FRESHWATER BIOLOGICAL ASSOCIATION

WIT/73/5.
RL copy

TEESDALE UNIT

Report to: Department of the Environment
Natural Environment Research Council
Northumbrian Water Authority

Date: July 1981

Title: Information collected in Teesdale concerning free-swimming stages of brown trout (*Salmo trutta* L.).

E.M. Ottaway, A. Clarke, D.R. Forrest

c/o Northumbrian Water Authority
Lartington
BARNARD CASTLE
Co. Durham DL12 9DW
England

FRESHWATER BIOLOGICAL ASSOCIATION

TEESDALE UNIT

PROJECT 73

Report to : Department of the Environment
Natural Environment Research Council
Northumbrian Water Authority

Date : July 1981

Title : Information collected in Teesdale concerning free-swimming stages of brown trout (*Salmo trutta* L.).

E.M. Ottaway, A. Clarke, D.R. Forrest

CONTENTS

SUMMARY

I Fish densities and the Base Flow Index

1. The densities of brown trout, as measured in a selection of Teesdale streams, were low compared with those in other parts of the country.

2. Densities of brown trout fry fluctuated considerably from year to year.

3. No correlation was found between Base Flow Index (BFI) and fish density (no. m^{-2}) or biomass (g. m^{-2}).

II Observations on the movement of brown trout (Salmo trutta L.) in two upland streams

4. Fish movement was examined by electrofishing (Thorsgill Beck) and by trapping (Carl Beck). Downstream movement of juvenile trout occurred predominantly in the autumn and the spring.

5. Some correlation between discharge and movement was observed in both streams.

6. The percentage of the R. Lune brown trout population which originated from Carl Beck was estimated as approximately 10%.

I. FISH DENSITIES AND THE BASE FLOW INDEX

Introduction

During 1978 and 1979, electrofishing surveys were made in Teesdale - both to provide background information for ecological work on the streams, and to provide data so that the influence of discharge regime on the fish population densities could be examined. The discharge regimes of the different streams were compared using the Base Flow Index (BFI) as developed by the Institute of Hydrology (Beran & Gustard, 1977; Anon, 1978). This index is a measure of stream flashiness on a scale from 0 to 1.0; the smaller the index the flashier the stream.

Information presented here was collected during electrofishing surveys in August 1978 and 1979 . The relationship between BFI and brown trout densities is examined.

Methods

Details of the streams surveyed are given in Table 1. Stream reaches were fished using a pulsed d.c. technique (Moore. 1967) and population estimates were calculated after two fishings according to the method of Seber & Le Cren (1967). Fish densities were obtained by dividing the population estimates by the area of stream fished. Length/frequency histograms were used to separate the brown trout into 2 age classes, T_1 (0+-fry), T_2 (all fish older than 0+). Weights of fish were estimated from length/weight regression equations calculated for each site. The weights were used to determine the biomass (g m^{-2}) of fish present in each reach in August 1979. Where more than one reach was electrofished per stream fish densities and biomass values were meaned between reaches.

+ Electrofishing surveys were also carried out during November 1978 and May 1979. Information obtained during these surveys is available at the FBA Teesdale Unit.

Table 1. The streams electrofished around Teesdale. Area fished in mid-summer, measured during August 1979 at discharges of approximately 60-80% average daily flow (adf). Bt = brown trout (*Salmo trutta*) B = bullhead (*Cottus gobio*), M = minnow (*Phoxinus phoxinus*), Sl = stone loach (*Nomacheilus barbatulus*). BFI's were estimated from geological data except for values marked with an asterisk which were calculated using water level data (for methods of estimation, see Anon, 1978).

Beck	Nat. Grid reference of fishing reach(es)	Altitude of fishing site (m O.D.)	Area fished (m^2)	Fish species present	BFI	Water Chemistry: Total ion concentration meq l^{-1}	Water Chemistry: Calcium concentration meq l^{-1}
Beer	NY 990223	229	48	Bt	0.51	1.70	1.02
Carl	NY 946231	255	76	Bt, Sl	0.23*	1.56	1.12
	NY 944228	259	56	Bt			
Cleve	NY 846206	411	121	Bt, B	0.39	1.47	1.27
Deepdale	NZ 040166	152	215	Bt, B, Sl	0.59	1.04	0.72
	NZ 023163	183	314	Bt, B, Sl			
Gill	NZ 026170	195	73	Bt, B	0.51	2.68	1.42
Great Eggleshope	NY 982294	350	567	Bt	0.34*	0.59	0.28
Hargill	NY 887216	350	298	Bt	0.15	1.16	0.97
	NY 897215	330	172	Bt			

Table 1 continued.

