 cc solution were very satisfactory for these. During the course of the following experiments it was demonstrated that 1 fry in 300 cc solution, or 1 parr in 1800 cc solution, remained in good condition for as much as 18 hours. We may safely conclude that the fish had an ample supply of oxygen when changed at 2-4 hour intervals in the day and remaining for 12 hours at night.

Experiments to Determine the Lethal Times for Different Sized Fish in Waters of Different Salinities.

Experiment A

Large and small hatchery fry were tested. Measurements showed that the larger fry were 3.5 times heavier. It was then necessary to have one large fry to 3½ small fry. As it was deemed safer to place only one large fry in a bottle two series of small fish were tried, one with 3 per jar and the other with 4 per jar. As no difference in behavior of these two sets was noted the results given below are for a combination of them. A second series of large fry was run as a check.

The salinity of the water used here was found to be 28.44‰. Waters of salinity 10‰ - 20‰ and 28.44‰ were used.

The following table gives the results in abbreviated form:-

Effect of Salt Water on Young Salmon.

Time	Temp.	Small Fry (Av. Length 2.7cm)				Large Fry (Av. Length 3.8cm)			
		[per mille]				per mille]			
		0	10	20	30	0	10	20	30
°C									
July 28 Experiment Commenced									
11.15 a.m.									
1.45 p.m.	19.0								1 fry on side.
2.25 p.m.									3 fry dead
3.25 p.m.	19.1			1 fry on side					All dead
4.15 p.m.									Fry on side
4.35 p.m.	19.0								3.7cm fry dead
5. p.m.									4.0cm almost dead
7.30 p.m.	18.1			2 fry dead					4.0cm fry dead
7.45 p.m.				Fish less active					
9.45 p.m.				4 fry dead					
July 29									
8.15 a.m.	16.2	1 per- siti- zed		All dead					
1.30 p.m.	19.6							3.5cm dead.	
4.45 p.m.	18.8							4.1cm on side	
5. p.m.								Almost dead.	
7.30 p.m.	17.4							Dead.	
July 30									
9 a. m.	18.0								
12 a.m.	17.3			1 fish dead					
July 31									
3 p.m.				Other fish dead					
									Remaining fish in good condition August 15th.

+ Controls seem to be parasitized and several die before conclusion of experiment.

* Several fish died but their condition was poor and factors other than salinity have probably been operative.

Experiment B.

This experiment was the same as the last except that native fry and parr were used as subjects. Determination of the weights of the fish showed the parr to be 6 times as heavy as the fry. Enamel pans containing 1800 cc were used for the parr, and pint fruit jars with 300 cc for the fry. The sea water obtained had a salinity of 28.6‰. The following table summarizes the results:

Effect of Salt Water on Young Salmon

Time	Temp.	Small Fry (Av. Length 3.1cm) (per mille)				Large Fry (Av. Length 8.5cm) (per mille)			
		0	10	20	28	0	10	20	28
Aug. 6									
10 a.m.	18.8								
2.15 p.m.	20.6								
4. p.m.	19.8								Slightly weakened.
6. p.m.									Dead - (4.9cm)
6.30 p.m.	18.5								On side.
7. p.m.									Dead - (8.5cm)
Aug. 7									
6.15 a.m.	15.8								Dead (5.1cm)
4. p.m.									Dead (9.7cm)
Aug. 8									
2.30 p.m.	22.1								
8.30 p.m.	19.3								
Aug. 9									
6.30 a.m.	18.8								
4. p.m.	22.1								
6. p.m.	20.2								

Fish in good condition on Aug. 12th

Experiment C.

Native fry were placed in water of 45‰ and 60‰ at 8.35 a.m. (Temp. 29.1). At 9 a.m. the fish were still swimming well and apparently in good condition. At 9.30 a.m. both fish were dead.

Discussion-

Although temperatures were recorded throughout, and their effect is evident, we shall neglect them in the following general discussion.

The following table summarizes the results of the three experiments:-

Lethal Times At Various Salinities.

Length of Fish Control (average)	10‰	20‰	28‰	45‰	60‰
2.7 cm.	75 Hrs.(?)	10	3-4		
3.8 cm.		26-32	5-6		
5.1 cm.		11-20*	8	0.5-1	0.5-1
8.5 cm.		23-30	9		

*Note- Another series lasted 40-48 Hours.
(Temperature several degrees lower)

The data is also shown in the two graphs on page 7^b. Figure 1 shows the lethal time in full strength sea water in relation to the length of the fish, while Figure 2 shows the lethal effects of different salinities on native fry.

Thus it is evident that the larger the fish the more resistant it is to salt water. Moreover, waters of higher salinities bring about death more rapidly than waters of lower salinity.

Figure 2 shows that above salinities of 20‰ the curve rises very rapidly, so that at the highest salinities there is very little difference in the lethal times.

Young salmon were kept alive in excellent condition at salinities of 10‰ for over a week. The smallest fry did die at these low salinities, but they were weakened fish in poor condition as evidenced by the fact that even the controls could not be kept alive indefinitely. These became weakened, moved in a spiral fashion for a time and eventually died. Parr have been seined from the estuary at points where salinities of 10‰ and up to 18‰ have been reported (Rogers' MS. Report on The Margaree Estuary 1936). Our results tend to show that the young salmon may live perfectly well at these lower salinities. This is particularly true since the salinities would fall much lower than this at times in the tidal cycle, thus giving the fish time to recover from any harmful effects before the next salt water (see below).

The Effect of Changing Salinities on Young Salmon.

Native fry from Widow Lord's Brook were selected for this study. Pint jars with 300 cc of solution were used and changes made every two hours. Three fish were observed -

1. In stream water changed to the same every 2 hours.
2. In sea water (salinity 23‰) changed to the same every 2 hours.
3. In sea water changed to stream water, these alternating at 2 hour intervals.

The experiment was commenced at 6.30 a.m. and continued until 10.30 p.m. Water temperatures at 6.30 a.m., 2.30 p.m. and 6.30 p.m. were respectively 18.5°, 23.0° and 19.9°C. Between 1.30 and 2 p.m.

(i.e. after 7 hours) the fish which was continually passed into sea water died. At the end of the day the fish passing from sea water to stream water and back, although it had spent 8 hours in sea water, was in good condition.

The following morning at 8.45 a.m. the experiment was continued and run until 9.45 p.m., giving the fish 6 hours more exposure to salt water. It was apparently unaffected. The water temperatures on this day were 19.5°C at 8.45 a.m., 22.2°C at 3.15 p.m. and 20.6°C at 7.30 p.m.

It seemed that the fish might be maintained almost indefinitely under these conditions, so on the next day both fresh water control and the experimental animal were placed in full salt water. It was thought that by determining the resistance of the two animals to salt water some effect of changing salinity on the fish might be demonstrated. Temperatures this day were 20.1°C at 8.45 a.m. and 21.5°C at 3.30 p.m. At 4 p.m., after 7 hours, both fish were in good condition, although the experimental animal seemed less active. Unfortunately, the experiment could not be followed closely to its conclusion. However, since it was nearing the lethal time (8 hours) for fry of this size, it seems probable that no great difference in death rate would have been found. The comparative inactivity of the experimental fish mentioned above was no greater than we might expect from individual variation.

The experiment shows that fry are little affected by sea water during an exposure of 2 hours. Any effect which such an exposure may have seems to pass off when the fish is returned to fresh water.

The Effect of Increasing Salinity on Young Salmon.

It was hoped to demonstrate whether young salmon could be climatized to waters of high salinity, or whether they could live longer at high salinities when given a period for adjustment. Time, however, permitted the carrying out of but one experiment.

A fry - 5.2 cm. long - and a parr - 7.9 cm. long - were placed in an enamel pan containing 900 cc fluid of a salinity 5% at 8.30 a.m. The salinity was increased by 5% every hour. The fry died in salinity 40% and the parr in 45%. The difference in time, however, was not great as the parr died 15 minutes after going into the last solution.

This experiment reaffirms the fact that the larger fish are more resistant to salt water and can stand waters of higher salinity. One cannot make any statement from this experiment as to whether the salmon may be climatized to salt water or not.

Summary.

1. Sea water kills young fresh water salmon.
2. The higher the salinity of the water the more rapidly is the fish killed.
3. Larger fish can stand higher salinities, and can stand salt water for longer periods of time than the smaller ones.
This can hardly explain, however, the ease with which the smolt passes into the sea, since many smolts are scarcely larger than parr which are killed by sea water.
4. Water of low salinity - up to 10% or more - has no apparent effect on fry and parr.

5. Young salmon are apparently uninjured by salt water exposures of 2 hours, or are capable of a complete recovery from any such injuries when placed in fresh water for the same time.
6. The last two facts indicate that young salmon may adapt themselves to a life in parts of the estuary. Indeed we have found them there.

MARGAREE SALMON INVESTIGATION

1937

Report No. XI. Miscellaneous Memoranda - 1937.

By W. S. Hoar.

June 10 The AuCoin Bros. report that they have taken more slink salmon than usual this year.

June 14 The fishermen commenced "gutting" their fish before shipping them away. This was continued until July 12. During this period 422 of the stomachs were examined, and a search made for tape worms. Sex ratios were also recorded. The data is given in detail in the Condition Factor report - Appendix E. All of the stomach contents were preserved for study.

Mr. Turnbull of the North East Margaree Fish Hatchery reports that he has taken many smolts in his traps as early as February.

June 15 Smolts were taken at the Chapel Bridge.

June 17 Observed a few smolt at Laurence's wharf for the last time.

June 18 Took a smolt at Margaree Ford.

June 24 Found capelin in the salmon stomachs. There were found, sometimes in great numbers, for five days.

June 27 Hand seined in Bochan Brook, and took some yearling and 2-year parr between the river and the road bridge but could take no fry.

June 29 P. F. Elson and I seined several 2 year parr, a smolt and a yearling gasperes from the main river below the Hatcher Retention pond. The gasperes had very pale gills.

July 7 Napoleon AuCoin reports seeing a school of capelin near his salmon nets. Other fishermen gave reports of capelin from June 25 onward, but say that they have not seen them here for some years.

July 13 Observed a large salmon near Laurance's wharf. Some have been seen in the harbour lately.

July 20 Angus McKinnon took two butterfish (Poronotus triacanthus) in his salmon nets today. Only one of these was brought in to the freezer. This specimen has been preserved. It was 26.4 c.m. long. Inquiries among the fishermen indicate that this fish has not been noted here before, although many of them have fished it elsewhere and know it.

July 26 Joseph E. Cornier took a 16 pound salmon on his cod trawls, two miles off Margaree Harbour.

AUG. 2 P. F. Elson took a 22.6 c.m. salmon from Trout brook, beneath the road bridge.

Observations indicate that there were more salmon of extreme lengths this year than in the two previous years. More grilse were taken during tagging and more salmon of more than 100 c.m. length were brought in.

MARGAREE SALMON INVESTIGATION

1937

Report No. XII. Water temperature, water level, and wind on the Margaree River system, 1937.

By H. M. Rogers

In the preparations for the continuation of the Margaree investigation, several machines for recording the water level were designed and manufactured during the winter of 1936-37 for use the following summer. A description of these gauges has been prepared separately. In addition to these, a machine for recording the wind direction was also constructed.

During last summer, four of these hydrographs were put into operation. One was placed on the inside of the south-west pier at the harbour mouth, the purpose of which was to measure differences in water level due to tidal fluctuations. A second was placed just above the head of tide on the north bank of the river, another on the North-East Margaree just beneath Doyle's bridge on the east bank, and the fourth on the South-West Margaree on the west bank a short distance above the highway bridge at the Forks.

Each machine was so placed for a definite purpose. The harbour tide-gauge was to measure mainly the tidal fluctuations so that a definite record for all hours of the day could be obtained, but it also could be counted on within limits to show an irregularity in the river discharge. The "head of tide" machine, which was actually far enough above the limit of tidal influence so as to be unaffected by it, was intended to measure fluctuations in the level of the river proper, freshets and any other disturbances being thus

automatically recorded. The other two machines made records of the levels in their respective branches of the river, being placed as near as possible to the mouths of the streams, so that the data obtained would be a record of the total flow for these branches, a desired improvement for instance upon the data to be obtained at the station at Frizleton, some little distance above the mouth of the North-East Margaree. Not only were they advantageous from this point of view, but a record of the particular hour that a freshet began could be obtained, a feature that is lost if water levels are measured only once or twice daily.

Each hydrograph and its case was placed within another box for protection and the whole set on the top of a wooden column which extended down into the water. In this column, the copper float connected to the machine by a chain, was free to move vertically as the water rose and fell. The harbour hydrograph was mounted on the side of the breakwater, but in the case of the other machines, where no such ready made supports were available, a scaffolding was constructed to support each one in water of a suitable depth.

With the exception of three or four occasions when the pencil carrier stuck, the hydrograph installed at the harbour mouth operated quite successfully, and everything hoped for was obtained. The possibility of the carrier sticking again is a matter which can be remedied quite simply, so that in the future, no trouble should arise from that angle.

Wave action is quite noticeable in some of the curves, and is a fault, not of the machine, but of the wooden column in which the float was free to move vertically. Had the column been constructed of matched lumber, this undesirable feature would have been removed to a great extent. For future use, the seams in the column can easily be filled with some suitable material.

The success of the other hydrographs was only partial, and as much confidence can not be placed in their graphs as would be desired, their sensitivity to very small fluctuations in water level over a considerable period, not being absolutely dependable at all times. From the knowledge already gained from their first performance however, it is felt that a few minor alterations will render their future operation quite successful.

The wind direction recorder was set up on the property of Capt. William Dawson at the Grey Capes, a location which was considered to be the best in the neighbourhood for the object in view. It was not a great success due to the pencil carrier sticking on the slide. To overcome this difficulty, the only necessity is a reversal of the position of the clock so that it will lift the carrier pencil up the arm instead of relying on the weight of the arm to carry itself down, as the clock slackens the supporting chain. The almost perfect records obtained on several occasions were sufficient to show that with this minor alteration, the wind directional recorder should also be a complete success.

On the last of June, an old style anemometer, borrowed from the Meteorological Service in Toronto, was set up beside the other for recording the velocity of the wind. It was discontinued after

a week's operation, since it necessitated attention each day instead of weekly as in the case of the other machines, a feature which involved considerable time as well as money. If the investigation is continued, it is proposed to alter this machine so that it will run for a week at a time without requiring attention.

As was done the previous year, a thermograph was placed upon a raft and set in the current of the west channel just above the harbour bridge. Since only one level in the water could be measured at a time, the surface was chosen as being most representative of conditions in the river proper, and more dependent upon atmospheric conditions than water at a depth.

The length of time that the various machines were in operation is as follows:

1. Harbour hydrograph.....May 29- Sept. 11
2. Head of tide hydrograph.....June 12-Sept. 11
3. North East hydrograph.....June 17-Sept. 11
4. South West "June 17-Sept. 11
5. Thermograph.....May 29-Sept. 11
6. Wind direction recorder.....May 23-Sept. 13
7. Anemometer (Velocity indicator).....July 1-July 8.

The graph which follow are those recorded by the above machines, and are so grouped as to facilitate comparison with one another.

The Tides.

The greatest range in the tide of the Margaree Estuary over a 24 hour period, as measured by the gauge placed at its mouth during the summer months, was four feet, one inch. This range occurred on June 10th and 11th, when the effect of new moon springs coincided with the influence of perigee. The corresponding period in July was almost as high, but due to an increasing interval between the time of new moon and perigee, the range did not come up to that of the previous month. In August the space between these two determining factors has again further increased, the greatest range during that month being but $3\frac{1}{2}$ feet.

As was shown by the records obtained last year, there was a diurnal inequality in the tides (common to all parts of the gulf of Saint Lawrence), so that one of the two daily high tides may be almost entirely eliminated, as occurred on July 14th, and Aug. 16.

The smallest diurnal range would be expected during either the first or last lunar quarter, and so it proved, there being little to choose between either of these periods. The smallest range was about thirteen inches on July 16th.

Water Temperature.

The temperature of the water at the surface in the west channel just above the harbour bridge showed a variation during the summer from a low of 50° Fahrenheit on May 30th, to 81°^{P.} on August 9th, the latter temperature being registered about 5.30 p.m. on a falling tide when the air temperature was about 78° Fahrenheit.

Factors influencing water temperature.

As was very apparent in the records last year, the most obvious force governing fluctuations in water temperature is the tide. An inflowing tide brings in cold sea water causing an abrupt lowering in the temperature as recorded by the thermograph, followed by a rise as the water flows out again. The increase in temperature, which is of a more gradual order than the decrease, seems to follow almost immediately the turn of the tide, so that it may be assumed that the sea water which has entered has to some extent undergone a warming. This increase in temperature is recorded as it flows out past the thermograph, and the temperature further increases as the warm river water itself begins to pass out. As was found last year, in addition to that in the river proper, there is opportunity for a considerable quantity of sea water to be warmed to high temperatures over the shallows of the upper harbour.

Several modifications are to be noted in this general scheme. There is evident a different type of temperature curve depending on the type of tide, the springs producing a graph like an inverted U, the sides of which are more or less vertical, whereas the neaps are instrumental in causing a curve more like an inverted V, with gentle sloping sides. The springs cause this abrupt fluctuation in the daily temperature no matter at what time of day they occur, but during neaps the effect of the tide may be dominated by another factor, that of solar radiation.

It is the solar radiation which produces the inverted V curve, a curve that tends to occur at mid-day or in the early afternoon, when the temperature of the air as a rule is also at its highest,

At springs, the effect of the tides is too great to permit solar radiation to be very influential, but during the small tidal fluctuations of neaps, it has a chance to exert an effect. This is undoubtedly due, not only to the smaller amount of water flowing past the thermograph, but also its lower velocity, a small quantity of water flowing at a slow rate having a greater opportunity to be warmed than a large quantity at a rapid rate. This is exemplified by the neap tides of June 16th or 17th. The temperature of the water instead of falling as would be expected on an inflowing tide is rising, a rise which began however before the tide had finished falling. This is in direct contrast with the springs of say June 24th, where there is a direct correlation between the tides and the water temperature. On the other hand, during the springs of August 16th, when diurnal inequality was at a maximum, no marked fall in temperature occurred with the flood tide, since there was a long period for the rise of $2\frac{1}{2}$ feet, three times the length of an ordinary rising tide, a lapse of time sufficiently long to permit warming of the water as it flowed in past the thermograph.

The effect of solar radiation, in so far as it affects the water temperature at different times of the day may also be noted. During the night and early morning, solar radiation is absent, and the effect of this can be seen in the tides of say June 10th to 22nd. On the 10th, as the tide falls shortly before midnight, there is a small rise in the thermograph record, since at this time ^{the} heat ~~is~~ assimilated during the day has not been entirely lost. By the 16th or 17th however, when the fall in the tide is well past midnight (3 or 4 a.m.) the heat received during the previous day has to a considerable extent been lost by radiation, and the

temperature shows a steady fall. On June 19th, there was little fluctuation in water temperatures due to the clouds which obscured the sky. By June 22nd, the morning ebb tide is sufficiently late to show evidences of heating, and the evening outflow ^{ing} tide is early enough to also raise the temperature.

It should be noted that the high spring tides occur at just that time of day as the high temperatures which they foster, i.e., mid-day or afternoon, whereas water temperatures occurring at neap tides, which are largely controlled by radiation from the sun, also tend to have their peak at mid-day. The water temperature curves do not coincide with those of the neap tides, which, occurring either six hours earlier or later than the corresponding springs, come at an inopportune time for assisting in the production of high water temperatures.

There are different sizes of the inverted U curve which may be explained partially by the time of day they occur, and partially by an examination of the tidal curves which correspond to them.

It may also be noted that the fall in temperature on a rising tide is more rapid than the rise on an ebb tide. On the flood tide, the cold sea water has an almost immediate effect, while in the out-flowing water, the temperature gradually rises as the water that was up river on the high tide and was heated to some extent, passes out to be followed by still warmer river water.

On June 12th during spring tides, there seemed to be an exception to the above general conclusions, namely, the water temperature did not fall with a rising tide. This is due to the fact that the temperature of the water was already at a very low level.

Comparison in water level at the river hydrographs.

The summer of 1937, especially the latter part, was rather a dry one, and with a few minor exceptions, without freshets on the rivers. Though the first part of the season seemed wet, the precipitation was light and spread out, thus not affecting water level to any great extent. The South-west branch showed a greater fluctuation in water level over the summer period than did the North-east, a feature rather unexpected since the South-west is fed by lake Ainslie, while the North-east derives its water mainly from springs. The lake acts as a reservoir, and tends to exert a steadying influence on the level of the stream which drains it. The sudden fluctuations in the level of the South-west must be due to precipitations of a restricted nature.