Howgill	NY 957196	274	137	Bt, B, M, Sl	0.48	2.01	1.41
Huddeshope	NY 944293	345	284		0.52	1.02	0.68
Hunder	NY 933182	285	428	Bt, M, Sl	0.15*	0.45	0.21
	NY 932179	290	260	Bt, M, Sl			
	NY 931176	315	224	Bt, M, Sl			
Rokehole	NY 951193	270	136	Bt, M, Sl	0.20	1.57	1.11
Scur	NZ 033174	65	203	Bt, B, M	0.51	1.13	0.67
	NZ 038173	140	120	Bt, B, M, Sl			
Thorsgill	NZ 061152	135	275	Bt, B	0.50*	7.42	4.41
	NZ 059152	136	315	Bt, B			
	NZ 054151	140	345	Bt			
	NZ 051151	167	222	Bt			
Wemmergill	NY 898222	365	287	Bt, B	0.16	1.32	1.14
	NY 901216	336	197	Bt, B			

Results

The estimates of fish density and biomass obtained in August 1978 and 1979 are shown in Table 2. Where streams were electrofished in succeeding years considerable variation in densities of 0+ (T_1) fish, but not in the densities of older (T_2) fish, was seen between years. Density estimates of fry were higher in most streams in 1978 than 1979 with the exceptions of Rokehole and Howgill Becks. The highest density of fry was recorded in 1979 in Howgill at 1.2 fry m^{-2} and the greatest biomass (T_1 & T_2) in Beer Beck in 1979 at 14.6 g m^{-2}.

No correlation could be found between BFI and density or biomass of T_1 or T_2 - using data for one particular year or meaned data between years. A selection of the correlations tried is shown in Fig. 1. Neither could the variation in fish biomass between sites be related to the total ion content or the calcium concentration of the water.

Discussion

Densities of brown trout in Teesdale (Table 2) are low when compared to those in other parts of the UK (Le Cren, 1969), the densities of fry also varied considerably from year to year. Streams in this part of England tend to have lower BFI values than those in other parts (Carling & Reader, in press). This high degree of stream flashiness could influence the fry populations either by the washout of trout eggs buried in the stream gravels or by the displacement of young fry. No significant correlations could be found between BFI and fish density or biomass, however. This does not disprove the existence of a relationship between stream flashiness and fish populations. BFI, especially as calculated from geographical data, may not be a sufficiently sensitive measure of discharge regime. The correlation coefficient was improved by pooling data between years (Fig. 1) which smoothed the data. Considering the extent of density fluctuations between years it may have been better to pool electrofishing data over a wider time span still.

Table 2. Fish density and biomass values for streams in Teesdale in August 1978 & 1979. T_1 rep. 0+ trout, T_2 rep. brown trout older than 0+. The mean efficiency of electrofishing for T_1 was 61.8 ± 6.9% (S.E.) in August 1978 and 76.0 ± 5.4% in August 1979, and for T_2 54.1 ± 7.3% in August 1978 and 75.2 ± 4.1% in August 1979.

	Fish density no m^{-2} (Fish biomass g m^{-2})					
Beck	1978		1979		1978 & 1979 meaned	
	T_1	T_2	T_1	T_2	T_1	T_2
Beer			0.52 (1.24)	0.49(13.40)		
Carl			0.36 (1.75)	0.40(10.61)		
Cleve	0.22	0.20	0.10 (0.17)	0.20 (2.95)	0.16	0.20
Deepdale			0.01 (0.02)	0.14 (5.05)		
Gill			0.22 (0.41)	0.56(12.29)		
Great Eggleshope			0.50 (0.95)	0.08 (1.61)		
Hargill	0.08	0.11	0.01 (0.02)	0.11 (3.83)	0.04	0.11
Howgill	0.62	0.21	1.20 (1.86)	0.38 (6.11)	0.91	0.29
Huddeshope	0.06	0.10	0.00 (0.00)	0.21 (3.13)	0.03	0.15
Hunder	0.09	0.10	0.01 (0.03)	0.09 (5.54)	0.05	0.09
Rokehole	0.24	0.02	0.40 (0.51)	0.02 (0.32)	0.32	0.02
Scur	0.57	0.11	0.12 (0.24)	0.21 (4.36)	0.34	0.16
Thorsgill	0.80	0.14	0.19 (0.38)	0.12 (2.55)	0.50	0.13
Wemergill	0.21	0.08	0.03 (0.06)	0.18 (4.33)	0.12	0.13