The general level of the South-west was about 15 inches lower at the end of the summer (Sept. 11th) than it was at the beginning (June 17th), while the water level at the head of tide dropped some 10 inches. Due to the fact that the North-east column was overturned on July 12th, (by human agency it is believed), and not reset until July 16th, the relative level of the water during the latter part of the summer, with reference to that of the first part, can not accurately be determined, since the stationary water level scale was attached to the column itself, and unless it was replaced at exactly its former level, there would be a discrepancy in the graphs recorded before and after the interruption. It is believed that the column was placed some six inches deeper in the water when set up the second time, and thus the curves obtained since July 16th are six inches higher than they should be. If this be true, the North-east dropped over the summer period, a distance of but eight inches.

Effect of rainfall on river level.

Only three freshets of any appreciable magnitude were experienced during the summer, and they caused but slight temporary rises in water level. The first which occurred on June 19th, but seemed to be confined almost entirely to the South-west branch and main river, was caused by a rain which at Margaree Harbour gave a precipitation of over $\frac{1}{2}$ inch. If the North-east branch remained constant in level, then the greater part of the head of tide fluctuation would be expected to be due to the rise in the level of the South-west branch alone. The level at the head of tide began to rise a short time after that at the South-west hydrograph in agreement with this expectation. This rise at this time was a matter of but $4\frac{1}{2}$ inches on each branch.

The second freshet occurred on July 6th, and was felt by all three of the up-river hydrographs, but due to incomplete records, the rise in water level was not determined. This freshet was brought about by a rain totalling 1.17 inches at the harbour. It seemed to have little or no effect on the level of the tide at the river mouth as recorded by the tide-gauge, the low tide as a matter of fact being lower than ordinarily, a phenomenon that can not be easily correlated with a freshet in the river.

A freshet of $8\frac{1}{2}$ inches appeared suddenly on the South-west branch on August 18th, disappearing almost as rapidly as it came, and was occasioned by a rainfall which at the harbour measured a third of an inch. This freshet was not recorded on the North-east, and at the head of tide, was felt to but a small extent.

Rain, which gave a precipitation of $\frac{1}{2}$ inch at the Harbour on Sept. 8th, resulted in a brief freshet at the head of tide, but this was not felt on either of the river branches.

The wind.

The direction of the wind was recorded by the wind machine imperfectly as previously stated. The type of machine used was one in which a vertical drum surrounded by a paper was turned by a vane. A pencil actuated by a clock moved down the drum once a week, and thus drew a line on the paper, the point at which the pencil pressed upon it corresponding to the direction of the wind. Due to the fact that the wind, which never seemed to blow constantly in any one direction, caused the vane to move continually, the curve drawn was seldom a single clear line, instead, a wide path of nearly parallel lines was traced. Because of the difficulty in transferring such recordings accurately to another scale, only a small portion has been so transferred as an example, (May 31 - June 3), the rest being merely drawn in as a single line.

For the wind velocity, see records kept by P. F. Elson.

Effect of the wind.

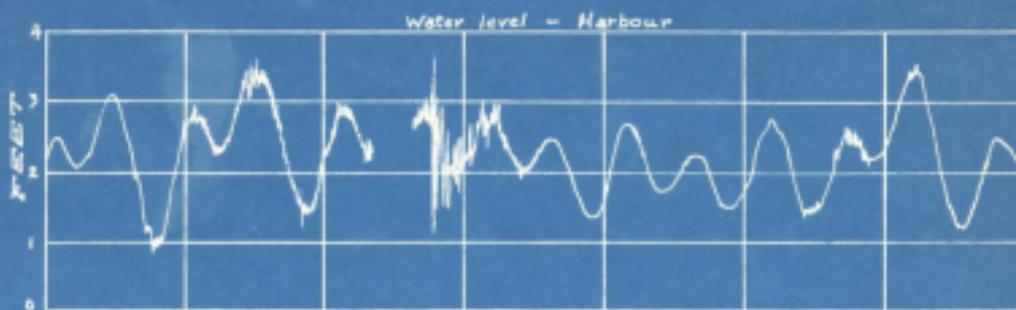
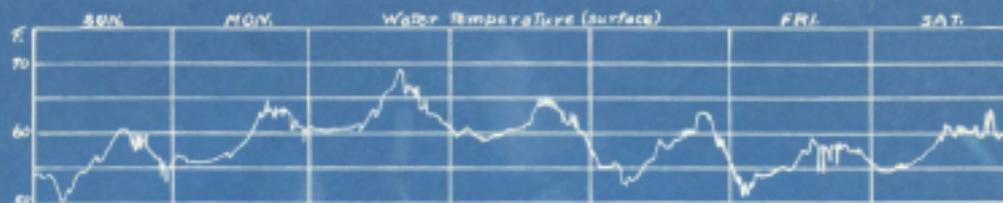
The wind affected the tide-gauge readings in two ways. Firstly, by inducing waves which, with the tide-gauge column in use, caused the float to rise and fall as much as a foot, as may be seen on September 8th. The wind effect was always very noticeable in an onshore breeze, but somewhat less obvious when it came from an easterly direction.

Secondly, the wind influenced the height of the tide, an onshore breeze tending to push the water toward land. On Aug. 6th the wind obviously increased the height of the tide, and on Aug. 17th

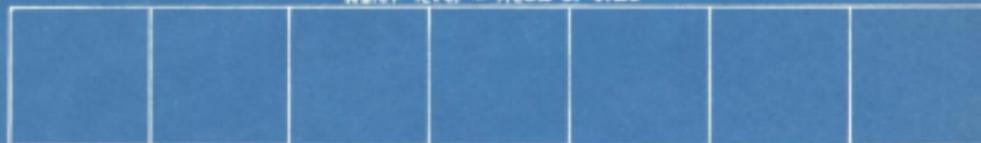
and 18th, the general level of the tides was raised by the westerly winds. Again for example, on Sept. 8th, the effect of a heavy northerly wind was not only to induce wave action, but to raise the tides above their usual level.

On June 1st, a curious phenomenon was noted. According to local fishermen, on that afternoon, within the space of an hour or so, the water level three or four times had risen and fallen a distance of as much as three feet. The recording of the hydrograph at the harbour showed such a movement, caused by several large waves originating in the gulf of Saint Lawrence.

May 30 - June 5



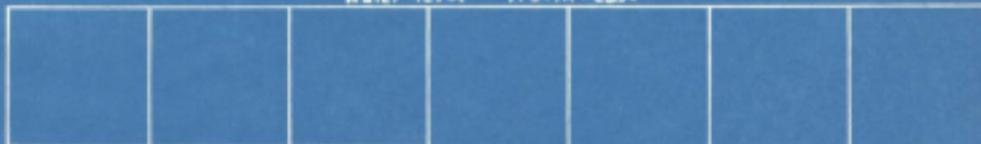
Water level - Head of tide



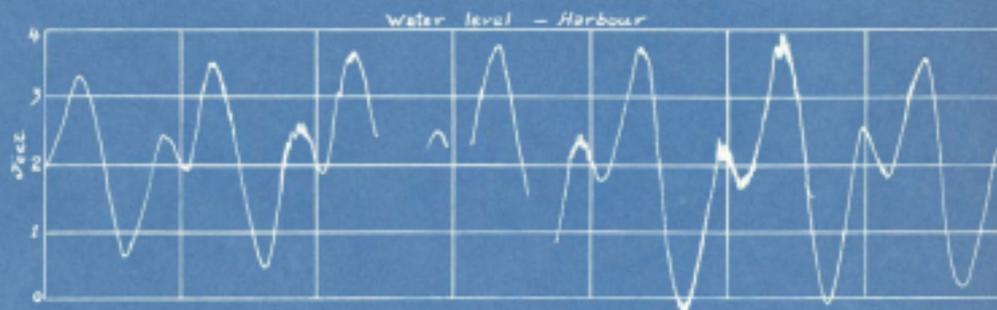
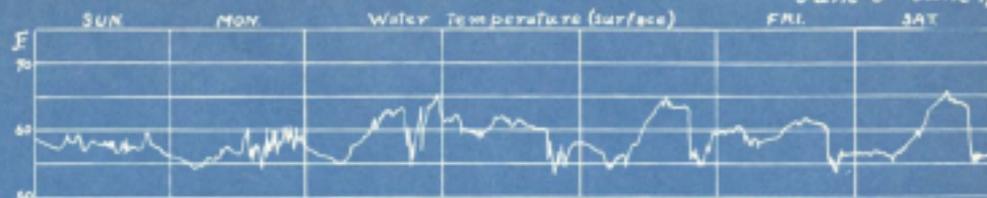
Water level - South-west



Water level - North-east



June 6 - June 12



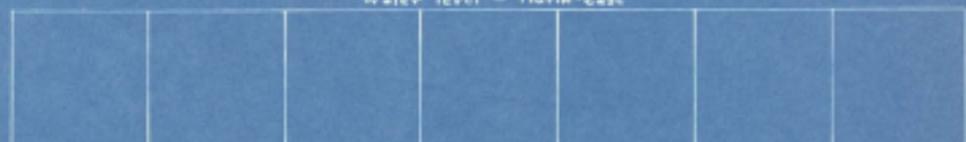
Water level - Head of tide



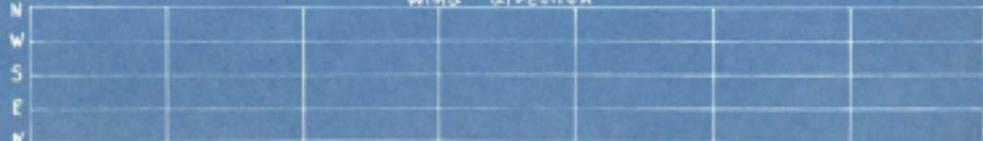
Water level - South-west



Water level - North-east



Wind direction

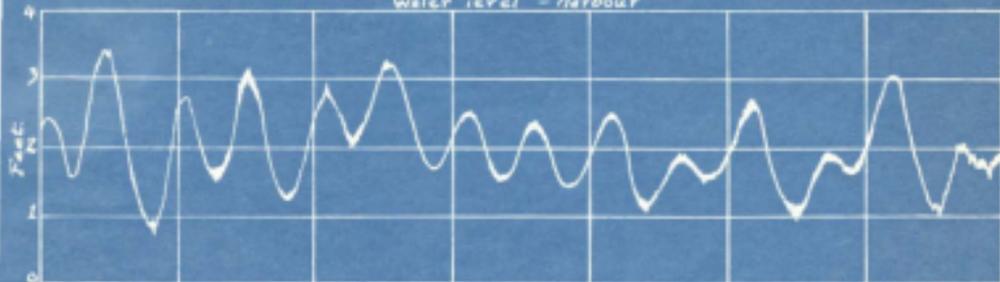


June 13 - June 19

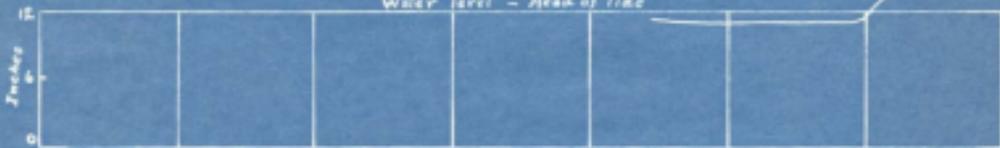
SUN MON Water Temperature (surface) FRI SAT



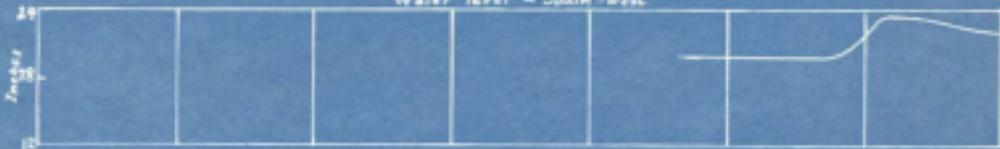
Water level - Harbour



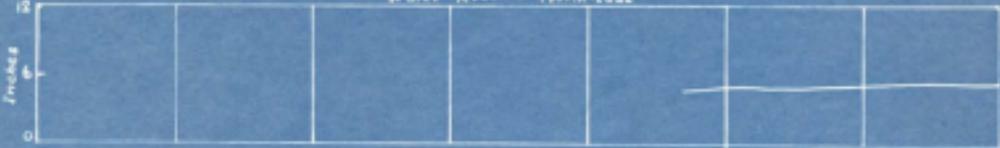
Water level - Head of Tide



Water level - South-west



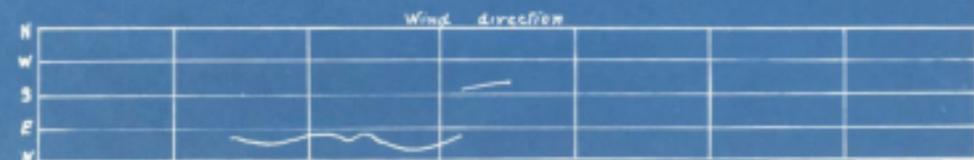
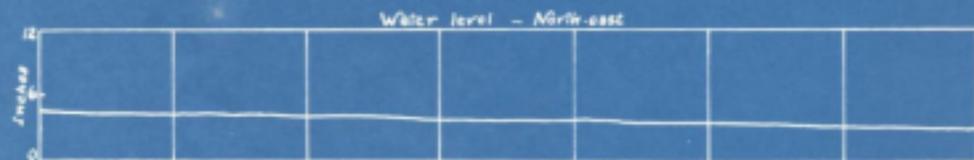
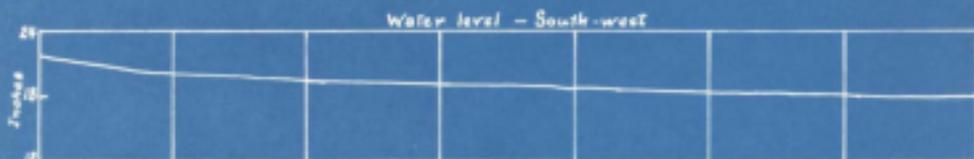
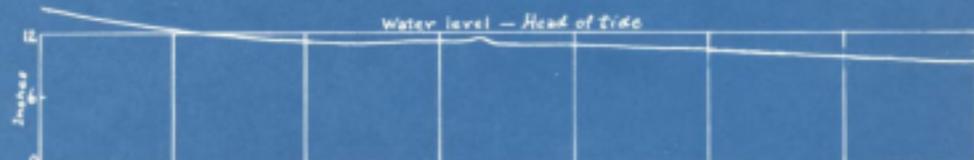
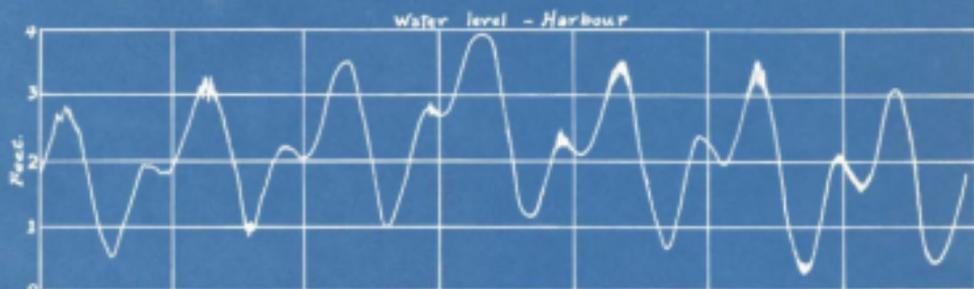
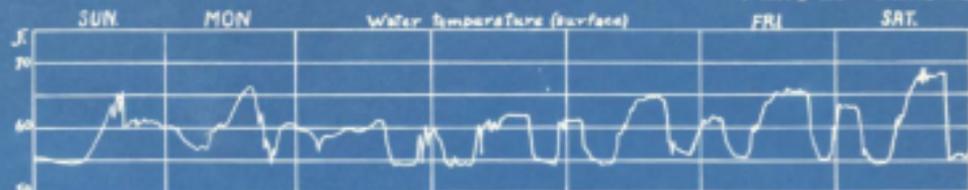
Water level - North-east



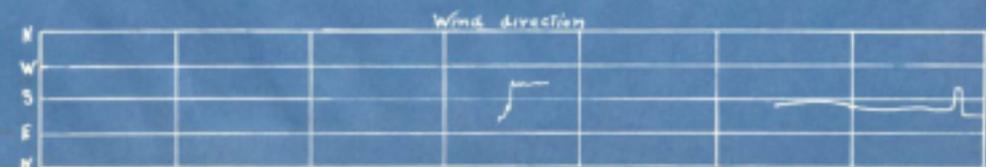
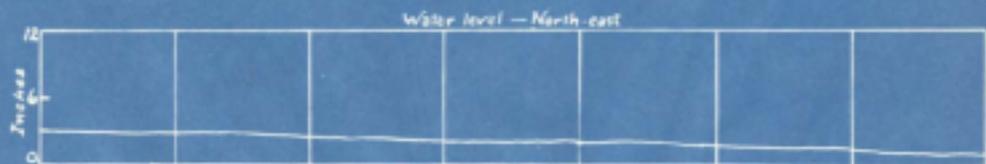
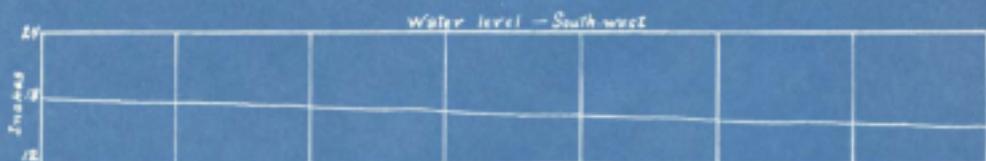
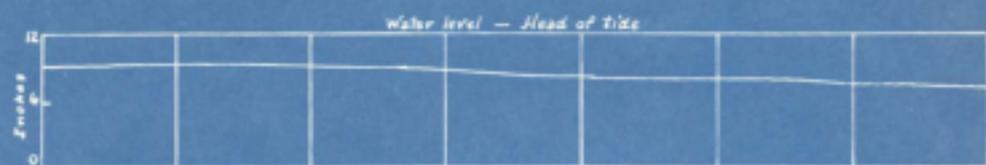
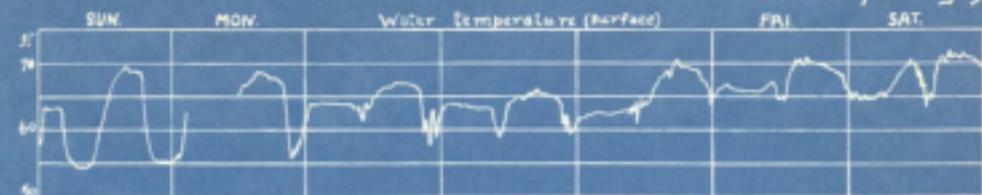
Wind direction



June 20 - June 26



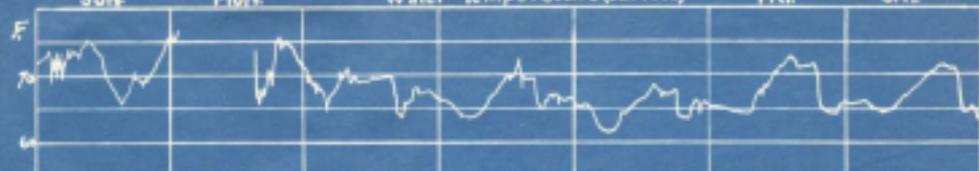
June 27 - July 3



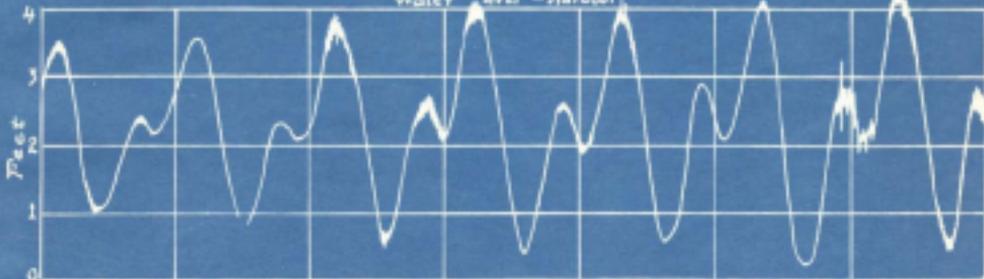
July 4 - July 10

SUN MON TUE WED THU FRI SAT

Water Temperature (surface)