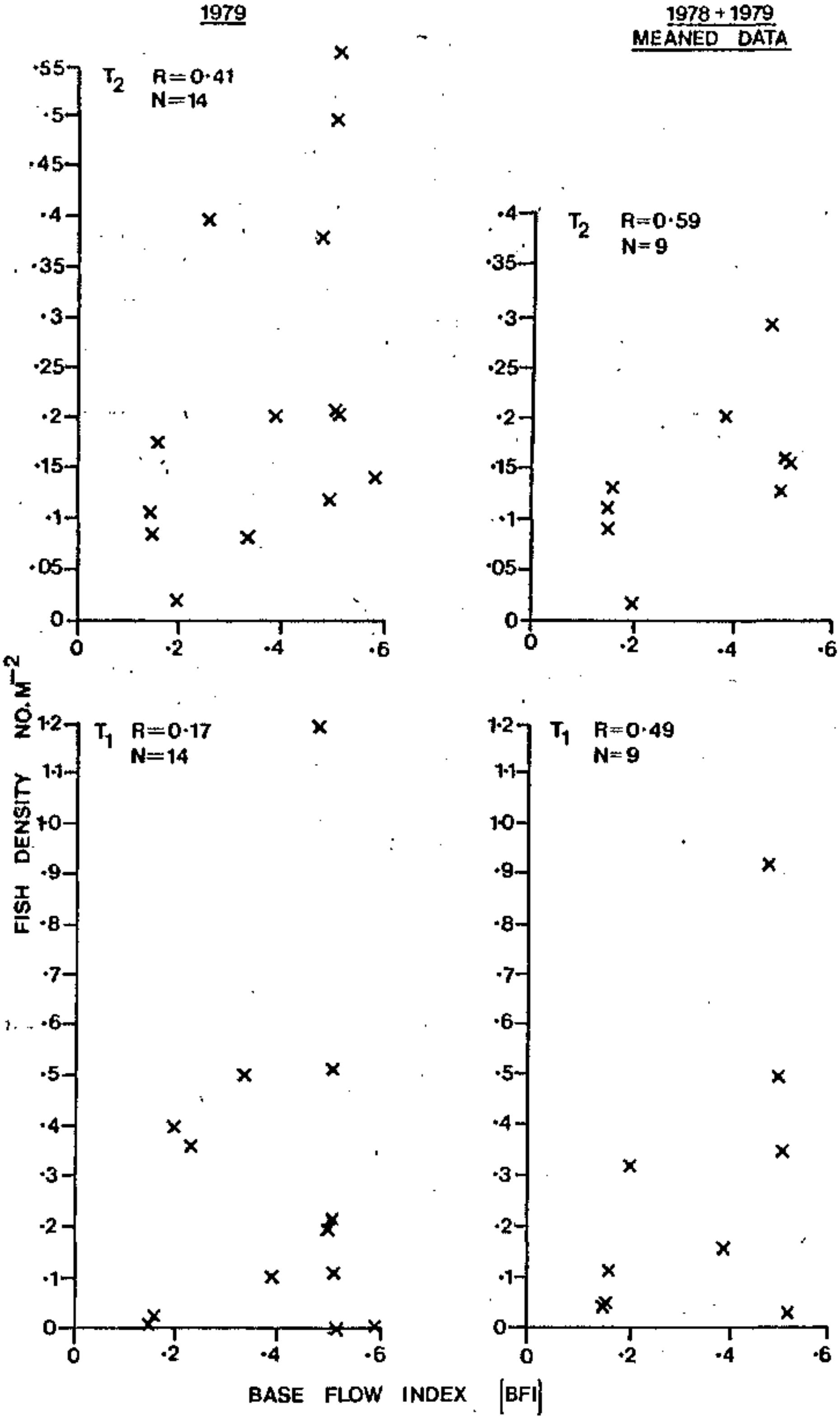


Fig. 1. Fish density plotted against BPI for sites in Teesdale. Fish density determined by electrofishing. T_1 = 0+ fish, T_2 = all fish older than 0+. R = correlation coefficient. N = number of data pairs.

A relationship between calcium concentration and bottom fauna/plant detritus was found in streams by Egglishaw (1968). No relationship was found however between biomass and calcium content of water in Teesdale streams - Le Cren (1969) also failed to detect such a relationship.

II OBSERVATIONS ON THE MOVEMENT OF BROWN TROUT (SALMO TRUTTA L.) IN TWO UPLAND STREAMS

Introduction

This section describes the general pattern of brown trout movement in two streams as determined by i) electrofishing (Thorsgill) and ii) trapping (Carl Beck). The streams chosen were 'nursery' streams in that outside the spawning season their fish populations consisted predominantly of juvenile fish. The influence of water discharge on movement is examined.

i) Fish movement as examined by electrofishing - Thorsgill Beck

Methods

Four electrofishing sites were established" together covering approximately 25% of the total study area (Fig. 2). The four sites were fished 13 times between September 1978 and October 1980 using pulsed d.c. equipment (Moore, 1967). Each site was double fished and the population size estimated by the method of Seber & Le Cren (1967). The length of all fish caught was recorded and in addition trout from reaches I-III were given individual site marks according to their age. Older fish were marked with a Panjet using Alcian blue as the dye (Hart & Pitcher, 1969), 0+ fish were marked from the age of 6 months using a system of pelvic fin clips. To test for loss of marks the adipose fin was clipped on all marked trout, this fin does not regenerate so that its absence permitted quick recognition of recaptured fish. The Panjet marks remained easily visible over the course of the study. Some regeneration of pelvic fins occurred but this was readily detectable. Fish in site IV were simply caught and measured, the site was established in order to detect upstream movement of fish beyond site III.

Fish movement was observed in two ways, first, where individual site marks were given, by the movement of marked or 'mobile' fish from one site to another.

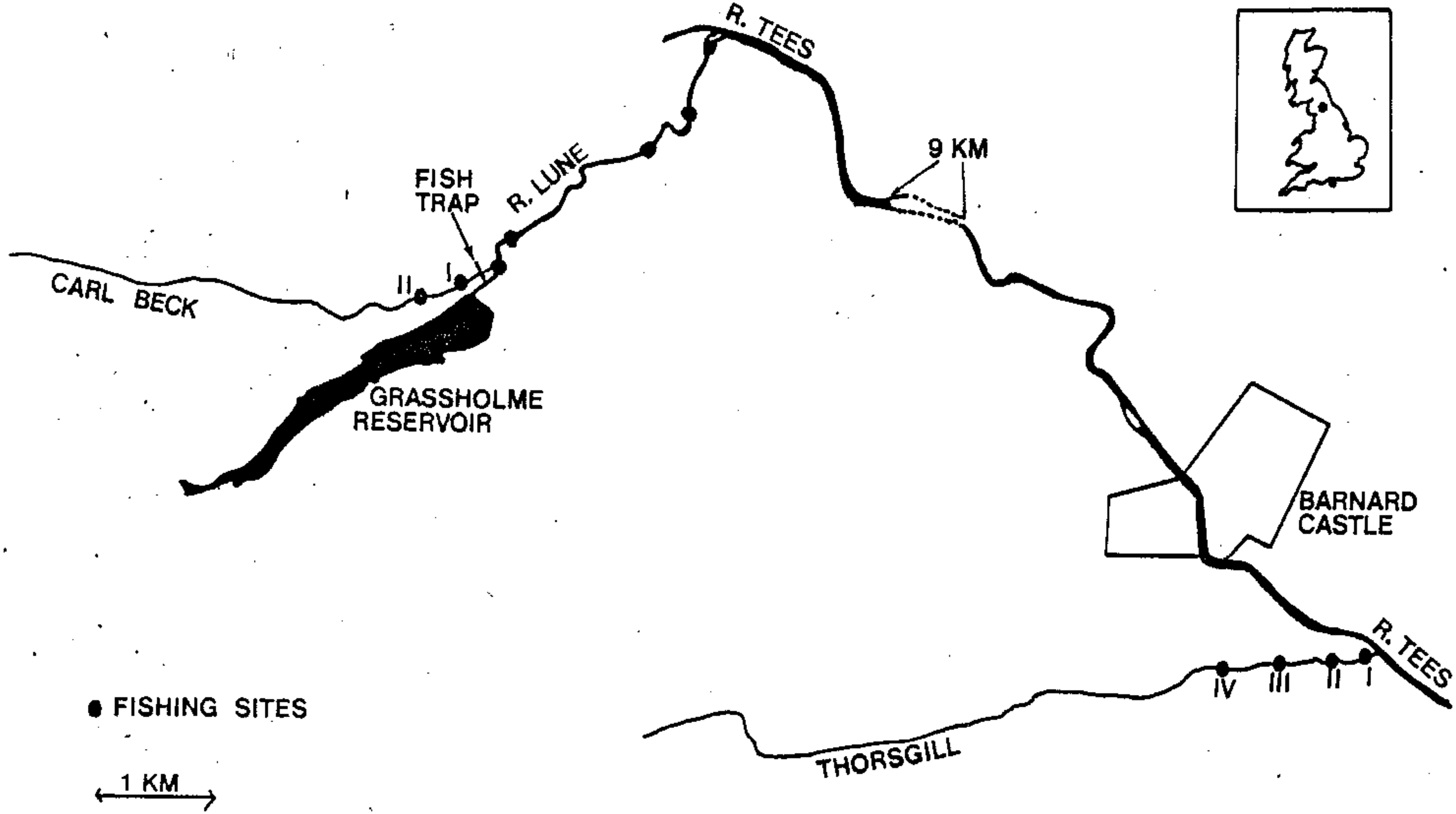


Fig. 2. Diagram showing the location of the study sites. I, II, III, IV signify the position of the electrofishing reaches on Thorsgill Beck.

Second, by the occurrence of 'unmarked' fish in the sites. Unmarked fish represented either resident fish which had not been previously caught or new fish moving into the site. Since most (90-100%) of the population were caught and marked on each occasion ('residents') the majority of unmarked fish in subsequent catches were assumed to have moved into the site. Immigration rates for these fish were calculated after Milner et al (1979) where :-

$$I = \frac{N_I \; 100}{N t}$$

I = net specific immigration rate per 100 days

N = number of unmarked fish in the population at the end of the inter-sampling period.

N = average population size during inter-sampling period.

t = duration of intersampling period in days.

The fate of fish lost from the sites was not known, mortality and migration could not be distinguished.

Scales were removed from the mid-body region of all unmarked fish caught in Thorsgill Beck. Scale reading, together with length/frequency histograms of captured fish, were used to age the trout.