Water level - Harbour



Water level - Head of tide



Water level - South-west



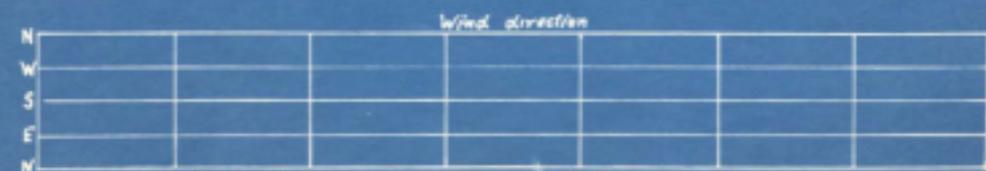
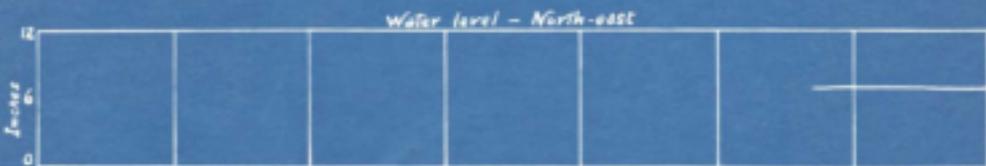
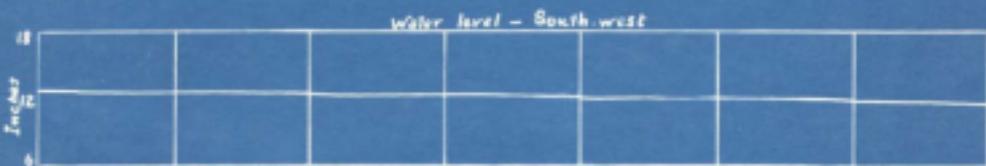
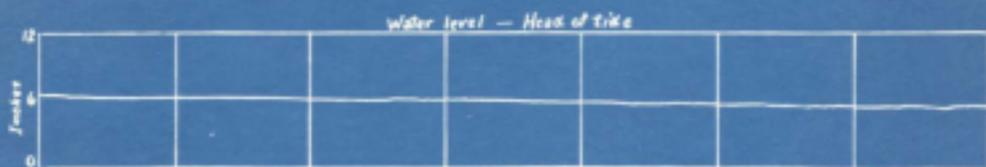
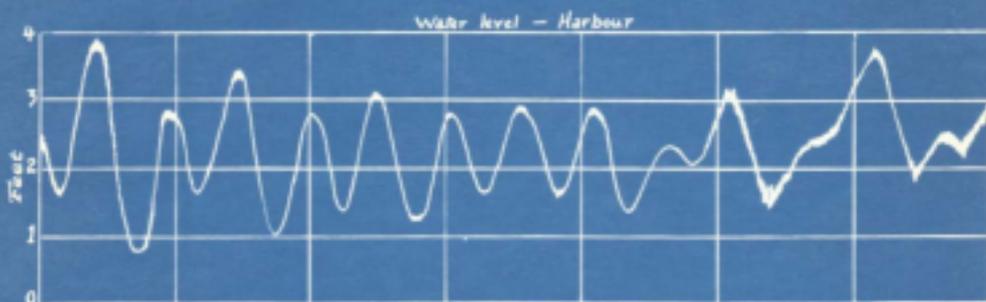
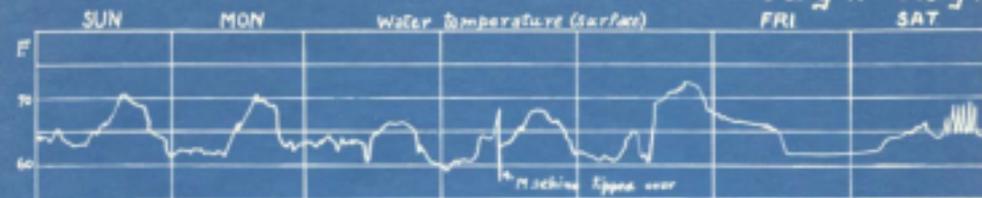
Water level - North-east



Wind direction



July 11 - July 17



July 18 - July 24

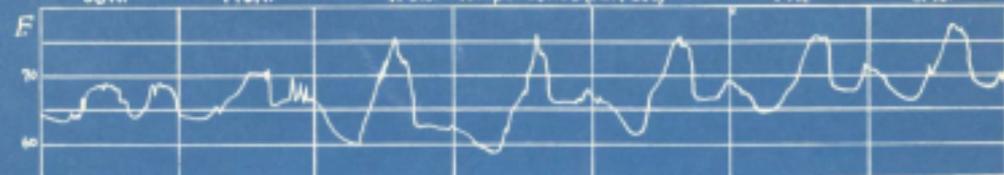
SUN.

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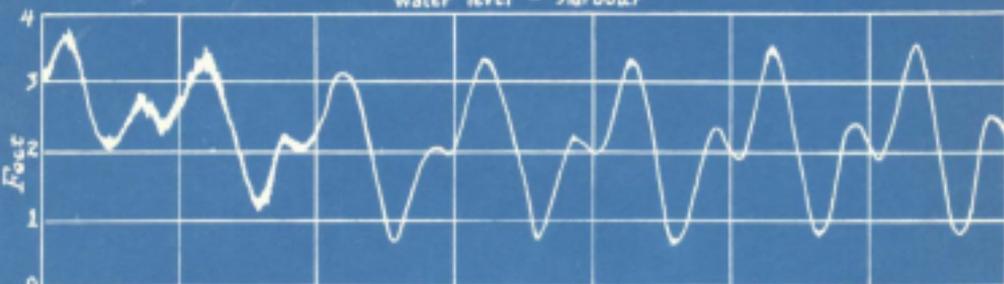
Water Temperature (surface)

FRI

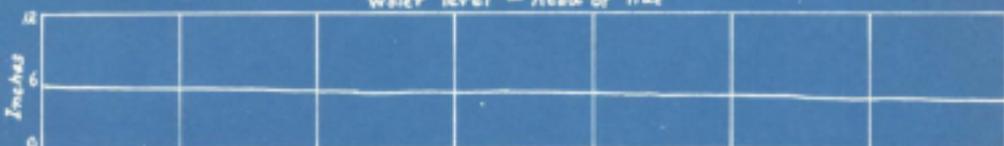
SAT



Water level - Harbour



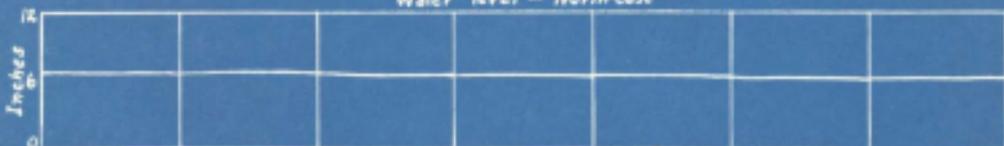
Water level - Head of Tide



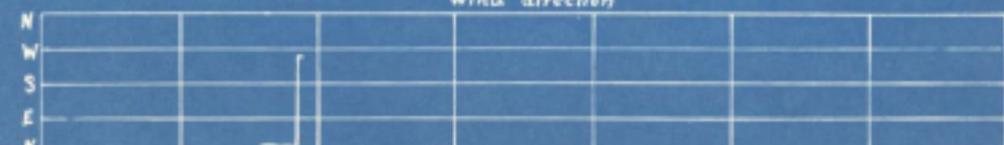
Water level - South-west



Water level - North-east



Wind direction



July 25 - July 31

SUN

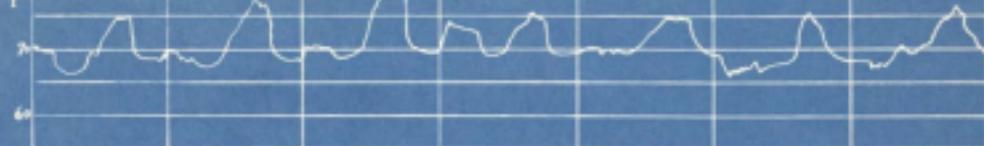
MON

Water Temperature (Surface)

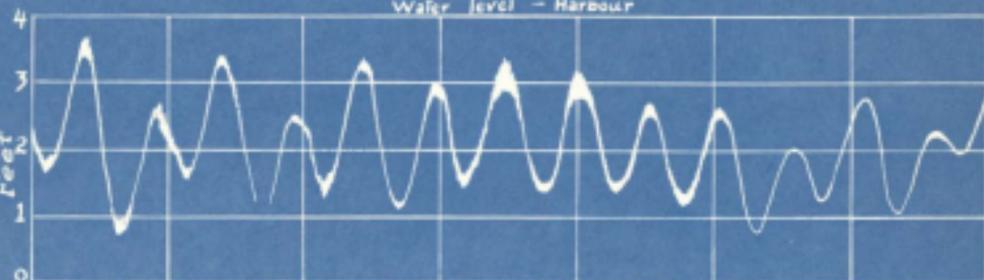
FRI

SAT

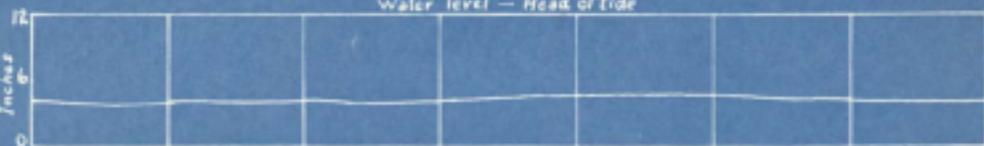
F



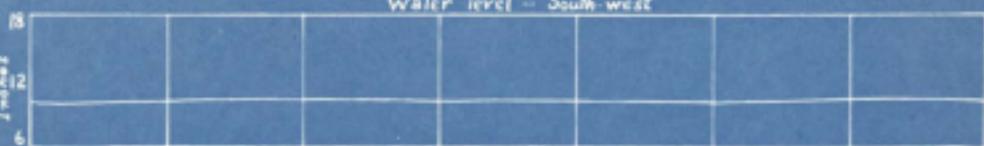
Water level - Harbour



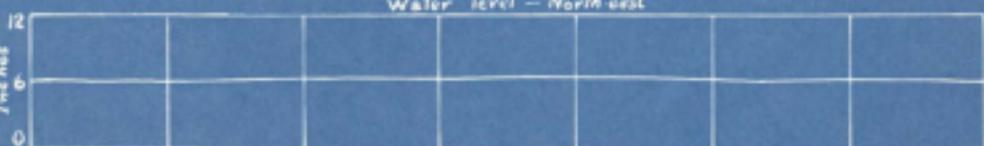
Water level - Head of tide



Water level - South west



Water level - North east

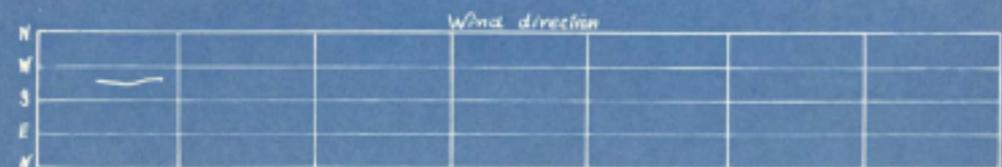
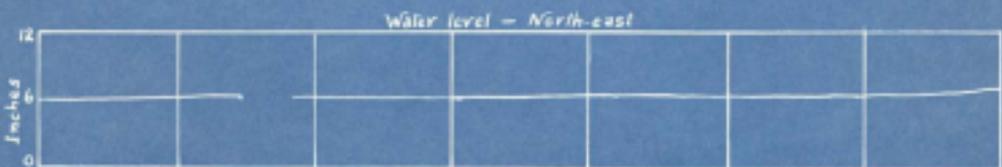
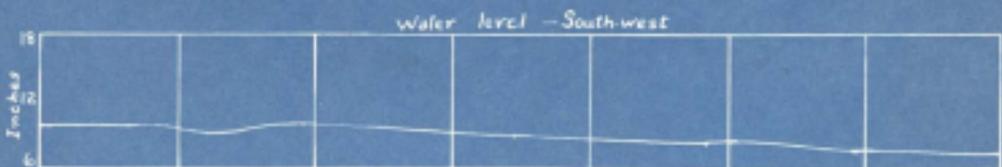
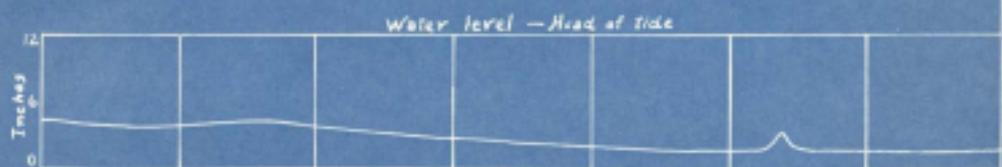
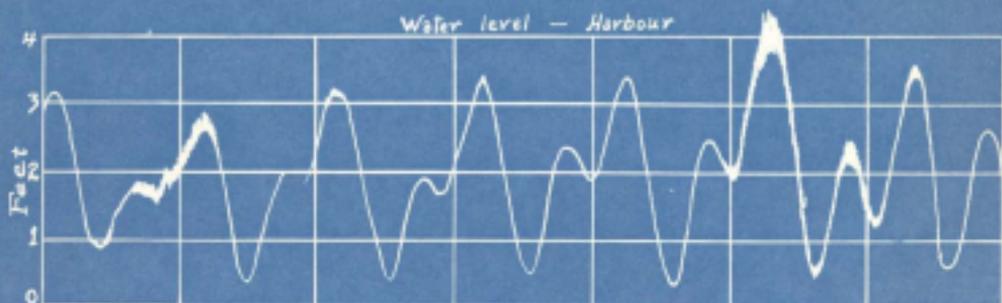


Wind direction

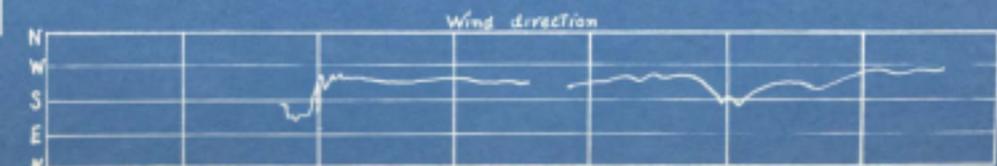
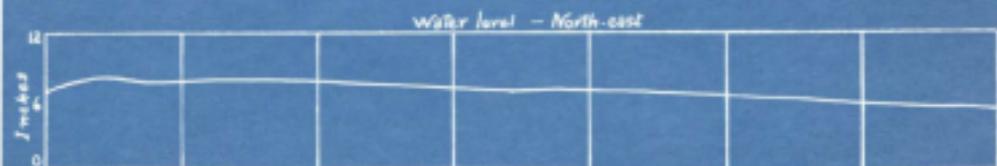
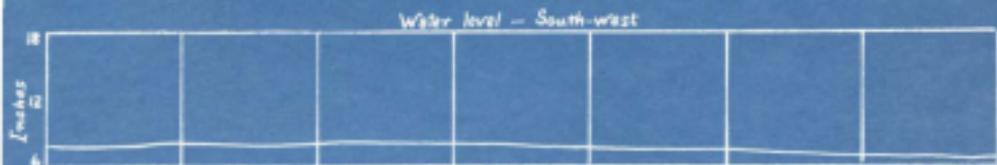
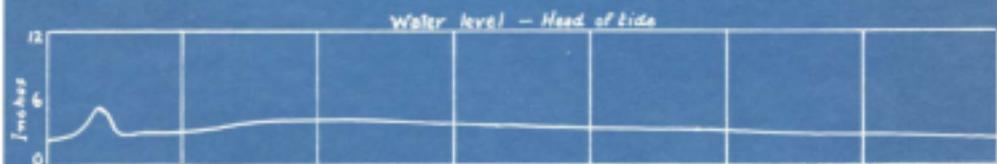
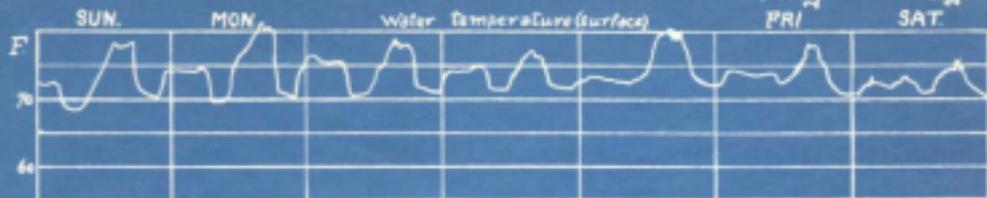


Aug. 1 - Aug. 7

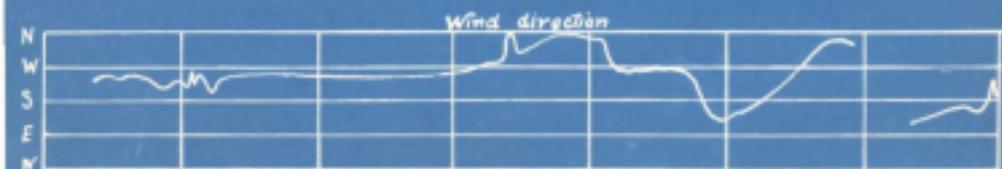
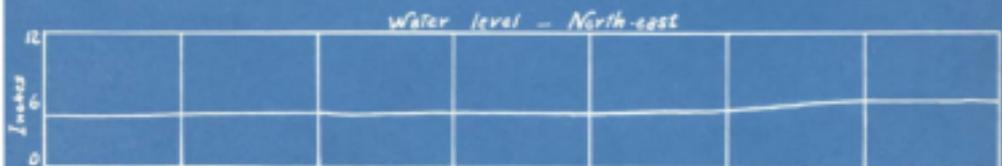
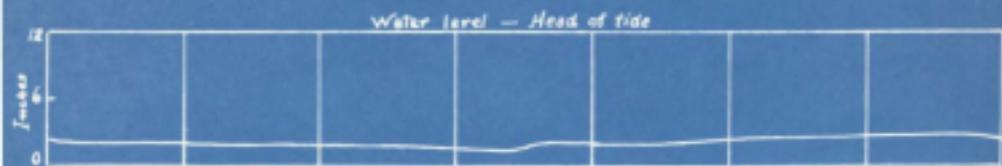
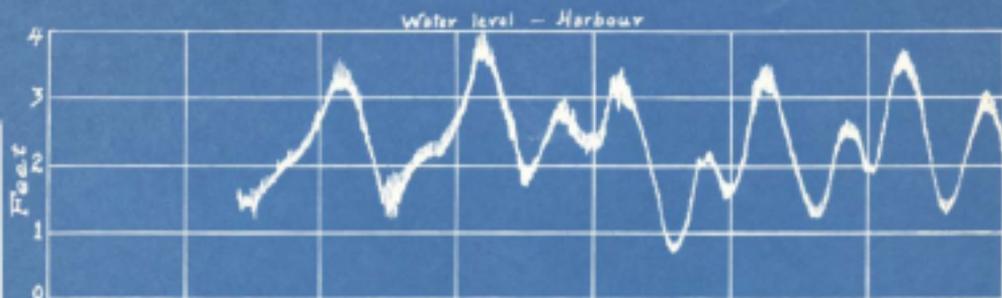
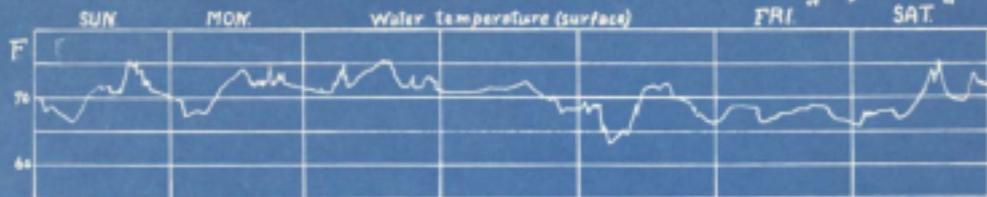
SUN. MON. Water Temperature (surface) FRI. SAT.



Aug. 8 - Aug. 14.



Aug. 15 - Aug. 21



Aug. 22 - Aug 28

SUN.

MON.

Water temperature (surface)

FRI.

SAT.