Results

Immigration rates of 0+ and 1+ fish were estimated from the electrofishing data (Fig. 3). The information on 0+ fish was limited because for a large part of the year the fish were too small to mark. Immigration rates of fry (0+ fish) were generally high in the autumn. Immigration rates of 1+ fish were higher in the spring/early summer than in the autumn, and low at other times of the year (Fig. 3).

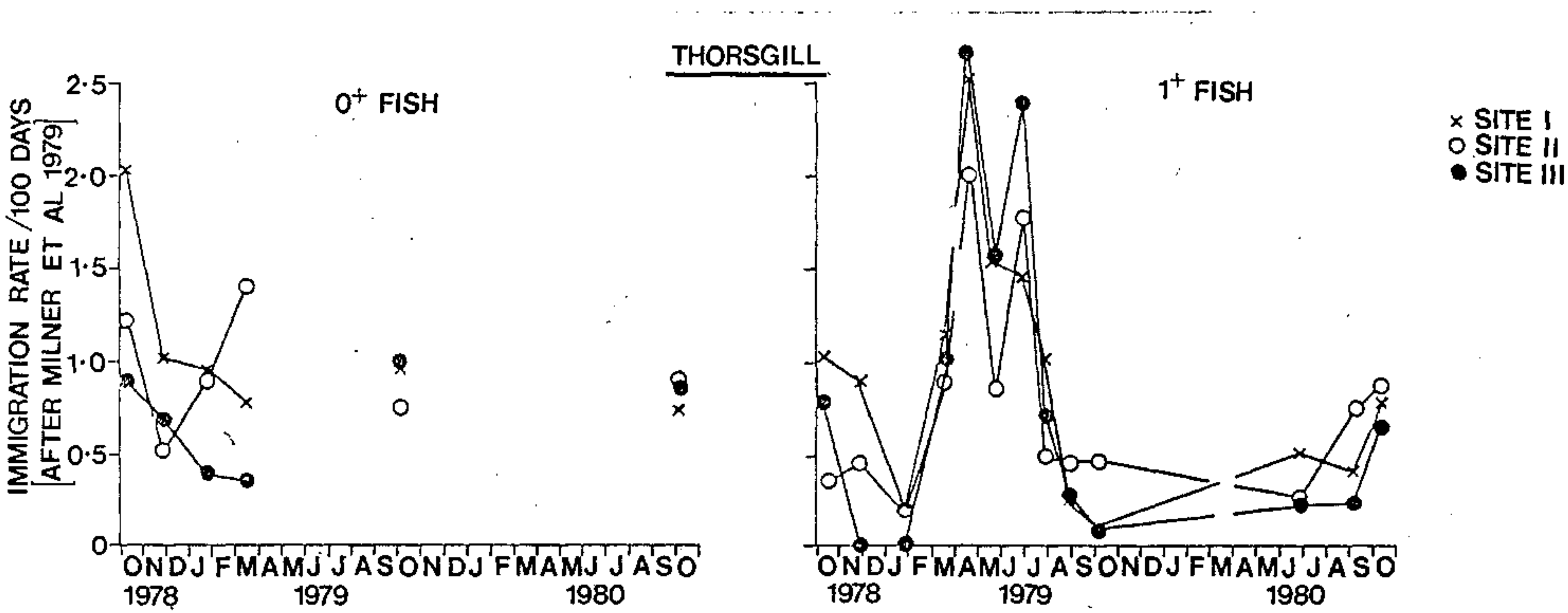


Fig. 3. Change in Immigration Rate with time in Thorsgill Beck (calculated after Milner et al 1979).

The individual site marks permitted examination of movement of mobile fish from one site to another. Movement was generally downstream. No fry were ever found to have moved upstream from site to site and upstream movement of fish >0+ was generally limited to the spawning season. Only one marked fish was ever caught in site IV.

Analysis of data on the size of 0+ fish caught (Table 3) showed that in Thorsgill between autumn 1978 and spring 1979 the resident fry in the sites were larger than the unmarked or mobile fish. This difference in length was significant in site I in October, November 1978 and March 1979, and in site II in January 1979 (Student's t-test $P<0.05$). These differences in length did not however apply to fry caught in the autumn of 1979 or 1980 although in these years the densities were lower (0.07 - 0.20 fry m^{-2} as compared to 0.29 - 0.47 fry m^{-2} in October) and the sample sizes therefore smaller.

The electrofishing data were examined for an influence of discharge on fish movement by plotting the number of days between fishings that discharge exceeded the arbitrarily chosen value of 0.1 m^3 s^{-1} (145% adf) against a) percentage of catch which were mobile fish and b) percentage of catch which were residents (Fig. 4). The percentage residents in the sites only represented an approximate index of fish movement since a decrease in this value could also have been due to fish mortality. The percentage of mobile fish in the site was a better measure of movement but the numbers of such fish were rather low, especially for the >0+ category. Thus a relationship was established between number of days for which discharge exceeded 0.1 m^3s^{-1} and percentage of mobile 0+ fish but not for >0+ mobile fish (Fig. 4). Considering %'s of resident fish relationships were established for both 0+ and >0+ age groups (Fig. 4) and the two lines had significantly different intercepts but similar regression coefficients (F-test, Snedecor & Cochran, 1967).