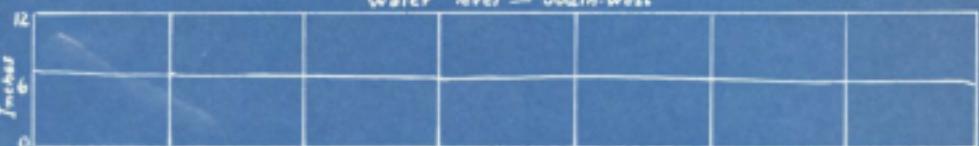
Water level - Harbour



Water level - Head of tide



Water level - South-west



Water level - North-east



Wind direction



Aug. 29 - Sept. 4

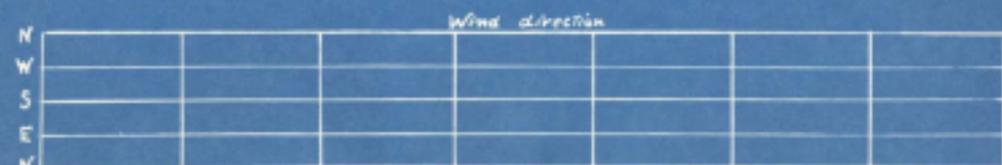
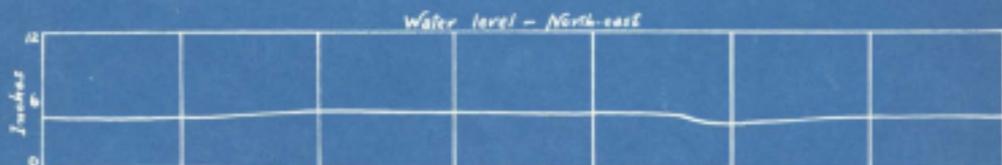
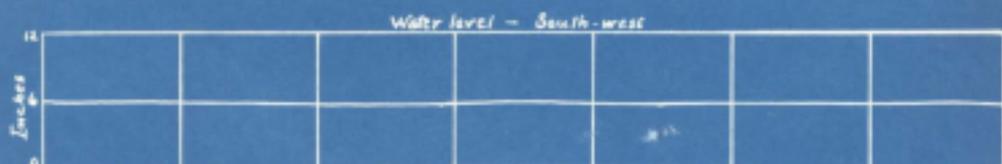
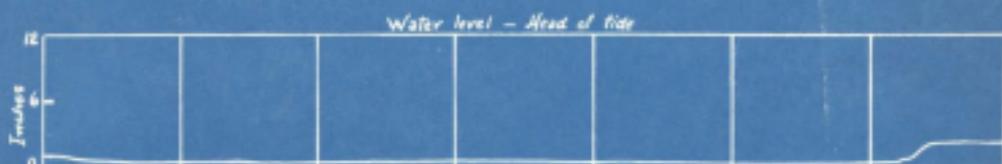
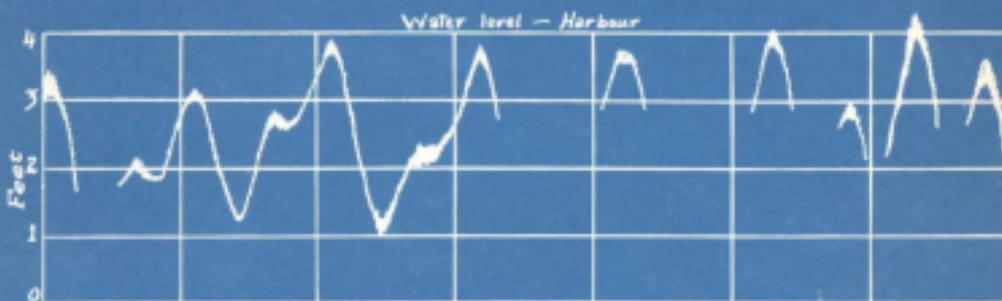
SUN.

MON.

Water temperature (surface)

FRI.

SAT.



Sept. 5 - Sept. 11.

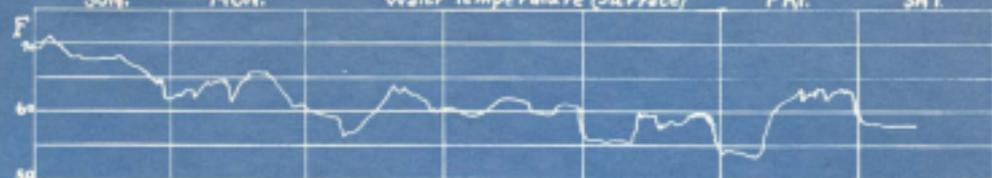
SUN.

MON.

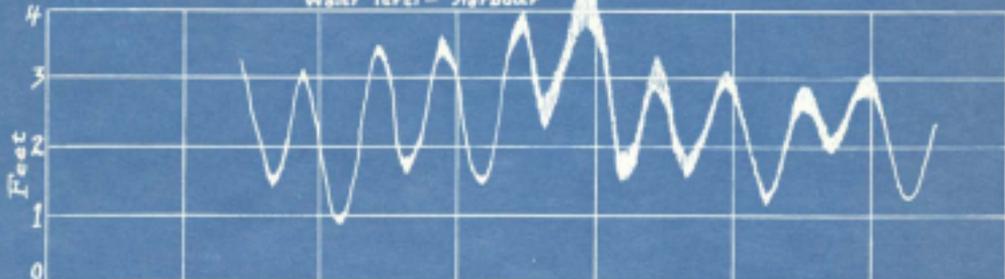
Water Temperature (surface)

FRI.

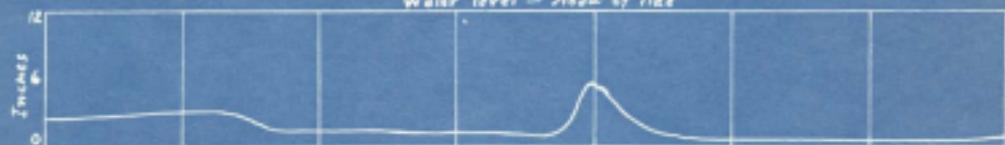
SAT.



Water level - Harbour



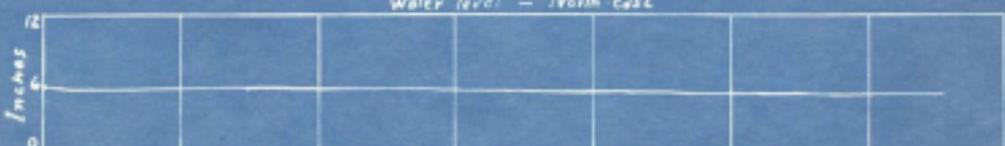
Water level - Head of tide



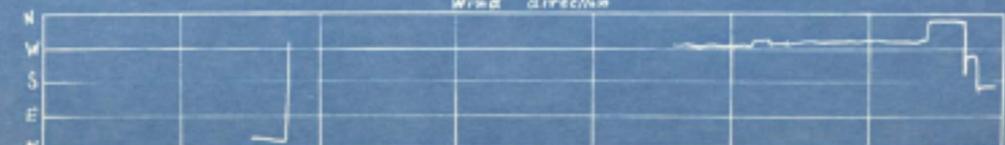
Water level - South-west



Water level - North east



Wind direction



MARGAREE SALMON INVESTIGATION

1937

Report No. XIII. A Study of the Effects of Current and Light
on the Behaviour of Salmon Fry and Parr.

By P. F. Elson.

Introduction.

In the observations described below an attempt was made to investigate particularly the effects of various types of current on young salmon. It was not possible to control all other factors which would influence the behaviour of the fish, so one of the most important of these, light, was also investigated to a small extent.

While the observations made leave much to be desired in completeness and accuracy it is believed that certain facts which are important in considering the behaviour of such fish are brought out.

Location and Apparatus.

The experiments were carried on at Widow Lord's Brook, about 2 miles up river from Margaree Harbour, where certain apparatus had been placed at my disposal by Dr. Huntsman.

Two pieces of apparatus were used. The first was used primarily to investigate the effect of simple current changes and horizontal eddies. It consisted of a trough about 5 feet 3 inches long with a box about 2 feet square at its lower end. The lower end of the box and upper end of the trough were screened. At the upper end of the trough two movable wings were provided which allowed control of the current

through the apparatus. Box and trough were built on the same bottom to eliminate any vertical currents. The second piece of apparatus consisted essentially of a trough with a device to control the water supply, at its lower end a tank of the same width as the trough, about $3\frac{1}{2}$ feet long and $3\frac{1}{2}$ feet deep. This allowed the production of vertical currents without lateral eddies. The tank was also used for observations on the effect of light. One side of the tank was formed by a glass window opening into a darkened chamber from which the fish could be watched without being disturbed.

General Procedure.

Observations were made on the behaviour of the fish in still water; in simple currents and currents with various eddies; in strong and weak currents; on the effect of changing the rate of current flow; on the effect of vertical currents on distribution and movement, and of the effect of light on the distribution and movements of the fish. An attempt was made to check some of the observations by experimental manipulation of the various factors.

For those observations in the first piece of apparatus fry from the hatchery at Frizzleton were used. An attempt was made to check some of the observations on native fry and parr. In the second piece of apparatus native fry and parr were used almost entirely.

Observations made using the first Apparatus.

In Still Water, Aug. 12. The apparatus contained eleven

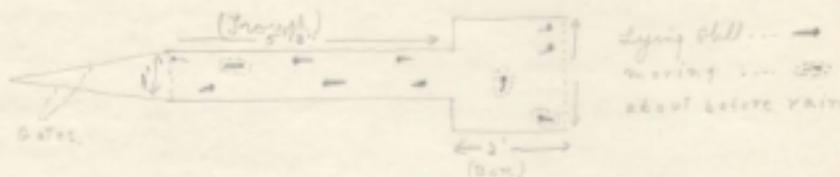
hatchery fry. Depth of water was 2 inches throughout. The current had been completely shut off for over 24 hours. About 2.15 p.m. the current was allowed to run for 10 minutes while dead fish and detritus were cleared from the apparatus. The current was then closed off again and the fish left for half an hour in order to allow them to become well adjusted to the conditions. Observations were commenced at 3.00 p.m. The sun had been shining brightly but about this time clouds began passing over the sun. The changes in light did not seem to have very much effect on the fish as they were always quite close to the bottom in the shallow water provided. From 3.15 to 3.30 the light was quite uniform and the fish were not disturbed in any observable way.

Two of the fry swam back and forth the length of the apparatus, showing a tendency to rest for about 2 minutes at a time in a slight shadow in one corner of the box. One fish maintained a position lying quietly at the upper end of the box, as though heading a slight current. (No current was visible). This individual drove away any other fish which approached within about 4 inches. Two fish lay motionless on the bottom of the box for the whole period. Five stayed in the trough, lying horizontally to the surface and distributed uniformly through the trough. None of these fish moved more than three inches from its original position. One fish swam about the trough quite actively but did not venture into the box.

At 3.35 a few drops of rain fell on the surface of the water.

At once all fish sank quietly to the bottom and all wandering ceased. The distribution was as in fig.1.

Fig. 1.



From 3.40 to 3.50 the sun appeared and disappeared twice. Each time as the sun went under the fish became still and sank to the bottom. As it came out they rose and wandered about more. Those fish in the trough were more closely distributed than those in the box, the proportion, in spite of a small amount of migration, being nearly always 8 to 3.

At 3.55 there was little wandering by any of the fish except when a small particle of 'food' fell on the surface. Then the 2 or 3 nearest fish would dart towards it. All fish tended to keep intruders away from the point which they had taken up.

Aug. 13 - The current was left closed off over night. From 9.00 to 10.00 a.m. the distribution picture was essentially as in fig.1. with but slight shifting of individuals. The proportion of fish in trough to fish in pool varied between 9 to 2 and 7 to 4. When the depth of water was increased to $3\frac{1}{2}$ inches there was a somewhat greater tendency to wander noted, particularly on the part of the fish in the box. The distribution was otherwise essentially as in fig. 1 still, with

very little more exchange between trough and box.

Subsequently when the current was shut off prior to observing effects of current change the fish were observed to take up, in about 10 minutes, positions as indicated above. Those in the trough would be distributed quite uniformly, some heading 'upstream', some 'downstream'. Those in the box would be heading in any direction. The distribution was less dense in the box than in the trough, and the fish here seemed less pugnacious in keeping others from approaching them. Each fish did, however, maintain its own position fairly well with slight wandering relative to the condition when the current was first shut off.

Native Fry - Aug. 24, 3.30 p.m. I placed 7 native fry in the trough. At first they swam about in the lower box but by 4.00 all were lying quietly in the box, heading in all directions. Between 4.00 and 4.40 the current was turned on but was off from 4.40 to 5.00 p.m. At 5.00 all fish were lying quietly. At 5.10 there was a slight wandering by all individuals. Two swam the length of the trough and back to come to rest finally in the box. For some reason these fish seemed to prefer the box to the trough. Depth was 2 inches.

Aug. 25 - At 3.00 p.m. the fry were spread uniformly throughout the apparatus. The current had been closed off since the previous evening. They were disturbed when I removed the cheese-cloth covering, but by 3.05 were quiet again. Five were lying in the box, headed in various directions, two were at the upper end of the trough.

Native Parr- similar observations were attempted on

native parr. During 5 days that 4 parr were kept in the apparatus, however, no observations comparable to those for fry were recorded. The parr seemed to be frightened and whenever observed were merely lying quietly in one of the corners of the box; usually all were crowded into one corner.

Summary of Behavior in Still Water - When they have been in still water for over 10 to 15 minutes the fry wander slightly but not very vigorously. They may head in any direction unless the limits of the container are quite close on 2 opposite sides (as in the trough), then they tend to head parallel to the longer dimension. Under such circumstances they may lie somewhat closer together than in a more spacious container. Each fish tends to maintain an area around it free from intruders and its own wanderings, unless after food, are generally confined to this 'home area'. The effect of shadows passing over the sun is to cause a temporary stillness on the part of the fish.

In Water Moving at a Uniform Rate. Aug. 12 - To test the effect of a slight current on the movements of the fish the gates at the upper end of the trough were opened 2 centimeters. This permitted a current to flow through the apparatus at a rate of about 1 foot in 8 seconds.

As the current was turned on the fry, which had been scattered uniformly throughout the box and wandering slightly in all directions, turned so as to head directly into the current and now remained largely in one spot with very little tendency to wander. Of the 11 fish in the apparatus 9 were in the trough and but 2 in the box. During the following 7 minutes only 1 fish moved. This fish swam down the trough at about the same

rate as the current flow, remained in the pool thirty seconds, then returned to its original position again. While the fry did make sorties 1 to 2 feet in length after food particles, these were always parallel to the current and not in all directions as was the case in still water. 'Wandering' was entirely absent. The 2 fish in the pool remained in line with the trough, heading into the current. Occasionally they would swing into side eddies, only to swing back into the current again. They did not lie for any length of time in the eddies in the upper corner of the box.

Aug. 13 - The fish were observed after they had been in running water for 30 minutes. Distribution in the trough was uniform, though 3 fish were moving about parallel to the current. Most of this movement occurred at times when the sun had been under the clouds for 5 or 10 minutes. The general picture was of the fish maintaining a uniform distribution in spite of a certain amount of movement by individuals and on the whole the amount of movement was small. When the depth was changed from 2 to 3½ inches no difference was noted in distribution. The fish kept just far enough off the bottom so that they could swim freely.

Aug. 19 - 11.00 a.m. A current of 1 foot in 4 seconds had been flowing through the apparatus for 1 hour. Two fish were within 2 feet of the upper end of the trough; the rest were lying in the pool. The 2 fish in the trough were lying close to the corners. One would drop back to the 'pool' about once in 7 minutes and immediately return to the trough and its

original position there. All fish lay in the shadow of a board placed to keep the sun from shining directly on the apparatus. Two fish shifted around the lower end of the trough but did not ascend and 4 remained constantly in the pool.

Aug. 24. Native Fry - When these were placed in the apparatus and the gates opened the fish remained pressed against the lower screen and would only move away if startled by the operator. Then only 3 out of 7 moved. When I moved away these 3 again fell back to the lower screen. Two days later, however, the fish did assume a uniform distribution throughout the apparatus. There was a slight migration with or against the current. Only 1 fish tended to lie consistently in the eddies in the pool. The reaction was very similar to that observed with the Hatchery fry, but the fish were more vigorous and were very easily disturbed.

Summary of behaviour in moderate, simple current. These salmon fry do not wander in all directions, as they do in still water, but tend to maintain a position at one spot, heading the current, and occasionally make short sallies with a definite object - as after a food particle. Straight simple currents seem to be preferred to eddies. Very frequently the fish are found in the weaker current at the edge of the trough rather than in the stronger current in the centre.



Fig. 2 Distribution of Hatchery fry in a current.
Arrows indicate direction of current flow.

Change from Still Water to a Current, or vice versa.

The outstanding characteristic of the behaviour of these fry in still water is their tendency to wander about in all directions from a 'home' point. In running water the same fish remain very closely to the chosen spot and any movement is parallel to the direction of the current. The fish always heads upstream. Under either of the above 'constant' conditions the fish is related more or less closely to a given spot. A marked contrast is produced under changing conditions.

Aug. 13. The current in the box had been closed off from 10.00 to 10.30 a.m. The 11 fry had assumed a normal distribution pattern of 8 in the trough and 3 in the pool. At 10.30 the gates were opened to the full extent. Immediately all fish turned to head into the current and began swimming vigorously. In the first 2 minutes 4 fish reached and maintained a position within 2 feet of the head of the trough. Then some of these fell back, so that by 10.35 the distribution was again nearly uniform. The current was now shut off abruptly. All fish turned about to head into a back wash produced. As the water became quiet all but 3 sank to the bottom. These 3 swam vigorously back and forth the length of the enclosure for 3 to 4 minutes. It required about 25 minutes before this wandering was reduced to an amount normally observed in still water.

At 11.00 the experiment of opening the gates was repeated. There were 6 fish evenly distributed in the trough. All but the lowest moved up about 1 foot, swimming steadily against the current. The lowest individual fell back into the pool.

By 11.05 the fish had stopped advancing, swimming just sufficiently to hold their new positions in the current. At 11.22 the current was closed off. The fish oscillated with the water in the trough, always, however, heading the current, but being carried by it slightly. They tended to be concentrated in the middle of the trough. By 11.24 the water was quite still. The fish now began wandering about. In the trough they moved principally back and forth. Their movements were recorded.

11 hrs. 24 mins. 45 secs.	-	5 fish in upper 2 feet of trough
50 "	-	3 move back to lower end of trough
25 " 00 "	-	distribution uniform throughout box
40 "	-	all but 2 fish are in pool
50 "	-	2 fish at 3 feet from head of trough

2 others run entire length of trough and back again.

26 mins. 00 sec. - distribution about uniform and remains so; wandering of individuals confined to about 2 feet. This continues till 11.45.

2.00 p.m. The fish had been in still water for 2 hours previous. The gates were opened to full extent and apparatus arranged to give a current flow of 1 ft. in $1 \frac{1}{6}$ seconds. As the current was turned on 3 fish started swimming strongly upstream, and reached the head of the trough, remaining there. Two fish in the pool started up but went only 2 feet, then fell back into the pool. It was noted that the largest fry were the ones to ascend farthest. Of those in the pool some would frequently start up about 6 inches then fall back again.

Decreasing the rate of flow to 1 foot in 2 seconds resulted in 2 more fish ascending to within 2 feet of the upper end. On shutting off the current at 2.30 another fish swam to the upper end, then all fish began to move about, whereas previously those in the current in the trough had tended to remain in the spot to which they had succeeded in ascending.

The current was closed off from 2.30 till 2.50. at 2.45 observations were commenced, as below:

at 2.45 - 1 fry at head of trough

2 fry 2 feet below head of trough

2 fry 3 " " " " "

2 fry 4 " " " " "

1 fry 5 " " " " "

2.55 - Current of 1 foot in 1 1/6 seconds turned on. Both fish at 2 feet ascend by 1 foot. Four lower fish fall back into pool.

2.58 - Two fish enter lower end of trough. One of these is 'swept' out at once. One ascends to the 3 foot mark in 1 minute. In 15 seconds more he reaches 2 foot mark, and 30 seconds after this the 1 1/2 foot mark. He is swimming vigorously.

2.59 - He falls back to the 2 foot mark.

3.00 - Current reduced to 1 foot in 2 seconds. The four fish near the head of the trough maintain their positions. The fish at the 2 foot mark maintains its position. There are no fish in the current below this mark, the others remaining in eddies in the pool. Depth of water was 2 inches.

3.05 - Current cut off. Distribution remains as above.

3.12 - Current of 1 ft. in $1 \frac{1}{5}$ secs. turned on. The 4 fish at the upper end of the trough hold this position. All others are in the pool. Altering the current does not cause any change in the distribution of the fish.

3.20 - Depth reduced to 1 inch. Rate of flow as above. Three fish remain at head of trough. One drops back to pool, reascends to the 3 foot mark and again falls back to pool.

3.30 - Depth $\frac{5}{8}$ inches. Rate of flow as above. Two fish remain at upper end. One more drops back to pool.

3.40 - Current closed off. Depth $3\frac{1}{2}$ inches.

3.45 - Current of 1 foot in 2 seconds turned on. Two fish ascended to the 3 foot mark and fell back. One fish remained at the upper end.

Conditions were left as above for half an hour. During this period fish several times ascended to the head of the trough but were driven back at least as far as the 2 foot mark by the fish which had held his position at the head through-out.