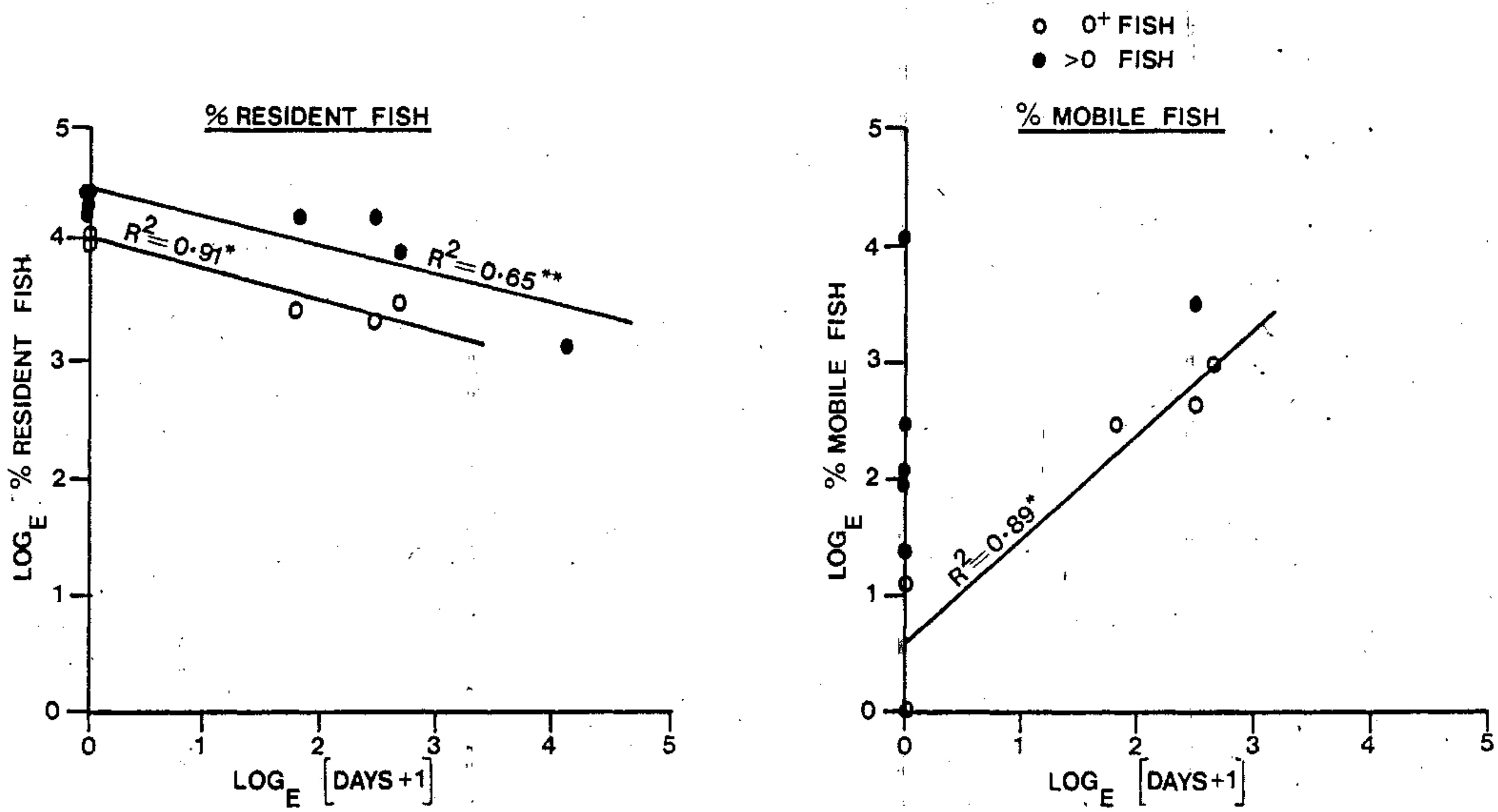
Table 3. Mean fork length (FL) of fry in electrofishing catches in Thorsgill Beck. For the definition of resident, mobile and unmarked fish see text. Asterisk indicates resident fish significantly larger than unmarked fish (Student's t-test, P<0.05).

sampling date	site	mean FL RESIDENT FISH	(cm ± S.E. (n)) of :- MOBILE FISH	UNMARKED FISH
Oct. 1978	I	*7.4 ± 0.1 (56)	6.9 ± 0.2 (22)	6.9 ± 0.1 (65)
	II	6.7 ± 0.1 (67)	6.6 ± 0.3 (11)	6.8 ± 0.1 (47)
	III	4.7 ± 0.1 (56)	-	6.2 ± 0.1 (54)
Nov. 1978	I	*7.6 ± 0.1 (23)	6.9 ± 0.2 (8)	6.9 ± 0.2 (46)
	II	7.2 ± 0.1 (28)	6.7 ± 0.6 (4)	6.9 ± 0.2 (18)
	III	6.5 ± 0.2 (31)	-	6.5 ± 0.2 (28)
Jan. 1979	I	7.4 ± 0.4 (10)	6.9 ± 0.4 (6)	6.5 ± 0.2 (29)
	II	*8.1 ± 0.3 (6)	7.5 (2)	6.7 ± 0.3 (19)
	III	7.3 ± 0.2 (10)	-	6.5 ± 0.4 (9)

Table 3 continued.

March 1979	I	*8.2 ± 0.3 (8)	6.7 ± 0.5 (5)	6.9 ± 0.3 (13)
	II	7.5 ± 0.3 (8)	7.5 (1)	6.9 ± 0.3 (17)
	III	7.8 (3)	-	6.9 (2)
Oct. 1979	I	6.8 ± 0.3 (9)	-	6.9 ± 0.3 (9)
	II	6.1 ± 0.1 (39)	-	5.9 ± 0.2 (16)
	III	5.8 ± 0.1 (41)	-	5.9 ± 0.1 (30)
Oct. 1980	I	7.4 ± 0.1 (37)	7.0 (1)	7.6 ± 0.2 (16)
	II	6.8 ± 0.1 (19)	-	7.1 ± 0.2 (20)
	III	7.0 ± 0.1 (21)	8.0 (1)	7.3 ± 0.2 (16)

Fig. 4. Relationship between % resident or % mobile fish (Thorsgill Sites I-III values meaned) against number of days between electrofishing that discharge exceeded 0.1 m^3 s^{-1}. Asterisks indicate significance level of correlation coefficient * $P < 0.05$ ** $P < 0.01$



ii) Fish movement as examined by trapping - Carl Beck

Methods

An upstream and a downstream trap were installed a little above the confluence of Carl Beck with the River Lune in September 1978 (Fig. 2). The upstream trap was a box trap with a v-shaped entrance intended primarily for catching spawners, the smallest fish ever caught was 13.5 cm. The design of the downstream trap was based on a Wolf trap (Wolf, 1951) and the mesh of the trapping basket was sufficiently small that the whole size range of downstream moving trout could be caught.

The traps were visited at least once a day during the spring and autumn and were checked at other times approximately twice a week. The fork lengths of fish moving upstream were measured, the fish were sexed and then examined for fin clips before release approximately 60 m upstream of the traps. Downstream fish were handled in a similar manner but in addition they were marked before release with an adipose and pelvic fin clip.

At discharges < 0.0052 $m^3 s^{-1}$ (8% adf) the stream was so low that no water passed over the chute of the downstream trap, any water seeping through the banks and concrete piers of the trap. At discharges > 0.2447 $m^3 s^{-1}$ (365% adf) water overtopped both the upstream and downstream traps and fish could thus move up and down the becks avoiding the traps. Discharges in excess of 365% adf occurred for approximately 7% of the time, discharges less than 8% adf for approximately 6% of the time.

Scales were removed from the mid-body region of all fish passing downstream and used to estimate ages.

Results

Fish movement through the traps was concentrated in 2 main periods, the autumn and the spring (Fig. 5). In the autumn there was a spawning run of mature fish up and down the beck coincident with a downstream migration of juvenile fish. In the spring there was a downstream movement of spawners (early spring) which had over-