Those fish which remained in the pool during the above manipulations lay, for the most part, in the eddies in either side. They would occasionally swing out into the current, stem it for perhaps 30 seconds, and occasionally rise in the trough to the 6 inch level, but would then fall back into the eddies again.

Similar observations to those above were made on different occasions with the same sort of results.

The observations on change of current may be summarized

as follows.

A slight current decreases the wandering tendency and causes the fish to orient itself against the current.

A pronounced increase in the current results in some fish ascending against the current. The amount of ascent varies with individual fish and there is some indication that the response is dependent on the physical state of the fish. Too strong a current will cause the fish to drop downstream. Fish which do not ascend the increased current fall back into eddies and maintain their positions. Occasionally such fish may attempt to ascend the stronger current, but swing back into the eddies in a short time.

The tendency to wander is maintained for a longer time when the space limits are greater on all sides. (It was observed that fish in the pool kept up wandering for a longer time than those in the trough, after the current was closed off).

The behaviour of native fry was similar to that of the hatchery fry, but again they were found to be very susceptible to inadvertent movements of the observer, or other stimuli.

Effect of Stones on the bottom in Experiments as above.

Stones of $2\frac{1}{2}$ to 3 inches diameter were placed in the lower 3 feet of the trough. Experiments with still water, steady current and change in current were carried out as above. When the stones were first placed in the box 2 of the 8 fish extended the range of their wandering to include all the area on which stones were placed. Eventually, however, all but 1 of the fish confined themselves to the area free of stones, in the pool. One fish remained lying under a stone near the pool.

The depth was arranged at $6\frac{1}{2}$ inches and the gates opened fully, giving a rate of flow of 1 foot in 2 seconds. One fish ascended above the first 3 stones then came to rest in a backwater, facing down stream. The others remained in the trough for 10 minutes. The depth was then decreased to $4\frac{1}{2}$ inches. Five fish now headed into the current below the trough but did not ascend at all. Fifty minutes later two fish had gone up the trough $2\frac{1}{2}$ feet and were lying quietly under overhanging bits of stone. Two remained in the eddies in the trough and 3 were still leading the current below the trough.

Experiments with opening and closing the current gates did not result in the fish altering their positions in the pool. While there did seem to be a slight initial tendency to ascend as the current was turned on none of the fish passed up into the trough. On closing off the current wandering was confined to the pool. In this case the effect of the stones, through their effect on the current, or directly on the fish, was to limit wandering. At this time the responses of the fish, without stones, were somewhat weaker than previously and the animals appeared less vigorous.

A little mud inadvertently stirred up in the brook resulted in 3 fry entering the lower end of the trough. They dropped back to the pool almost at once, however,

Using native fry a greater tendency to hide under the stones, in either still or running water, was noted. When the current was left at 1 foot per second for 30 minutes 3 fry were found to have ascended to the head of the trough. Without stones they did not ascend so readily. The effect of the stones may be to provide hiding places by which the fish

can advance in short stages or may be in altering the nature of the current. On several occasions fish were observed to swim past 5 or 6 stones at a time.

The second piece of apparatus was used in the observations described below. The tank was used in observations on the effects of light and of vertical currents. The trough leading into the tank was used for observation on some of the factors resulting in movement of the fish up or down stream.

Observations on the effects of light.

The water in the tank, even with a full current running, was practically without movement except in the upper 3 or 5 inches, unless baffles were placed so as to direct the incoming current downwards into the tank. The observations below are made in water which is practically still unless otherwise stated. The water was 30 inches deep and depths are given in inches below the surface.

Evening, Aug. 25. Sunset about 7.30 p.m. The fish in the tank include 1 thin Hatchery fry, 3 native fry, 3 1-year parr and 3 2-year parr.

7.15 p.m. - All fish are lying close to the bottom and moving very little, even less than earlier in the afternoon when the light was brighter.

7.30 p.m. - As it gets darker 1 native fry rises to 20 inches from the surface.

7.40 p.m. - First fry is now at 15 inches and another at 20 inches.

7.55 p.m. - One small parr stirs and rises slightly above the bottom.

8.05 p.m. - Two small parr are moving slowly up and down through the lower 15 inches.

8.15 p.m. - It is now quite dark. All fish are well up off the bottom and all but the Hatchery fry and 2 parr keep near the surface, unless I turn on the flashlight, when they descend rather slowly as long as the light is on. This light is focused through the top of the glass window, below some of the fish which descend as it is turned on. The two largest parr entered the lower end of the trough, out of the direct rays of the lamp, but even these descend right to the bottom if the light is left on about 2 minutes. The native fry remained close to the surface of the tank, heading the current here. The momentary glow of a cigarette in the observation chamber caused these fry to drop 2 or 3 inches. In the dark they would immediately rise again. The effect of this small light was very pronounced and its control on the fish very direct. Sometimes fish dropping in the dimmer outer area of the flashlight beam would swim ahead slightly as they dropped, thus avoiding the bright central part of the beam. Sometimes the fish would drop through the brightest part of the beam. During this period movement was general and principally near the surface. As a result of this a slight increase in current at this time had a much more pronounced effect in 'stirring up' the fish than a similar increase in current had during daylight.

8.40 p.m. - Moon rises. The sky is quite clear and the light quite bright. During the next 5 minutes all fish settled quietly to the bottom, except 2 parr lying in the lower part

of the trough. The fish remained thus until 10.00 p.m. when observations were stopped.

Morning, Aug. 27, 4.45 a.m. Light about as at 15 minutes after sunset. One fry is lying quietly near the surface. One parr is lying on each of the 3 supports at 4, 12 and 20 inches respectively. All fish are very quiet. The light now increased very rapidly.

5.10 a.m. - Fish begin to move about slightly.

5.15 a.m. - All but 1 fish on the lowest support are swimming about in the tank. They are at all depths.

5.16 a.m. - The fish on the support moves away about 6 inches, then returns. It appears restless, and moves off and back about once in every 45 seconds.

5.19 a.m. - The other fish remain at various depths in the water. One parr is at the surface, 1 at 9 inches, the rest near the bottom. The native fry are at 2, 10 and 20 inches.

5.20 a.m. - For some reason all fish become more active than they were a moment ago. At this time observations on the effect of currents were started. It was 7.00 o'clock before nearly all of the fish settled quietly to the bottom, even though there had been no current for some time.

Turbidity of the water. Aug. 26, 4.30 p.m. The dam at the saw-mill was let out resulting in muddy water in the stream. It was noted that while there had been no change in the current in the tank the fish here were 'stirred up' as compared with their condition half an hour earlier. They rose to 10 inches. The actions were about comparable to those seen about 7.20 p.m.

the previous evening. It was noted through the observation window that this turbidity cut down the penetration of light into the tank very definitely. The gradient is more rapid than at night but I would estimate that the intensity at 20 inches was roughly comparable to the intensity at the same depth at the hour mentioned above on the previous evening. Further observations on the effect of turbidity are mentioned below.

Summary of observations on effect of light. When the fish were in water of about 30 inches depth their tendency to move about was not nearly as great in daylight as it was after dark. During the day the fish were usually seen near the bottom of the tank. In the dark all fish tend to rise to the surface and move about. Just before dark there was a short period when all fish lay perfectly quietly at the bottom, even though they had been moving about a few moments previously. While in the darkness movement is at a maximum in bright moonlight it is again very limited or quite lacking.

While in the evening the period of greatest activity did not occur until after sunset, in the morning the fish were quite active for an hour or an hour and a half after sunrise.

One effect, at least, of turbidity is that it cuts down the penetration of light into the water.

Small fry seem to be less sensitive to bright light than large fry.

Observations on the effect of vertical currents.

To produce vertical currents baffles were arranged in the tank as in fig.3. In one case a board was simply placed

vertically at the middle of the tank. This directed the incoming current downwards. Another arrangement was to limit the space where the current could flow and place screens so that the fish had to be in some type of current. This is shown in the second and third diagrams. There was a space about $\frac{1}{2}$ inch wide between the baffle and the observation window. A slight current flowed through here at all depths and occasionally fish would pass from one side of the tank to the other by this route. Only fry and small parr could do this.

Apparatus for Vertical Currents.

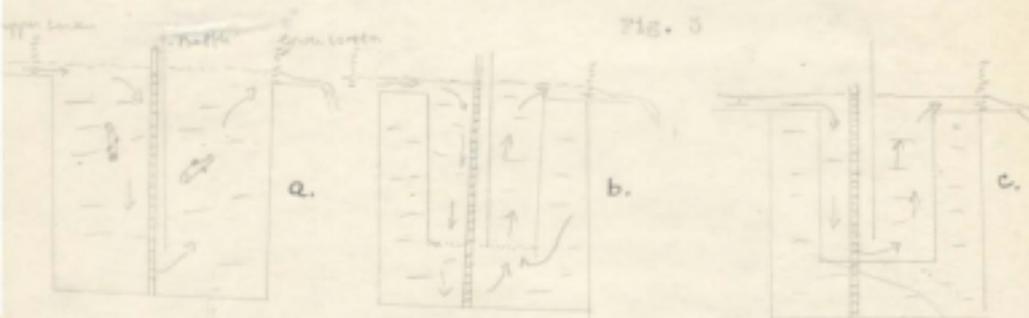


Fig. 3

Aug. 26. Apparatus as in Fig. 3 a. At 5.30 p.m. 3 native fry and 3 parr were placed in the descending current. They went to the bottom at once and the 3 larger fry immediately commenced to swim upward against the current. For 15 minutes they continued to swim up to the surface, 'drift' back to the bottom, then return to the surface again. They came to the surface about once every minute. Finally they came to rest with the others on the bottom. All fish were lying in the up-stream end of the tank.

Ten minutes later 2 parr had passed back into the ascending current and were carried slowly to the surface. They would

swim down and the process be repeated. This lasted for 10 minutes in one case and 20 minutes in the other. Finally they came to rest on the bottom. In swimming downwards the fish descended rather slowly and did not head directly into the current but seemed to work down while keeping at an angle of about 45° to the current. Their movements were not nearly as vigorous as those of the fry in the descending current.

Aug. 27, 5.34 a.m. Current, which had been off, is turned on to full extent. The fish which had been swimming slowly about the lower half of the tank, dart at once to the bottom.

5.35 a.m. All fish begin to rise somewhat and move even more vigorously than before, except for 2 fish lying on the platforms at 18 and 20 inches depth. The distribution was rather uniform from the bottom to 10 inches from the surface. Those fish in the descending current are more active than those in the ascending current.

5.37 a.m. Current is closed off. One large parr moves under lowest shelf and remains in the shadow there. The smaller parr remain at 15 to 20 inches depth, while all fry sink to the bottom.

5.39 a.m. - 5.40 a.m. There is some activity among the smaller parr which are continually rising and falling in both descending and ascending currents. They tend, on the whole, to keep in the former.

5.42 a.m. One fry comes to rest on top of the shelf at 12 inches. Large parr are lying under both the lower shelves.

5.45 a.m. - 6.00 a.m. (Observations under 'Light' for Aug. 26).

6.04 a.m. The fish have been fairly active. No current is flowing.

6.05 a.m. The current is turned on full. At once all fish drop to the bottom and remain rather quiet.

6.06 a.m. Fish at the bottom become 'restless'. Two parr move over to the right side (ascending current).

6.08 a.m. - 6.10 a.m. Activity increases. All fish are swimming about at various depths below 12 inches, and appear to be feeding.

6.11 a.m. Activity of all fish diminishes.

6.17 a.m. Two large parr are now lying on the bottom. The other fish are moving slowly about in the bottom half of the tank. The 4 parr seem, on the whole to keep to a higher level than the fry. Two rather thin parr are far more active than the other fish.

6.18 a.m. Current shut off. The small hatchery fry rises to a position under the 8-inch shelf. No other fish rise so near the surface at this time.

6.20 a.m. Those fish in the right side, which is a little brighter than the left side are becoming quieter and sinking slowly to the bottom, except for the small fry under the upper canopy.

6.21 a.m. Movement in left side is slight. All fish are distributed over lower half.

6.23 a.m. Movement increases.

6.25 a.m. All the large parr are lying on the bottom.

Two small parr are heading the descending current at 13 and 20 inches respectively. These two maintain a pretty constant position at an angle of 30° to the vertical plane.

6.27 a.m. A large parr under the second shelf descends to the 3rd shelf and drives away all fish within 6 to 8 inches before settling under the shelf.

6.35 a.m. Activity throughout the box decreases for some reason.

6.40 a.m. (From outside the tank). When I look into the tank those fish about one half way up sink to the bottom. Apparently they are very sensitive to shadows from above.

7.00 a.m. All but 2 parr are lying quietly on the bottom.

7.10 a.m. Open the current. The two parr at 15 inches, which rose again after I moved away from the tank, sink slightly. Those at the bottom remain very quiet.

7.11 a.m. All fish at the bottom become more restless.

7.13 a.m. All but 1 large parr are off the bottom and distributed evenly to 8 inches from the surface, there is no sorting according to size.

While in the above observations the effect of current was principally studied the effect of increasing daylight was not entirely excluded.

Aug. 27, 3.00 p.m. All fish are at the bottom except 1 small parr and 1 native fry. All current was now shut off. No change in distribution was noted.

3.30 p.m. Open current to full strength. Those

fish lying under the descending current are 'stirred up' and rise off the bottom. One small parr rises to 15 inches in the descending current and holds its position here.

3.45 p.m. All but the one parr are 4 to 8 inches off the bottom, moving about slowly and heading slightly up, which is equivalent to heading directly into the current where they are.

4.00 p.m. - 4.20 p.m. The dam above has been opened resulting in turbid water. The fish in the influence of the descending current are quite stirred up and move about in this current keeping below the 12-inch level. (Three yearling trout which had been placed in the tank just previously were also 'stirred up' and tended to keep right at the surface. Apparently they are less sensitive to light than the parr. These trout kept invariably to the descending current, never in the ascending. They made no attempt, however to run up the trough. The trout would chase away the salmon fry if the latter approached them. Apparently the fry would have occupied the region held by the trout. The trout were in turn driven off by the larger parr whenever they descended low enough. The larger parr did not, however, rise above the 20 inch level. The parr were seldom seen to drive off the salmon fry, however, when both were in the same vicinity).

Effects of both vertical currents and light operating at the same time.

In the observations above an attempt was made to exclude the effect of light as far as possible. In the following observations both current and light are factors to be considered.

Aug. 26. About 7.15 p.m. the fry begin to move about. All fish have been nearly motionless since 6.00 p.m. Those fry in the descending current move up to about 10 inches then down to 20 inches, then right up to 1 inch and enter the trough. When the flashlight is turned on they sink at once to the bottom.

7.20 p.m. Parr move up to 15 inches and remain here till 7.25 p.m.- 7.30 p.m., when they move right up to the surface. The parr are even more sensitive than the fry to the flashlight, sinking directly to the bottom if it is merely flashed on and off.

8.00 p.m. Three parr and 2 native fry have been at the surface for some time, and ascended about 8 inches in the trough, at which distance there was a screen. One large parr remains on the bottom. When the light is turned on through the window all fish sink to the bottom but recover their positions in the trough in about 3 minutes.

Ascending current 8.00 p.m. - 8.30 p.m. Two fry rise up in the ascending current at about the same time the parr rise in the descending current, and at about the same rate. Three parr also rose in this column but descended very rapidly as the light was turned on. The parr then worked over to the descending current by a horizontal leak past the baffle, and rose to the surface here, ascending the trough to the screen. The fry descended rather more slowly than the parr as the light was flashed on, and not as far. In the darkness they rose again and dropped back to the shallow water below the tank.

It was observed on several occasions that in the dark-

ness the smaller fish - especially the fry but sometimes the

ness the smaller fish - especially the fry but sometimes the small parr - would rise by the ascending current and then drop back to the shallows below the tank. The larger parr almost invariably rose by the descending current and ascended the shallow trough. Fry were also seen to behave in the latter way, usually when there were fewer of the larger fish.

8.30 p.m. It was still quite dark and the fish were all keeping at the surface except for 1 small hatchery fry which remained at the bottom of the tank. Possibly this was due to low physical condition.

Aug. 27, 5.20 a.m. Observations had been carried on in still water for 25 minutes previously. At this time the current was turned on. The fish were quite active and within 10 inches of the surface. As the current started to run in the tank those fish in the descending current dropped slightly, then headed upwards a little. Those in the ascending current dropped down to 20 inches, then began to rise again. Two of the parr in the ascending current worked through to the descending side, where it was darker; also the current was a little stronger here. All the fish in the descending current side of the tank were quite vigorous, moving in all directions, but tending mostly to head into the current.

5.29 a.m. - One large parr comes to rest under the 18-inch shelf.

5.30 a.m. - The fish in both sides are below 15 inches, rising and dropping but keeping in the currents.

5.31 a.m. - Current closed off. All fish sink close to the bottom.

5.33 a.m. - Opening current results in all fish sinking right to the bottom.

5.35 a.m. - Fish under the descending current become restless and begin to rise again.

Aug. 27, 6.30 p.m. - 8.00 p.m. All fish were close to or on the bottom from 6.30 p.m. to 7.10 p.m. (Current flowing).

7.10 p.m. - Two native fry slowly rise to the surface.

7.15 p.m. - Three small parr. rise slowly to the surface.

7.30 p.m. - All fish are rising towards the surface.

They wander about the tank while doing so. The fish rising against the vertical descending current rise faster than those rising with the ascending current. However, this side is slightly darker than the other side. By 8.00 p.m. no fish had left the tank to run upstream. A screen was arranged to permit fish to run up the trough but to cut down the possibility of their descending to the tank once they had passed the screen. In the morning no fish were found in the trough. (The trough had been covered with boards the previous night so that increasing daylight would not cause the fish to seek the deep water of the tank).

The apparatus for Aug. 26 was as in fig 3.c; for Aug. 27 as in fig. 3.a.

(On this night (Aug. 27) it was noted that trout about 8 inches long commenced to wander about in a pool caused by

an old dam about 10 minutes after the large parr had left the bottom of the tank. Fishing with a fly trout of 8, 9 $\frac{1}{2}$, 10 $\frac{1}{2}$, and 16 inches length were taken out, in this order, at about 3 minute intervals for the first 3 fish. The largest was taken about 10 minutes after the preceding fish. This seems to indicate that for trout, as for salmon, the smaller fish become active first with decreasing light intensity.].

Aug. 31, Afternoon. The tank was covered with a board so as to admit very little light. The intensity was comparable to that about 15-20 minutes after sunset on a clear night.

At the time observations were commenced all fish were lying on the bottom. Within 5 minutes of covering the tank all fish had risen slightly off the bottom. The fry and small parr rose highest but all fish remained in the lower 20 inches of water. At times it appeared that the small fry were 'forced' up by the larger parr. One small fry several times came to rest on the 4-inch shelf. When it descended the parr would dart at it.

When silt was allowed to run into the trough the activity increased and all fish rose nearly to the surface. They did not enter the trough and tended to keep below the horizontal current right at the surface. An exception to this was the small hatchery fry which occasionally ascended the trough a short distance, then fell back to the pool. Even after all silt had disappeared a few of the fish, of all sizes, remained within 4 to 6 inches of the surface, but in the descending current.

The experiment above was repeated without the baffles (eliminating the vertical currents) and with and without

the cover over the tank.

Without the cover over the tank. Current closed off. All fish remain at the bottom, even 3 which were most often seen rising to 15 inches in the vertical current.

Current opened. Very little disturbance occurs at the bottom of the tank where the fish are lying. The fish stir only very slightly.

With cover. Current off. Fish now rise to 18 inches and 3 parr to 15 inches. On opening the current the only result noted is that if any fish do rise to within range of the horizontal current - about 4 inches below the surface - they are apparently stopped here. There was no apparent effort of the fish to stem this horizontal current as they had stemmed the vertical current. Also under these conditions they did not rise quite so close to the surface. No fish entered the trough, even when box and trough were covered with boards.

Apparently rising against a vertical current is more likely to result in a fish going above the pool than if there is no vertical current. Low light intensity seems to increase the effect of the vertical current. There is some indication that a horizontal current at the surface of the pool was an obstacle to the fish ascending above this pool.

Effect of both vertical currents and turbidity.

Aug. 27, 7.15 a.m. - The fish have been under observation for more than 2 hours at this time. The current is running freely. All fish are well off the bottom and distributed evenly through the space to within 8 inches of the surface.

7.15 a.m. - Some sand was placed in the upper trough so that it would make the water running into the tank quite

turbid. As the cloud of silt fell into the tank by the descending current all fish sank to the bottom ahead of the cloud. As far as could be seen they remained there until the water cleared somewhat, but not entirely. As the water began to clear 2 fry rose off the bottom, then the parr rose, and all fish swam about, apparently feeding on some of the larger particles in the water. When the water was quite clear again another cloud of silt was sent down. The reaction of the fish was as above. But as the water cleared only 3 fish (all parr) rose until 5 minutes after the silt had been sent down by opening the current. By this time the water was nearly clear again and 6 more fish rose, leaving 2 parr and the hatchery fry on the bottom still.

7.40 a.m. - Decrease the current. Low water in the upper trough results in more silt being brought down. All the fish swimming about sink to the bottom, keeping below the cloud of silt as long as possible.

7.41 a.m. - Current shut off. As the water clears most of the fish rise to 15 inches.

7.42 a.m. - Increase the current. The water becomes very roily but the fish which rose as the water cleared just above descend only 3 or 4 inches.

7.42 a.m. - 7.50 a.m. - The fish will not rise above 8 inches from the surface regardless of manipulation of the current or of silt in the water. Those fish in the descending current show a sharp descent of about 12 inches when the current is turned on, then rise again and head the current at about 30 degrees to the perpendicular. By 7.50 a.m. only 2 fry remain

near the surface, the rest all having dropped to a lower level in the tank.

8.00 a.m. - There are 2 fry at 15 inches; 3 parr at 28 inches, and the rest of the fish lie on the bottom or under the shadow of the lowest (20 inch) platform.

8.01 a.m. - All fish are at about 28 inches and remain fairly quiet. Activity is decreasing. The current has been left on full strength.

Aug. 31, 2.00 p.m. - 8.00 p.m. Baffles as on Aug. 27 (fig. 3a) and current on full. Three parr are to be seen at 15 inches most of the time. These fish are 'thin' and seem to be more active than the other fish. The other fish are within 8 inches of the bottom and moving only very slightly. Out of 12 fish in the tank a number varying from 8 to 10 are either immediately under the descending current or lying on the bottom in the upper corner of the tank, ahead of the descending current. Two to four of the larger parr are seen principally in the lower bottom corner of the tank, beyond the ascending current. The upper corner is slightly darker than the lower corner, however, most of the fish in the upper end of the tank are seen usually under the descending current rather than in the dark corner.

When the current is shut off all but the 3 parr mentioned above, come to lie quietly on the bottom in a space of about 2 minutes. During this 2 minute interval the fish usually, not always, wander about the tank, rising as high as 10 inches from the surface. Movement was quite leisurely. No distinction in behaviour of the fry and two sizes of parr was noted.

If, after the fish have come to rest on the bottom, the

current is turned on full the fish become 'stirred up', and are quite active for 5 to 10 minutes, then become quieter and head into a horizontal current 2 to 3 inches below the surface.

If silt is now introduced into the current the fish sink, as observed before, but rise and 'feed' quite vigorously as the water clears. Again most fish are to be seen in the descending current; those in the ascending stream are much less active than the others. As the silt clears away completely they again drop to about 3 inches from the bottom, and in another 10 to 15 minutes sink right to the bottom. Shutting off the current now does not seem to have much effect. But an increased current, either when there is no current or a very slight current, does 'stir' the fish up somewhat. They do not, however rise as high as when there is silt in the water.

Summary of behaviour in vertical currents.

The fish tend to head into a vertical current, as they do in a horizontal current, whether it be descending or ascending. They will remain for some time in a descending current, but on the whole, do not remain nearly so long in an ascending current if they can avoid it. The depth at which fish remain in a descending current seems to be governed to a large extent by the intensity of the light. The effect of turbidity is comparable to the effect of decreased light intensity and seems to be, in part at least, a result of the decrease in light. If the light is strong enough the fish may lie on the bottom under a descending current, even though they could avoid the current. An increased descending current has the effect of 'stirring up' the fish in the pool. In the pool the fish will, under the

same conditions of light, rise nearer to the surface in a descending current than they will if there is a horizontal current near the surface. They tend, on the whole, to remain below the latter. When the vertical current was cut off 'wandering' was not observed, contrary to the condition observed when a horizontal current in which the fish were lying was cut off.

Observations on the effect of variations in current and light on the fish in a stream.

The observations below were carried out in the trough leading into the tank used in studying the effects of light and vertical currents. Variations in current were produced by manipulating the gate controlling the amount of water flowing into the lower end of the trough, and by the insertion of various baffles and dams in the trough. To observe the effects of changing light observations were made in the early morning, and in the evening.

Preliminary. - Aug. 19, 10.30 a.m. Dams were arranged in the trough as indicated in the accompanying diagram.

(fig. 4.)



Fig. 4. Arrangement of baffles in trough above tank to produce pools and variations in currents.

Four parr which had been lying quietly on the bottom of the tank were placed in the lower pool. The current, which

had been running very slowly, was then turned on full strength. Two of the fish began to move upstream to the first pool. Here they remained. But if the water above the third pool was agitated by waving the hand back and forth in it, thus sending a series of transverse waves down the trough, the two parr ascended to the second pool. One fish remained in the lower stretch, having ascended two-thirds of the way to the first dam while the water was being agitated. By decreasing the flow so as to expose the back of this fish he was stimulated to commence struggling upstream in the shallow water. Increasing the flow now resulted in this fish passing over the first dam into the first pool. After 2 or 3 attempts to ascend through the next stretch of swift water the fish seemed fatigued and a rest of about 10 minutes was necessary before a similar response could be evoked again.

The experiment of agitating the water back and forth by hand when there was a current flowing was tried several times. After 1 to 2 minutes the fish commenced to move slowly forward, would leap the first fall, and remain in the pool immediately above. Too violent agitation of the water seemed to inhibit this reaction, causing the fish to lie close in to the corner of the trough. When there was no agitation at all the fish remained in one spot, heading the current, as long as the water was sufficiently deep, (about 2 inches in this case).

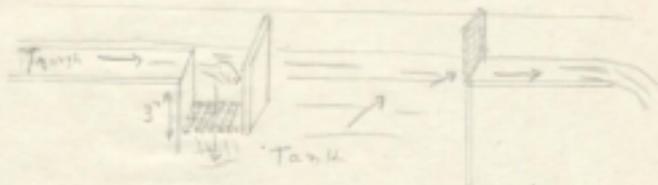
The effect of suspended material in the water was tried, but the results did not appear to be significant. Apparently a change from a relatively simple current to a more turbulent

current is an important factor in stimulating fish to run upstream.

Aug. 25, 5.10-a.m. - 6.20 a.m. The current had been left on over night, and fish in the tank had free access to the trough. Four parr were found in the upper part of the trough this morning. The lower end of the trough was screened off and these 4 fish placed just above the screen. One small parr persisted in running to the upper end of the trough, even though attempts were made to 'chase him back'. The other 3 fish ascended to the first pool only when the water in the lower stretch was so low that their backs were out of water. Then they would attempt to struggle up to the first pool if there was sufficient water to allow them to barely float. Contrary to the observations of Aug. 19 agitating the water by hand seemed to have no effect on the fish.

Aug. 31, 6.00 p.m. - 8.00 p.m. A small enclosure was arranged at the lower end of the trough, in the tank, having a screen bottom, so that there was a little pool in which the current was descending. (fig.5.)

Fig. 5.



Tank and lower end of trough with one side removed to show arrangement of the small pool with descending current.

Fish placed in this pool tended to lie right against the

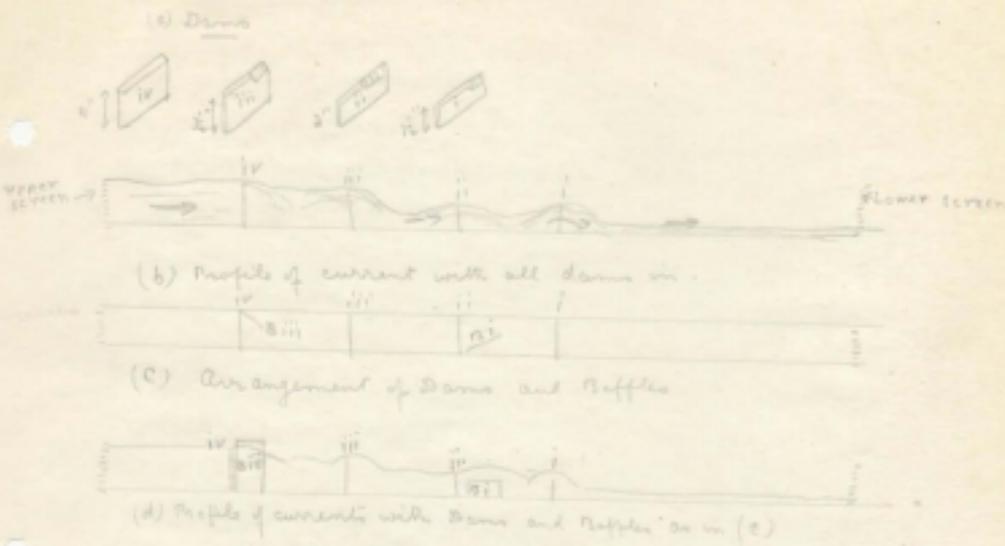
bottom screen. When first placed in small parr attempted to jump out, but the large parr did not. Cutting off the current entirely seemed to have no effect on the fish. Only when 'scared' as by moving a hand above the pool, would any of the fish go upstream. As it got dark the movements of these fish were compared with those of the fish in the tank. At 7.30 p.m. those in the tank had risen to near the surface and were quite active. The parr in the small pool were lying quietly near the surface. By 8.00 p.m., when it was quite dark, none of these fish had entered the trough. (The current had been flowing for over an hour). There was practically no 'fall' in the water here, but the down current was quite strong. Another observation with conditions slightly varied from those above was made on Sept. 2.

Sept. 1. An attempt was made to see if, by manipulating the currents in the trough and the small pool described above, the various factors investigated previously could be pieced together to explain certain behaviour of the fish. It was found that the behaviour of the fish could be predicted to a limited extent, but the conditions provided actually proved to be very complex and behaviour could not be predicted with any degree of certainty.

Effects of various baffles in the current.

Various types of baffles were placed in the trough so as to modify the simple current. The behaviour of the fish was then studied under the different sets of conditions produced.

Fig. 6. Diagram to show how baffles were used.



(A) Dams. A screen was placed across the lower end of the trough in order to keep the fish well within the influence of the currents being studied. A dam $1\frac{1}{2}$ inches high (1) was placed across the trough 1 foot above the lower screen. This formed a long, rather quiet pool above the dam and a stretch of fairly swift water below where the flow was about 2 feet per second. The fish were placed just above the screen. Three parr were used which had just previously been found to exhibit quite a pronounced reaction to variations in the current. Within 3 minutes of the insertion of the dam all 3 fish had ascended the swift water to the dam and passed into the long pool above. One came to rest just above the dam, one about a foot above, and one went to the upper screen. The experiment was repeated several times. The fish always ascended to the

pool, but once in the pool no particular order in their behaviour could be discerned.

A second dam 2 inches high (11) was placed 8 inches above the first. This resulted in a stretch of very turbulent water between the two dams. When now the fish were placed at the lower screen and the current allowed to run strongly all fish passed up to above the second dam. This experiment was repeated 3 times at intervals of about 10 minutes, and similar results were obtained each time.

A third dam about $3\frac{1}{2}$ inches high was placed 8 inches above the second dam, again resulting in a stretch of turbulent water between the two dams. Two more parr and 2 fry were added to the fish at the lower screen. As the current was turned on all, but 2 of the small parr which had been used previously, ascended to above the third dam quite readily. The fry were first to reach the upper quiet stretch. The two small parr ascended to the first pool only after increasing and cutting off the current several times. They 'went up on a freshet' eventually, and came to rest in eddies immediately below the second and third dams respectively.

The above series of experiments was repeated several times. The fish tended to ascend through the stretches of turbulent water until they reached a quiet pool above, even though they could, as was observed, lie in the lower stretch of swift water with very little apparent motion. In cases where fish did not ascend under the above conditions it seemed to be because they lacked vigor. Usually such fish as did not ascend were individuals who had already run through

the swift and turbulent stretches several times. Such fish might remain in the lower swift stretch pressed close in to the bottom corners, or in eddies immediately below one of the dams.

It was observed that if a board was placed across the upper end of the highest pool all fish in the pool assembled under the board. Otherwise they tended to be scattered uniformly throughout the pool.

As observed on Aug. 31 fish in the small pool with screen floor and descending current would not move out of this pool, regardless of current manipulation.

A 4 inch dam (iv) was placed at the end of the trough so as to cause the water to spill over into the pool. This caused considerable disturbance in the water of the pool, which was impossible for the fish to avoid. The fish, especially the largest parr were 'tumbled about'; frequently the head of a fish appeared above water and the fish seemed to be distressed. Three small parr succeeded in jumping the dam; several others attempted this but without success. The fish remaining in the pool eventually came to rest either behind the fall, or lying with head directly under the fall.

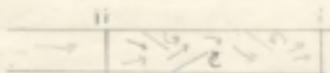
Between 5.45 p.m. and 6.20 p.m. a 2 inch dam (ii) was substituted for the higher dam (iv). No particular effect on the fish was noted. They remained on the bottom. Apparently those which had unsuccessfully attempted to leap the higher fall were either fatigued, or no longer felt the stimulus to leap over a falls.

(B) Oblique baffles. Three oblique baffles were arranged in the pool above the first dam, which was increased in length so as to afford about 15 inches of rather quiet water above

the baffles. The baffles had the effect of breaking up the simple currents into transverse and oblique currents, and eddies, of varying strength, so that only above all the baffles was there any stretch of smooth water.

Five rather large parr were placed above the lower screen and the current opened fully. Immediately one large parr moved upstream leaped over the first dam, passed up steadily through the swift, broken current above and finally came to rest in the first stretch of quiet water just above dam (ii).

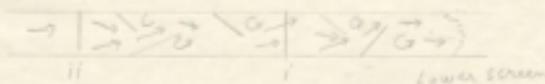
Fig. 7. Arrangement of oblique baffles.



Later the other 4 parr ascended to the first dam, but only one of these passed up above dam (ii). The experiment above was repeated 3 times. Each time the one fish went right up to the quiet stretch. On the third try only, the other fish entered the stretch where the baffles were. One came to rest at the foot of dam (ii). The other two remained in eddies behind the first and second baffles, respectively.

In order to break up the straight swift current in the lower stretch of the trough baffles were arranged as in fig.8.

Fig. 8.



This also had the result of raising the water level in this stretch from $\frac{3}{4}$ inches to $1\frac{1}{2}$ inches. Eight fish were placed

just above the lower screen. When the current was allowed to run at full strength all fish crowded into the eddy behind the lowest baffle. Within 5 minutes two of the fish ascended to behind baffles further up, one of these passing over dam (1) to lie in the eddy behind the lowest baffle in this pool. This apparently relieved the pressure of fish behind the first baffle for the remaining fish stayed here over one half an hour. Occasionally one would swing out towards the main current slightly, then swing back into the eddy again. Altering the current did not result in any change in distribution; neither, as far as could be seen, did declining light have any effect by 6.30 p.m. (At this time it was raining quite heavily. On a previous occasion fry had been observed to settle quietly to the bottom of a trough when rain drops fell on the water. Possibly a similar reaction was involved this time.)

From the observations above there seems to be some indication that obstacles causing horizontal eddies in a stream may give rise to the fish remaining in one spot. On the other hand vertical eddies seem to stimulate the fish to move away, frequently upstream.

Sept. 2, 2.00 p.m. - 7.30 p.m. The experiments recorded just above were repeated. On this occasion, however, at no time did any fish move upstream. If placed at the upper end of the trough the fish immediately moved down to the pool at the lower end. Covering the trough with boards, to exclude the light, had no apparent effect. At 7.30 p.m. the 4-inch dam was placed at the lower end of the trough, causing the water

to fall over into the pool with screen bottom. One parr leaped this dam at 7.25 and remained in the pool, immediately above the dam. (It was quite dark now.)

Sept. 3, 5.00 a.m. Light about as at 7.00 p.m. on the previous evening. The apparatus had been left overnight as described just above. In the morning 4 fish were found above this dam, and 3 below it, in the small pool there. One of the latter jumped over the dam as I looked into the pool, apparently started by my shadow. Another made 5 attempts within 5 minutes but was unsuccessful. The first fish soon passed back over the dam to remain in the lower pool again. These last 2 fish appeared rather fatigued and lay close against the bottom screen.

Boards had been left over the trough (the upper pool in this case) so that any fish passing up over the dam during the night would remain up, at least as far as reaction to light was concerned. The 4 parr in this section were scattered evenly over the upper 18 inches of the trough. On removing these boards only the fish which had just gone over the dam (see above) fell back to the lower pool.

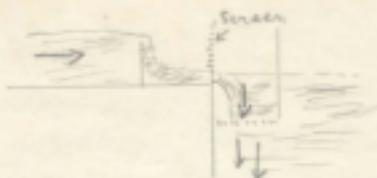
5.15 a.m. - The remaining 4 fish were concentrated at the lower end of the upper pool.

5.25 a.m. - The fish are spread evenly over the lower 3 feet.

5.28 a.m. - The two lowest fish pass back over the dam into the pool below. The dam(iv) was now set as in fig.9 so that the water falling over it fell in the trough and there was about 6 inches of swift, turbulent water to the

lower end of the trough, where a retaining screen was set.

Fig. 9



The eight fish used the previous evening were placed in the small stretch of rapid water. Between 5.29 and 5.32 there were 3 attempts at jumping the fall. None were successful. By 5.39 all struggling at the foot of the fall had ceased. Five fish were pressed against the screen by the force of the current. Some fish were lying in a normal position heading the current just below the falls and one was lying at the bottom of the dam, behind the falls.

5.44 a.m. - One large parr jumps over the falls, after having been nearly motionless for 5 minutes.

5.52 a.m. - Another large parr jumps over the falls. Both of these lie just above the dam. The remaining fish lie quietly, pressed against the screen by the current. The bottom fish lie across the current with their backs tilted towards the current at 45°. The others are pressed sideways flat against the screen.

6.00 a.m. - The uppermost fish has just completed 3 unsuccessful jumps in 5 minutes and is now resting quietly.

A second dam, 2 inches high, is placed 4 inches below the first. It does not quite break the force of the first fall. The fish mentioned just above makes several rather aimless

leaps, then lies at the base of the 2 inch dam. Dam (ii) was then arranged to break up one side of the main fall only. The fish made no further attempt to ascend but lay immediately below the second dam on the side where the first fall was not broken up.

6.10 a.m. - No change from above positions.

6.15 a.m. - Both dams were removed and the 3 fish which had moved upstream were swept back to the screen.

Dam (i) ($1\frac{1}{2}$ inches) was then placed so that the fish at the screen were in rather rough water. (All but the 3 which had passed over dam (iv) had been placed back in the tank.) In 30 seconds one fish had ascended over dam (i); another went over it in $1\frac{1}{2}$ minutes and the third in 3 minutes. No change in the amount of water flowing was used in this case, merely a 'turbulent' current

6.20 a.m. - All 3 fish have remained just above dam (i). Dam (ii) is placed 8 inches above dam (i), so that the intervening water, where the 3 fish lie, 'boils'. Two fish drop back to the lower reach at once. The third turns so as to lie in a backwater below dam (ii), facing downstream.

6.22 a.m. - The 2 lower fish rise above (i) and come to lie beside the first fish.

6.24 a.m. - The current is increased by cleaning some leaves and trash from the upper screen. The fish shift their positions slightly, one falling back to the lower screen.

6.25 a.m. - The fish which just dropped back has ascended above both dams. The other 2 fish remain in the pool between the dams.

6.26 a.m. - Dam (iii) (3½ inches) is placed above (ii) so as to cause turbulent water throughout the pool (ii-iii). The upper fish drops back from just above (ii) to the screen.

6.28 a.m. - This fish has ascended steadily so that he is now above all 3 dams. The other 2 are still in (i-ii). The one which ascended is the largest of the 3 fish. Dam (i) is now moved upstream to a position 5 inches below (ii), thus eliminating the backwater in pool (i-ii). One of these fish immediately ascends to (ii-iii) lying again in a backwater just below (iii). The other fish remains below the falls at (ii).

6.30 a.m. - Dam (iv) (4 inches) is placed 6 inches above (iii). The depth of water above (iv) is 5 inches. There is apparently quite a backwater below the surface current and the upper fish, (in (iii-iv)), remains in this. There is now a fish in each of the 3 pools. All 3 remain rather quiet.

6.40 a.m. - No movement noted in the last 10 minutes so all 3 are probably more or less 'in equilibrium' with the currents to which they are exposed.

6.42 a.m. - Move dam (iv) back 4 inches to alter the eddies in (iii-iv). The fish in this pool moves up to lie across the trough right at the base of (iv).

6.47 a.m. - Replace (iii) with (i) so as to cause more disturbance in this pool (now (i-iv)). The fish is carried to the screen with that in (i-ii). The latter is removed. The first fish stays quietly in a rather simple, but swift, current just above the screen.

6.50 a.m. - He swims rapidly up above all 3 dams, (ii), (i) and (iv), coming to rest above the upper dam.

6.51 a.m. - The fish in what was (ii-iii), now is (ii-i),

was disturbed by a movement of my hand and ascends above (i) and (iv) to lie beside the first fish.

6.51 a.m. - 6.55 a.m. - Remove (iv), having placed (iii) slightly upstream to it. The fish accidentally slip under (iii) as it is lowered into position. The fish were gently 'herded' back and (iii) replaced. The pool (ii-iii) is now fairly long and quiet in its lower end, where the fish lie. Dam (ii) is moved up to 6 inches from (iii), making the pool rather turbulent. At once the larger fish went up over (iii); the smaller fish fell back to the lower screen.

6.57 a.m. - Both fish are at the lower screen.

7.00 a.m. - Both are lying quietly in a simple swift current just above the screen. They do not swim much but seem to hold their positions by having the pectoral fins spread on the bottom. (This method of maintaining a position in a rather swift current had been observed before.)

7.15 a.m. - Both have ascended to above (iii) (over (i), (ii) and (iii)). Dam (iv) is now inserted 11 inches above (iii).

7.22 a.m. - One is over (iv). The other remains quietly on the bottom of the trough, at the base of (iv) and to the left.

7.25 a.m. - An oblique baffle is placed just below (iv) so as to direct a strong current at this fish. In 30 seconds he quietly rises and passes over (iv).

Now these fish have been brought from the lower end of the trough to the upper end by arranging dams and baffles so as to have the fish in the influence of vertical currents or turbulence whenever they stopped moving upwards. In the last case above an area of 'dead water' was altered to one of rather swift current.

7.28 a.m. - The fish are now placed at the lower end of the trough again. They quietly head the swift, rather simple current here. The oblique baffle at (iv) is removed.

7.30 a.m. - The smaller fish goes up to (ii-iii) hesitates 4 seconds, then moves up to (iii-iv) and takes the position he formerly held at the left side of the base of (iv).

7.31 a.m. - The other fish goes up to (i-ii).

7.35 a.m. - No further movement by either.

7.40 a.m. - No movement yet. The oblique baffle is arranged to direct the current at the fish below (iv), as previously. He drifts down to lie just above (iii).

7.44 a.m. - He goes up to and over (iv).

7.42 a.m. - 7.44 a.m. - An oblique baffle is placed just below (ii) as shown in fig. 6.(c). This directs the current at the fish lying in (i-ii). He drifts over behind the baffle and remains in the eddy there.

7.45 a.m. - The upper fish is again placed just above the lower screen. He lies quietly as before.

7.47 a.m. - He heads up stream slowly, then more rapidly, and comes to rest behind the baffle in (iii-iv), and remains there.

The fish lying behind the baffle in (i-ii) was at first very active, but has not moved from behind the baffle, except for a slight lateral motion back and forth across the eddy.

7.50 a.m. - He is placed at the lower screen.

7.52 a.m. - He ascends to behind (B1) again, then falls back to the lower reach.

7.55 a.m. - He ascends to (iii-iv), then falls back to (ii-iii), then to the screen again.

7.58 a.m. - He ascends to behind (Bi), then falls back to screen.

7.59 a.m. - He ascends to (iii-iv), and drops back to screen again.

8.06 a.m. - He has remained near the screen. The fish behind (B iii) has not moved since last noted.

Boards were placed over the upper part of the trough so as to darken the trough as far back as (B iii). In 5 minutes the fish here had not moved. Observations were stopped.

In the above set of experiments the rate of flow between the control gate and the upper screen was about 1 foot in 4 seconds, with a depth of 6 inches. It was not found possible to measure the rate of flow satisfactorily in the short stretches of rapid water below this. The same rate of flow was used below unless otherwise stated.

Sept. 3, 2.30 p.m. - On returning to the apparatus it was found to have been tampered with since morning. The dams had been raised allowing the fish to move up underneath and both were found under the board at the upper end.

2.45 p.m. - Both fish were placed at the lower screen.

2.46 p.m. - Mud was stirred into the water above the control gate for $1\frac{1}{2}$ minutes. One fish ascended to the first dam while the water was muddy and fell back when it cleared.

2.52 p.m. - Both fish in lower stretch. Mud is stirred in for 10 minutes. Water clears about 3.10 p.m.

3.12 p.m. - Smaller fish is up to (iii-iv) behind (B iii). Mud is stirred in till 3.21 p.m.

3.17 p.m. - Both fish are in (iii-iv) lying at outer edge of baffle with their head in the current, where the water seems slightly clearer.

3.23 p.m. - As water clears the fish drop behind the baffle. The small one is about $1\frac{1}{2}$ inches below the surface and frequently swings into the stronger current. The larger fish lies on the bottom.

.23'.30" - Small fish falls back to screen, then ascends to behind (B iii) again.

3.24 p.m. - Screen is removed from lower end of trough.

3.24' .30" - A large parr rose from the small pool below the trough and went straight up to the upper screen, hesitating slightly in (ii-iii) and in (iii-iv), in small eddies.

3.25 p.m. - He rises to the surface in the upper pool, falls back to (iii-iv), then goes to upper screen again.

3.29 p.m. - Close off current. All fish remaining in small pool below trough are placed in the tank. The 3 fish which had ascended the stream were placed in this small pool and left for 5 minutes.

3.36 p.m. - Two fish are jumping at the baffle forming the lower end of this pool.

3.40 p.m. - One starts up trough a short distance, but soon turns back. There is barely sufficient water for swimming. Open current.

3.41 p.m. - All 3 fish lie flat against the screen bottom of the pool, either under or behind the fall; and all head 'downstream'.

3.50 p.m. - No change from positions taken when current was first turned on.

3.52 p.m. - Mud is stirred into the current above the upper screen for 6 minutes.

4.00 p.m. - No sign of movement out of pool.

4.02 p.m. - Water becomes clearer. One fish is moving about near the surface. (The fish in the tank have been wandering about within 6 inches of the surface since the mud was first stirred into the current.)

4.04 p.m. - One fish enters trough to first dam, then falls back to the pool.

4.05 p.m. - He enters the trough again.

4.06 p.m. - Another enters the trough. Both remain in the lower swift stretch. The current is now cut down to about 1/3 of its former rate.

.06.' 30" - Three more head into lower end of trough.

4.08 p.m. - No change in position. Stir up silt in upper end of trough.

4.10 p.m. - all fish go to bottom of lowest pool.

4.11 p.m. - Water is clear. Three fish are again at the surface of the pool, heading into the trough.

4.15 p.m. - The trough is covered with a board. The disturbance causes the fish to sink to the bottom.

4.17 p.m. - One fish rises to the surface.

4.18 p.m. - All are up at the surface.

4.20 p.m. - One fish enters the trough about 2 inches.

4.30 p.m. - He is up to 6 inches. The others are still at the surface in the pool.

4.31 p.m. - Close off current. Two fish sink to the bottom.

4.32 p.m. - The upper fish drops back to the pool.

4.35 p.m. - The water in the pool is very quiet. The fish move about considerably and one enters the trough twice, but

falls back. (Depth in trough $3/8$ inches.)

4.38 p.m. - Open current to $1/3$ full strength. Water becomes muddy. The fish continue to wander about till it clears, then sink to the bottom.

4.39 p.m. - Two fish head into the trough again.

4.40 p.m. - Increase current to full strength. The fish head the current but remain in the pool. (Those in the tank are quite active, heading up into the descending current.

For the next hour various current manipulations and covering the trough with boards were tried, but the 3 fish remained in the pool throughout.

5.40 p.m. - 6.00 p.m. - Experiments as tried in the morning on the effect of dams and baffles were repeated with these 3 fish. The fish went up to (iii-iv) and remained behind the baffle (B iii) in this pool. Apparently they do still exhibit a noticeable reaction to the stimuli of varying currents etc., but it is not as strong as previously, due to fatigue, or possibly some unrecognized factor.

The apparatus for producing vertical currents in the tank was arranged as in fig. 3.c (p. 19), in order to allow the fish to move freely from tank to trough.

6.45 p.m. - All fish were placed in the tank and sank to the bottom within 10 seconds, with the exception of 1 fry which remained 8 inches from the surface, heading the descending current.

7.00 p.m. - All fish are now at the bottom. It is dusk.

7.10 p.m. - One fry rises in the ascending current and drops back to the shallow stretch at the lower end of the tank.

7.15 p.m. - Close of the current. One fry, 2 small parr and one large parr rise to the surface and remain there.

7.20 p.m. - Open current. All but one small parr sink to the bottom.

7.25 p.m. - The small parr at the surface enters the trough. Another rises by the ascending current and rests in the lower shallow stretch.

7.40 p.m. - One parr still in lower stretch. Four are lying just within the entrance to the upper trough.

7.45 p.m. - It is quite dark. Five small parr are lying in the lower stretch (downstream to ascending current). Three fry are just in the entrance to the trough. As the light was flashed on 3 of the parr on the lower shallows descended by way of the ascending current.

7.50 p.m. (Starlight). - The parr which had left the lower shallows as the light was turned on were back within 2 minutes after it was turned off.

8.00 p.m. - The fry in the entrance to the trough seem less sensitive to the light than the parr on the lower shallows. They do not move as the light is flashed on. One parr rises to surface, enters trough and ascends half way to dam (i).

8.02 p.m. - 8.03 p.m. - Three of the parr on the lower shallows were placed in the lower end of the trough. One of these ascended to (iii-iv). The others sank to the bottom.

8.03 p.m. - 8.15 p.m. - This parr remained in (iii-iv). Three parr are to be seen on the lower shallows most of this period. The fry at the entrance to the trough remained here throughout the period. The fish in the tank are moving around

2 to 10 inches below the surface. There was no attempt to go upstream. Observations were ceased at 8.15 p.m.

Comments on the behaviour of the fish under the conditions of current variation, light and turbidity described above follow.

It is apparent that a number of complex factors must be involved, some of which were unknown. In many cases the results of the observations seemed to contradict those obtained previously. Further experiments with the various factors under better control would be necessary to establish any of the observations as definite facts. Some points were brought out, however, which seem to be important.

A great deal depends on the individual fish under observation, its vigor etc. Hence many similar observations should be recorded.

An irregular turbulent current very often has the effect of causing a fish to move upstream. This turbulence is most effective when it takes the form of vertical irregularities in the current. Horizontal eddies and backwaters form places where the fish tend to lie quietly. Vertical eddies frequently result in the fish moving away, and since it usually heads against the current, this movement is upstream in most cases. The effect of a simple increase in current strength is not clear, though in some cases movement upstream resulted. The same may be said of a decrease in current. Possibly the effect of turbulence could be analysed as an effect of changing current. Movement upstream is more likely to occur in shallow water, (under 6 inches), in times of low light intensity than in times of high

light intensity. This latter is dependent on the particles of silt not having a direct unfavourable effect on the fish. That the fish tend to remain in one spot when in a simple current of moderate strength was again brought out in the observations just recounted.

MARGAREE SALMON INVESTIGATION

1937

Report No. XIV. A Study of the Behaviour of Trout Fry in Various Types of Currents.

By P. F. Elson.

The observations and experiments to be described below were carried out with a view to learning something of the behaviour of the brook trout in relation to the current factor in its environment. Since this trout (Salvelinus fontinalis) is essentially a stream fish a consideration of its reactions to currents is important in studying its behaviour and distribution. As far as possible the observations were made under uniform conditions of light and temperature. The general procedure has been to observe the fish under various conditions, to see what reactions seem to be involved. Then an attempt is made to correlate the observed facts in an order which would indicate the behaviour of the fish in its natural habitat.

The observations may be arranged under four main headings; in still water; in water moving in a slow, simple current; in water where both the above conditions are provided; in more rapid currents, involving change in rate of current, eddies, turbulence, and falls.

In still water.

The behaviour of the fish was first studied in still water so that their reactions to currents could be recognized by comparing the behaviour under the two conditions. Also the behaviour in still water is in itself important since the fish does occur in places where no current is evident.

Fry from the Frizzleton Hatchery were first used. Later native fry from the Duck Cove brook were studied. No difference between the two stocks in size or behaviour was apparent so no distinction between them is made below.

The observations were carried out in a small pool made for the purpose near the mouth of the Duck Cove brook. In the upper corners of the pool no current could be detected. The chute leading into the pool provided a rather slow flow of water. The trough leading out could be manipulated to give quite a swift current. A 'pool' formed of a square box was provided at the lower end of the trough. Both upper and lower chutes were screened to prevent fish leaving the main pool. A diagram of the set-up is provided in fig. 1. For most of the work a simple box, 30 inches long, 10 inches wide and 1 foot deep, screened at both ends was used. Wings were fixed to the outside of the box so that it could be sunk to any desired depth by placing stones on these wings.

July 22. Watched 25 trout fry which had been placed in the box 2 days previously. The box had been in still water all this time. The depth of water in the box was 3 inches. The trout fry tended to be dispersed evenly throughout the available space, both horizontally and vertically. A few fish were moving about at any given time. They tended to head in any and all directions but there was a little tendency to be oriented parallel to the long axis of the box. Some fish not swimming about actively were lying motionless on the bottom. Others kept at various levels off the bottom. These latter were constantly moving their pectoral fins alternately, the dorsal fin was 'waved' to one side and the caudal fin moved with a sort of 'screw' motion. Apparently the combination of movements

served to keep the fish in one place. Occasionally these fish would move slightly either forwards or backwards. All the fish would wander at one time or another. The movement was leisurely unless a dart was made at a food particle on the surface. In such cases the fish always turned about and retreated after either striking or missing the particle. When the fish were alarmed by waving a hand over the box they would dart swiftly back and forth the length of the box, moving on a zigzag course. If the waving were continued for some time the fish gathered at the opposite end of the box from the disturbance and took a position quietly in the water but with fins moving rapidly in the order described above. They were very alert in this position and would dart swiftly at any variation in the movement.

When stones were placed in the box at regular intervals the fish did not seem to take alarm so readily. Some would hide when startled. Others would not. After being startled those which hid remained under cover for about 5 minutes and further waving did not disturb them. Rapping the side of the box, however, would cause some to leave their hiding places and search others. As many as five fry would hide under 1 pebble about 3 inches across. If a board about 6" x 4" was floated on the surface of the water, instead of placing stones in the box, the fish would all gather under the board on being alarmed. The first 2 or 3 times there was a certain amount of darting about before all fish got under the board. After this the fish would move directly under it on being alarmed. As the board, with the fish under it, was pushed slowly about the fish kept under the board. This reaction of hiding under the board was

very pronounced. The board was removed and stones replaced in the box. In five minutes the fish had assumed a uniform distribution. Waving the hand again alarmed the fish less than when no stones were present. Only about one half of them sought shelter under stones. Twelve of the 25 simply milled about with no attempt to hide. Even splashing a hand or a stick in the water resulted in only four more going into hiding. Again the stones were removed and the board placed in the box. Once more the fish proved very excitable when a hand was waved. After three minutes they emerged from under the board a few at a time, and would dart back at a very slight movement.

July 23. Depth $5/8$ inches. 10.25 a.m. The fish startle very easily at movements on the bank such as reaching for an object, leaning over, etc. Very slow movements do not startle them, however. When startled they appear very anxious to find cover and will even hide under my flat hand as it is placed close to the surface. It is possible to flatten my hand, slowly, right down on the fish when they are hiding under it. Once it is raised about five inches above the surface, however, its movement stimulates the fish to dart about.

10.33. The fish have been undisturbed for about four minutes; at first they lay quietly. Now they wander about and are distributed quite evenly through the box. Most are quite close to the bottom, in this shallow water. Those actually on the bottom are quite motionless. Those floating in the water show typical fin movements as already described.

- 10.46 Put in the 4" x 6" board. On being alarmed all went under the board. Two of the fish required to be 'startled' three times before hiding. One fish has its head out in 20 seconds.
- 10.50. Four fish are out from under the board. There are two at each end and they head in two directions.
- 10.52. Seven fish are out. They head in three directions. All are lying very close to the bottom.
- 10.54. The two farthest from me begin to wander about.
- 10.55. More fish show wandering and they begin to rise from the bottom slightly.
- 11.05. About 8 fish are swimming around in the box. The rest are still under the board.
- 11.06. One large fry is 'chasing' others away from its vicinity and even wanders about 'looking for trouble'.
- 11.10. Ten fish are out now. They move in and out under the board. There is just sufficient depth for them to swim under. The sun now shines directly in the box. The activity of the fish is increased. On the whole the fish appear, however, to keep to one side of the box where there is a shadow.
- 11.55. Ten fish are out, and distributed evenly through the available space. Overhanging leaves caused shaded and bright areas on the bottom. The distribution of the fish appears to show no relation to the shadows, however. On being alarmed they dash quickly to cover.
- 11.56. Stones are put in. Only four seek hiding under the stones.
- 11.57. There are twelve fry spread through the opposite end of the box from me. Some lie in sun, some in shadow. All are quite motionless.

- 12.00. One starts to wander about, and immediately the rest also start wandering.
- 12.01. Some come to the end near me in wandering, but they tend to concentrate at the far end.
- 12.04. All are quite active. One side of the box is shaded but most of the fish are in direct sunlight. The distribution now tends to be uniform throughout the box.
- 12.07. On being alarmed by movement of my hand three of the fish hide under pebbles at the near end. The remainder rush to the opposite end and face the disturbance with no attempt at hiding, remaining quietly. If the disturbance is repeated most of the fish mill around at the far end and remain there. Four come towards the disturbance and hide under stones.
- 12.35. The fish have been undisturbed for 25 minutes. They wander about during the interval. On being disturbed now eight seek hiding under the stones, but most get as far as possible from the disturbance.

While waving the hand in the air causes quite a disturbance among the fish, splashing it in the box causes very little disturbance except to those fish in the immediate vicinity.

Four diagrams indicating the distribution described above will be found at the end of the paper.

Summary of observations in still water.

In still water the fish tend to be evenly distributed throughout the available space. There is considerable tendency to wander about. Over a uniform, light-coloured bottom they are very excitable and seek cover quickly if it is provided in the shape of some

floating or overhanging dark object. If there are stones spread about the bottom they seem to be less excitable. They are more excitable in shallow than in deep water.

In a slow, even current.

July 23. The box used above, containing 25 fry, was slowly moved over in front of the upper chute at 3.15 p.m. The current flowed through the box at a rate of 30 inches in 40 seconds. The fish showed no sign of disturbance until the current began to flow through the box. Then the fish all headed upstream, and none were actually lying on the bottom. They swam with a vigorous tail movement, and the movement of the fins described above in idling in still water was absent. At first the fish were concentrated at the upper end of the box. Occasionally a fish would jump about six inches out of the water. By 3.30 p.m. they were scattered fairly evenly through the trough. There was some wandering from one end of the box to the other, but always movement was parallel to the current. While scattered evenly throughout the length of the trough the fish were mostly in the middle two-thirds in regard to lateral distribution. Periodically the fish would collect at the upper end and several would jump out of the water. From 3.58 to 4.03 an average of five jumps per minute was counted. At 4.10 jumping occurred again; though at 4.07 the distribution had been fairly uniform throughout the box. By comparison with the sides of the box the highest jumps were estimated at about 9 inches from the surface. (The fry were 4 to 5 c.m. long.)

4.50 p.m. All are heading the stream. There is very little wandering, each fish tending to remain in one spot, but occasionally swing a centimetre or two to one side, and back again. Distribution is fairly uniform throughout the box, though at the middle of the box, near me, there are no fish. All are up off the bottom, and most at about the same level - 1 inch below the surface with a 3 inch depth of water. All jumping had ceased by 4.50.

When the fish are alarmed now, by waving the hand as before, they move as a school. Except for those too near the end they move forward about 6 to 8 inches at a time. They appear to be very much less excitable than in still water.

July 28. 11.00 a.m. The box had been left as described above, except that a 4" x 6" board was floated on the water to provide cover for the fish. The box was approached quietly. Only 2-3 of the fish kept near the upper end of the box, heading the current. The rest remained under the board which had drifted against the lower screen. This condition applied for 10 minutes during which time an effort was made to disturb the fish in no way. The sky was overcast. Temperature of water 19.8°C. When the board was removed quietly the distribution became somewhat more equal, though now there was a slight concentration in the upper two-thirds of the box. While the fish tended to maintain one position fairly well they would quite often leave this to take a particle of food thrown on the water. There was no jumping at the upper end of the box as described on July 23, but occasionally a fish would leap clear of the water when rushing at a food particle.

There seemed to be some indication that the larger fish tended to be at the upper end of the box and the smaller fish at the lower end. There were, however, frequent exceptions to this arrangement, caused by movement of the fish.

12.00. The box was slowly moved out of the current. The fish at once headed in all directions and commenced to wander about. This was a sharp contrast to the condition observed in the current. Wandering decreased somewhat after about 15 minutes.

2.00. The fish are uniformly distributed and wandering slightly. While there are fish heading in all directions there is a tendency for most fish to head towards the nearest open end of the box. (This may indicate the presence of some undetected current).

2.35. Moved box back into current. All fish head current and tend to keep well to the upper end of the box for the first 10 minutes. There was no jumping, as on July 23. After the first 10 minutes a uniform distribution was observed.

3.00. The sun shining through leaves causes shadows on the bottom of the box. The fish near the upper end of the box fall back 2-3 inches occasionally, but seem to stop at a definite place each time and work up again. In most cases the place where they stop seems to have a constant relation to one of the shadows.

Aug. 4. 2.00 p.m. No current. Fish are evenly distributed and heading in all directions. There is slight wandering. The fish seem to be getting 'thin'.

2.30. Box placed in current. The fish head the current and distribution is fairly uniform for the first 10 minutes. After this the fish tend to be more concentrated at the lower end (diagram for Aug. 4). The fish are moving about more than was previously

observed in a current. This movement seems to be related to feeding. There is considerable competition for food particles. A particle not immediately swallowed may pass to several fish before being disposed of. (The rate of current flow was 30 inches in 40 seconds, as before. Temp. of water 18.0° C.)

July 28. 3.30 p.m. An experiment was tried in the lower apparatus illustrated in fig. 1. This was designed to demonstrate the contrast in the behaviour of the fish in still water and in current. The outlet to the box was arranged so as to have a current in all parts of the apparatus. The ⁷fry in the apparatus lay principally heading the current in eddies in the box. When the box was allowed to fill and all current cut off the fish commenced to wander all about, and to feed. One jumped out of the box. As the current was allowed to flow again wandering ceased. The fish again took a position heading the current in a back-water, and were all quite close together, forming a small school. Later a similar experiment was performed. The pool was allowed to fill and drain from near the top. This minimized current in the pool. The current was allowed to flow in the trough slightly. The desired result was produced by raising the lower end of the trough and the outlet of the box. Six of the fish remained on the box, wandering vigorously in all directions. The other happened to enter the trough in its wandering, ascended the current a short distance (the current decreased steadily in strength, as it came down the trough), and then remained steadily in one spot for 10 minutes. He then dropped back to the pool and wandered about as did the other fish. While in the trough the position this fish held was immediately over quite a dark knot.

Summary of Observations in a Simple Current.

In a simple current of moderate strength trout head the current and tend to remain rather closely in one spot. If there are several fish distribution tends to be uniform through the available space. When first moved from quiet water into a current the fish are stimulated to move upstream. They may even jump. The uniform distribution appears from 10-60 minutes after. When moved from a current to quiet water the trout fry wander about quite vigorously. This wandering decreases slightly after about 30 minutes, but is still much more apparent than in a current. The fish do not appear to take alarm as easily in a current as if in quiet water, but if alarmed move largely in one direction, resembling a school (They will come to rest under a floating board, when alarmed, if such cover is provided.)

In Slow Current with Variations in Type of Current.

Aug. 4. 3.40 p.m. The box was in front of the upper chute. Baffles were arranged as in fig. 5. for Aug. 4. This disturbed the fish slightly but by 3.45 the distribution was ^{as} indicated. Distribution diagrams for 4.10 and 4.50 are also given. It will be noted that at first all fish but 4 were at the upper end of the box. Later distribution was rather more equal throughout the box, and still later there were more fish at the lower end of the box. The current was fairly strong at the upper end, strongest at the outer edge of the baffle, and weakest (30 inches in 40 seconds) at the lower end of the box.

4.50 Fish nearly all heading current and lying in or just below strongest current. One fish at extreme upper end, and 1 in still

water behind baffle. (The water behind the baffle was quite still. There was a weak eddy below the outer edge of the baffle.) The water was three inches deep and there were fish at all depths.

Aug. 5. Baffles were arranged as in fig. 6 on the previous night. The distribution at 9.00 a.m. was as illustrated. Most of the fish were immediately below the strongest part of the current. Occasionally a fish would enter the area behind the baffles, where there was little or no current. When in this area a fish would wander considerably, moving in and out of the still area to come to lie eventually below the lower end of the baffles. Fish entering the narrow portion with swift current did not tend to lie here but moved either up or down stream. Only one fish remained in the upper part of the box for any time. If the lower baffle was quietly moved distribution was as on Aug. 4 at 4.50 p.m. within 3 minutes. It is interesting that these fish, which seem to be rather thin, remain in the lower weak part of the current, principally, instead of being distributed more evenly.

10.15. The baffle was arranged as shown in fig. 7. The fish ^{most} for the part, remain below the baffle and below the strongest part of the current. The water immediately below the baffle is rather quiet and wandering occurs here. Only one fish remains above the baffle. He lies in the main current but just at the outer edge of the eddy formed above the baffle.

10.20. The baffle was then moved as shown for this time. Still most fish kept below the baffle.

10.38. I frightened all fish to above the baffle, where they

head the incoming current. In 1 minute 2 of the 15 fish are below the baffle again; in $1\frac{1}{2}$ minutes 8 fish are below the baffle; in 5 minutes 12 fish are below; and in 12 minutes only 2 fish remain above the baffle.

10.50. The baffle was then moved back to the lower $\frac{1}{3}$ of the box, as illustrated. At 10.58 all but the two fish mentioned above were still crowded below the baffle. All were now driven above the baffle. They did not move very readily. By 11.00 three fish were below the baffle again. They drifted backwards down the current to take up positions as before. By 11.20 seven fish were below the baffle and by 11.30 this proportion had not changed. The baffle was then moved back to about the middle of the box, as at 10.20. No change in distribution had occurred by 11.45.

11.46. Baffle moved forward another 3 inches. The seven fish below the baffle now moved up above it, but 6 of them immediately dropped back again. There is very little feeding or wandering now, while $1\frac{1}{2}$ hours ago the fish were quite active. (Temp. of water $17.3^{\circ}\text{C}.$) At 11.55 the distribution was still as figured for 11.46.

11.56. Since much of the lower part of the box was unoccupied the baffle was moved as figured for 11.56. All but 3 fish moved below at once. There was considerable wandering and distribution below the baffle was quite uniform. By 12.00 all fish were below the baffle, heading a current, fairly uniformly distributed and wandering of any kind was almost entirely absent.

12.01. Baffle moved to position as at 10.58. Immediately four fish move above. By 12.10 there are 7 fish above and 8 below the baffle with an occasional exchange of a fish from one place to the other. The distribution seems to be more or less at an equilibrium.

2.20 p.m. (Temp. 18.6°C.) There are 9 fry above and 6 below the baffle. Drove all to the upper end. In 2-4 minutes 4 or 5 drop below the baffle. The rest remain above, distributed uniformly, heading the current and rather stationary. They do not group about the upper chute.

2.45. Baffle moved to upper corner of box. Where the current is fairly straight the fish are distributed quite evenly through its length. There is a very slight tendency to wander into the still water behind the baffle, or the eddy below its outer edge. The fish remain longer in the eddy than in the still water. In the latter they tend to 'wander out'. (fig. 8).

3.15. Baffle moved about 1/4 of the way down the box. More fish assembled above the baffle, as illustrated. Otherwise there was not much change from the last set of conditions. (The fish must have been feeding more than was realized for their bellies are quite distended compared to the condition at 10.00 a.m.)

3.30. The baffle was placed still further back. This caused the dead water behind the baffle to take up much of the lower part of the trough. All but 1 or 2 fish remained below the baffle. Wandering in this area was fairly pronounced, but any one fish does not remain in the still water for any length of time. By 3.38 some of the fish had moved above the baffle but

but fell back again, so that there were still¹³ below the baffle.
3.40. Baffle moved close to lower end of screen. At 3.50 the distribution was as indicated, most of the fish still being crowded below the baffle. There had been a slight migration from below the baffle to the upper end of the box, and back again. That is, some fish actually experienced both places and stayed in the most crowded area.

Aug. 6. 8.00 a.m. Baffle as at 3.40 p.m. the previous night. All fish were behind the baffle.

9.30. Baffle still as above but fish now are all above the baffle.

10.30. Baffles arranged as illustrated. There was some wandering into the still area behind the baffles but the fish did not remain there, wandering out again. By 2.30 wandering was very limited. Most of the fish lay in the lower end of the box, below the strongest part of the current.

Summary of Observations using Baffles.

When the fish are given a choice of steady, slow current versus still water or eddies they tend to keep in the simple current. Fish are seen more often in still water than in eddies. In still water the fish, of course, wander about, while when in an eddy they tend to remain in one spot, as in a simple current. It was noted that in the forenoon, when the temperature of the water was low (16°-18°C) the fish wandered more than in the afternoon, when the temperature was higher (18°-20°C), even though the light happened to be brighter in the morning. Towards the end of the series of observations the fish, which appeared to be getting thinner, were frequently observed in the lower weaker part of the current.

Observations on Effect of Swift Current, Changes of Rate of Current, and other Factors.

The following experiments were carried out in the apparatus at the lower end of the pool (fig. 1). In this apparatus the flow of water could be varied from still to very swift.

July 31. 10.00 a.m. Seven fish were placed in the trough, which was screened at both ends. The outlet of the box was arranged to give a depth of 2 inches at the lower end of the trough, unless the current was cut off for several minutes, when the water drained out of the box, leaving the trough bare. The water was cut off at the upper end until only 1 inch of water was left in the lower end of the trough. A 'freshet' was then allowed to run down the trough. The fish, which were swimming about in the lower end appeared to be excited to more activity, and turned to head the current. They did not ascend more than about 6 inches however. Repeated freshets at 1 minute intervals had no different effect. When freshets were given after a 2 minute period of quiet they seemed to have more effect. In this case all the fish moved about half way up the trough, but fell back at once. On one occasion a fish ascended the whole length of the trough (about 30 inches). Occasionally a fish maintained its position half way up and would ascend to the upper end on the succeeding freshet. No jumping at the upper screen was observed on this occasion, though later jumping was observed.

The water was allowed to fall in the trough until the dorsal fins of the fry were exposed. They became quite active. A freshet was allowed to run for 2 minutes. Three fish ascended the trough and jumped at the upper screen. This was repeated

several times. Each time 1 to 3 fish ascended and jumped at the upper screen. This experiment suggested that some sort of 'disturbing' influence caused the fish to show the ascent reaction to a much greater degree. When the water in the trough was quite still, and from 1/2 inch at the upper end to 2 inches at the lower end the fish wandered about but only occasionally approached the shallow upper end. There was no jumping at the upper screen.

Aug. 4. Experiments as above were repeated with fish which had been exposed to currents for 4 days. On the previous occasion the fish had been in still water for several days just previous to the experiments. On this occasion there was no tendency to ascend shown. This suggests that a period spent in still water just previously is more likely to bring about an ascent reflex in the trout fry when they are exposed to currents, than if they have been in currents for some time.

Aug. 4. 2.00 p.m. The effect of shallow water in bringing about an ascent reflex has been mentioned. The effect of salt water was tried by placing the box used first in front of the upper chute, and running sea water by a siphon into the middle of the box. The fry kept in the lower end, in the deep, salty layer, and there was no attempt to move up to the incoming fresh water. When the flow of salt water was out off the fish assumed a uniform distribution throughout the box.

Experiments as on July 31 were repeated with fish which had been in still water about 5 hours. On the first 4 freshets 4 out of 5 fish responded by ascending to the upper screen. They then appeared fatigued and on subsequent freshets were swept against the lower screen.

On Aug. 6 similar experiments were tried but the responses of the fish were very weak. The water temperature was 20.0°C.

The apparatus was then arranged as illustrated. The side (P) was closed at the lower end so as to form a pool ^{with} water about 3 inches deep at the low end. The fish could pass from (P) to (C) or (C) to (P) by a small gate in the upper end of the partition.

The flow of water was cut off and the water allowed to drain out until the backs of the fish were exposed. On making a freshet 2 or 3 of the fish ascended to the head of the trough the first 4 times. All these went right past the gate into (P). After this the fish appeared fatigued and remained at the lower end of (C). The experiment was repeated with fry from still water. They showed a similar ascent reaction only the first 2 times. A small stick of cross section as illustrated (\vec{D}) was placed across the current. This caused a little chute just above the fish. On the first three freshets fish ascended to just above this dam. On the freshet after it mounted the dam each fish went to the head of the trough. When the stick was placed the other way (\vec{D}) a small falls resulted. The fish ascended to this on a freshet, and leapt, but were not successful in crossing the dam into the pool above. The fish seem to be less vigorous than previously, possibly due to the high water temperature.

A number of experiments similar to those above were performed but not recorded in detail.

From the observations the following points seem to be suggested. A sudden change in the rate of current flow stirs the fish up. If the water is a bit turbulent (as it was in all artificial freshets) the fish frequently move upstream. Movement upstream is more likely to occur if the fish is first "conditioned" by having been in still water for at least 3 or 4 hours. If, just before the freshet, the fish has been in some unfavourable condition - as very low water - it is more likely to ascend. Salt water did not seem to have this 'disturbing' effect. Making disturbances in the current by means of small chutes and falls resulted in the fish being brought up by a freshet, whereas without the fall or chute they would not ascend.

While the work recorded above is by no means as complete or precise as is desired it did bring out a few points about the behaviour of trout in currents. It is proposed to use this as a preliminary to further work on the behaviour of trout with respect to such factors as presence or absence of current, type of current, temperature of water, and possibly, to some extent, the effect of light. Studies on the effect of temperature on the activity of these trout (Salvelinus fontinalis) are now under way.

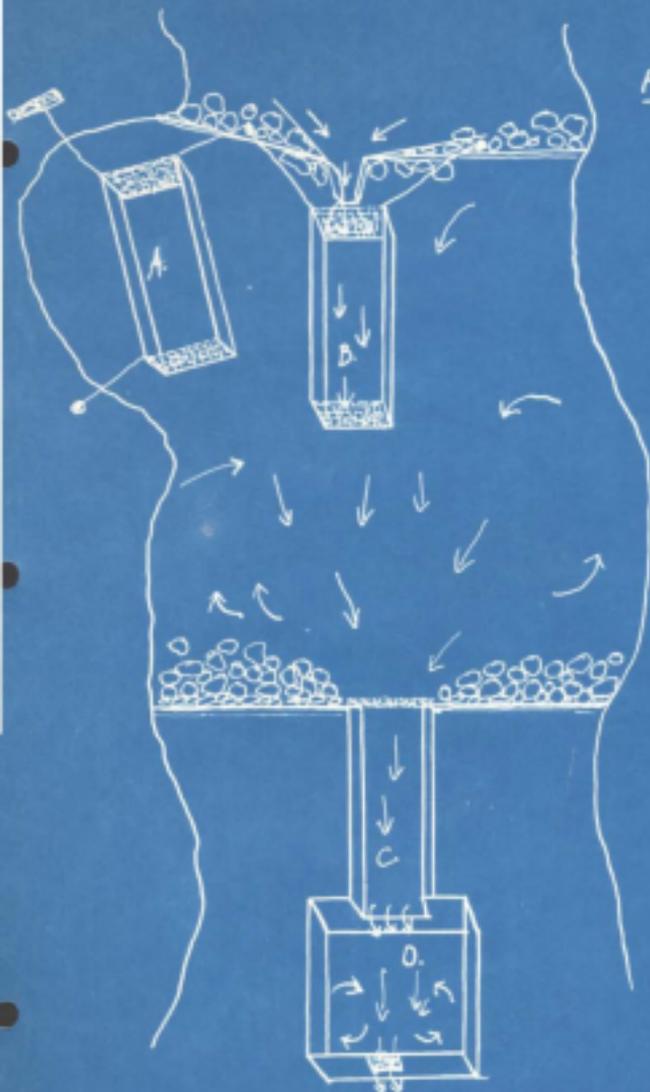


Fig. Arrangement of apparatus
in the pool in Dutch Cove Bend
for observations on the
behavior of limit flow.

- A. Bot in still water
- B. Bot with slow straight
C. Trough and P. part allowing
manipulation of rate of flow,
etc.



1.



2.



3.



4.

Still Water

Fig. 2. July 23, a.m.

Plain bottom

1. Normal distribution
2. Frighted by hand moving
- Slower on bottom
3. Normal distribution
4. Frighted by hand moving.

In 1. and 3. there is considerable wandering; very little in 2 and 4.



1. 3:45 p.m.



2. 4:30 p.m.



3. 4:45 p.m.



4. 4:50 p.m.

Fig. 3. Slow Current.

July 23. The fish were moved into the current at 3:15 p.m. at 4:05 grouping reached a maximum. By 4:50 the fish seemed well adjusted to the new condition.



1. 2:00 p.m.



2. 2:20 p.m.



3. 2:45 p.m.

Fig. 4. Aug. 4.

at 2:00 the fish were in still water.
at 2:20 the boat was moved in front of the current. At first the fish concentrated at the upper end. The final position was as at 3. - somewhat different from the run on July 23.

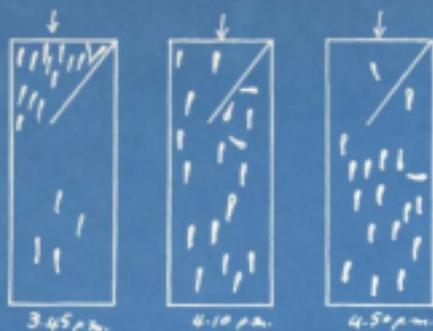


Fig. 4. Aug. 4. Distribution of fish when placed in current with baffle as shown.

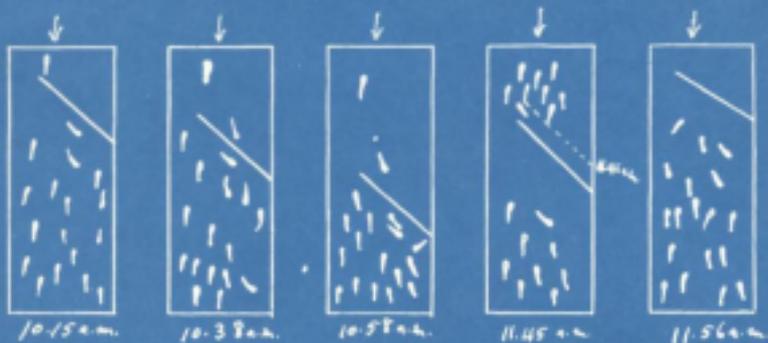


Fig. 7. Aug. 5. Distribution in various types of currents. Don't feed fish below the strongest current, and in rather straight current rather than in eddies. Wandering occurs in the 'dead' area immediately behind the baffle.

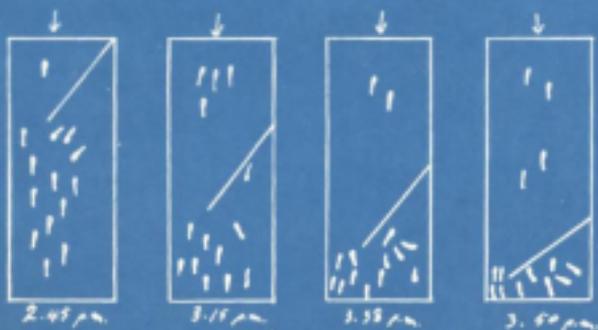


Fig. 8. Aug. 6. Effect of baffle, as shown, on the distribution of the fish in a current.

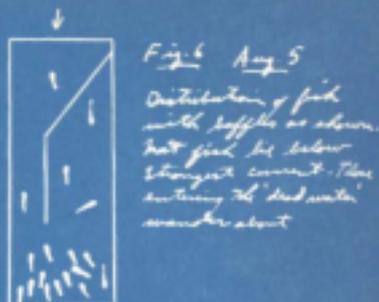


Fig. 6. Aug. 5. Distribution of fish with baffles as shown. Don't feed fish below strongest current. Those entering the 'dead water' wander about.



Fig. 9 Aug 6. Distribution with baffles as shown. 3 miles to Fig 6.

There is some wandering into the area of still water but the fish entering there move about and soon pass into the current again. Most fish lie at the lower end of the 'chute' formed by the longitudinal baffle. At the upper end of the chute the current is rather more complete than at the lower end. Don't feel we being in such a position that the current ahead of them gets progressively stronger for a short distance.



Figure 10 Apparatus arranged for producing variations in current strength, artificial 'fishlets' etc. C. - portion where current flows P. - pool area with deeper water, forming a small pool, reached from near the upper end of C.