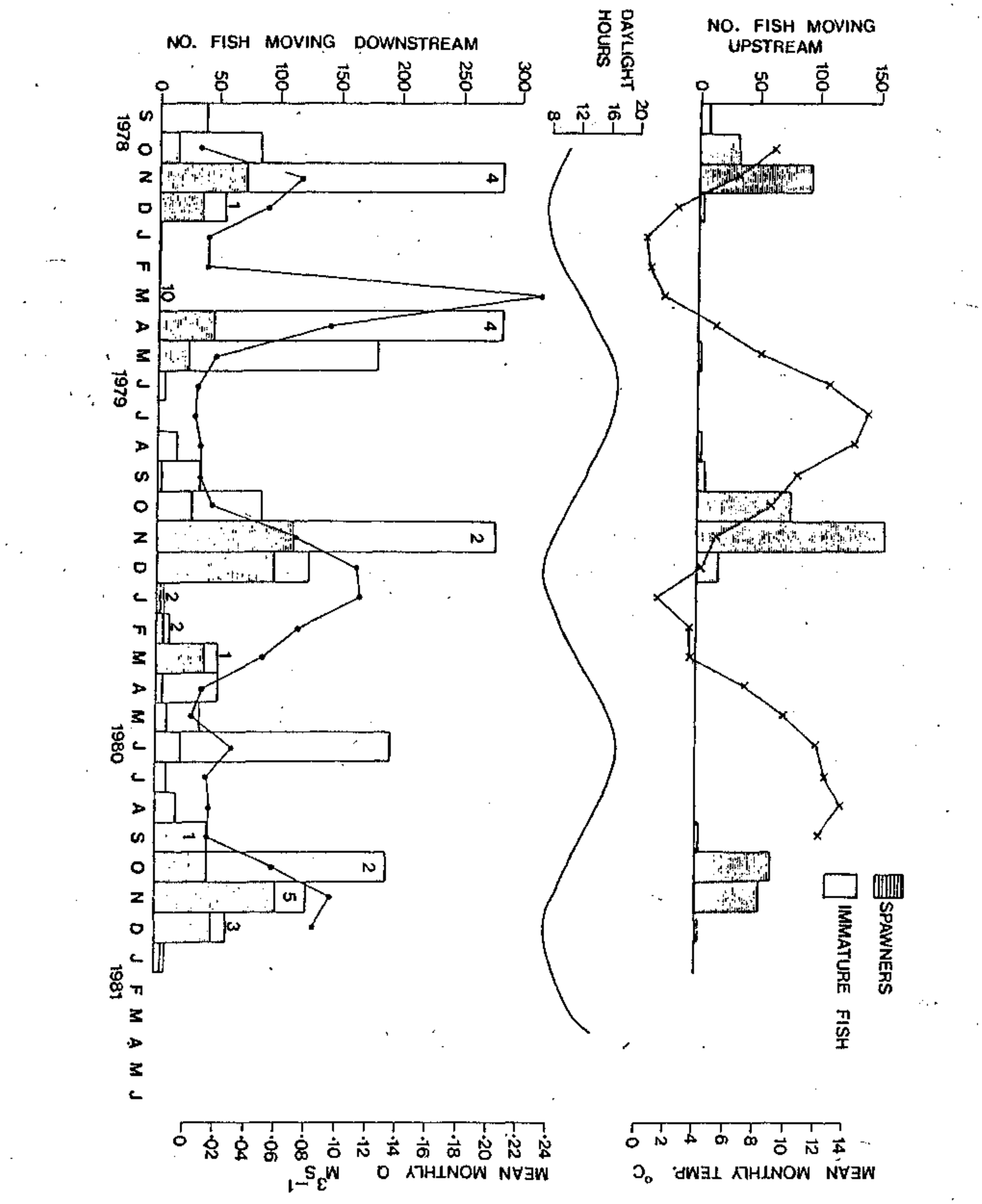


Fig. 5. Summary of the number of fish moving through Carl Beck fish trap and variations in mean monthly discharge, temperature and daylight hours. Numbers on histograms represent the number of days in each month in which trap overtopping occurred.

wintered in the beck and of immature fish. Little activity through the traps occurred in the winter or summer. The number of days when trap overtopping occurred are indicated in Fig. 5 i.e. the numbers of fish recorded during these months are a minimum estimate of those moving.

Juvenile fish moved downstream either in the autumn of their first year (as 0+ fish), in the spring or autumn of the second year (as 1+ fish) or in the spring of their third year (as 2+ fish) (Table 4). Very few fish passed downstream in the spring of their first year and those that were found in the traps were caught after spates. It is questionable therefore whether these fish were actively moving or were being passively washed downstream.

The influence of discharge on fish movement was seen in general terms in that the months in which activity through the traps was greatest coincided with the months in which stream discharge was highest (Fig. 5). When discharge was < 0.01 $m^3 s^{-1}$ (22% adf) very little fish movement occurred. In 1980 the early spring was particularly dry and the main downstream migration was delayed until rain in June. Cumulative probability distribution plots showed that fish tended to move on discharges higher than those generally available (Fig. 6). The same analysis was carried out on a month to month basis to test whether the results were due to coincidental differences between discharge and the availability of fish (Alabaster, 1970) but similar results were obtained.

Correlations were obtained between the number of fish trapped and the maximum discharge recorded between trap visits (Table 5). The correlation was however never very strong and the calculated coefficients showed considerable variation from year to year. Attempts to improve the model by incorporating other factors, such as temperature and daylength, were unsuccessful. The main problem was that although several hundred fish passed through the Carl Beck traps each year, the number moving at any one time was rather small.

In August 1979 and 1980 electrofishing surveys were carried out in the River Lune to determine the contribution of Carl Beck to the brown trout population

Table 4. Summary of fish movement in Carl Beck 1978-1981. Spring = April-June, Summer = July-August, Autumn = September-December, Winter = January-March. * = 2+ fish not distinguished from spawners after June.

	Numbers of fish moving					
	1978/79	Total	1979/80	Total	1980/81	Total
SPAWNERS						
Upstream		140		263		125
Downstream - autumn	126	197	253	331	199	246
- spring	71		78		47	
IMMATURES						
0+ - spring			2		76	
- summer			5	211	18	297
- autumn	306	307	202		149	
- winter	1		2		56	
1+ - spring			176		44	
- summer			9	281	6	186
- autumn	29	30	84		78	
- winter	1		12		58	
2+ - *spring				222		124

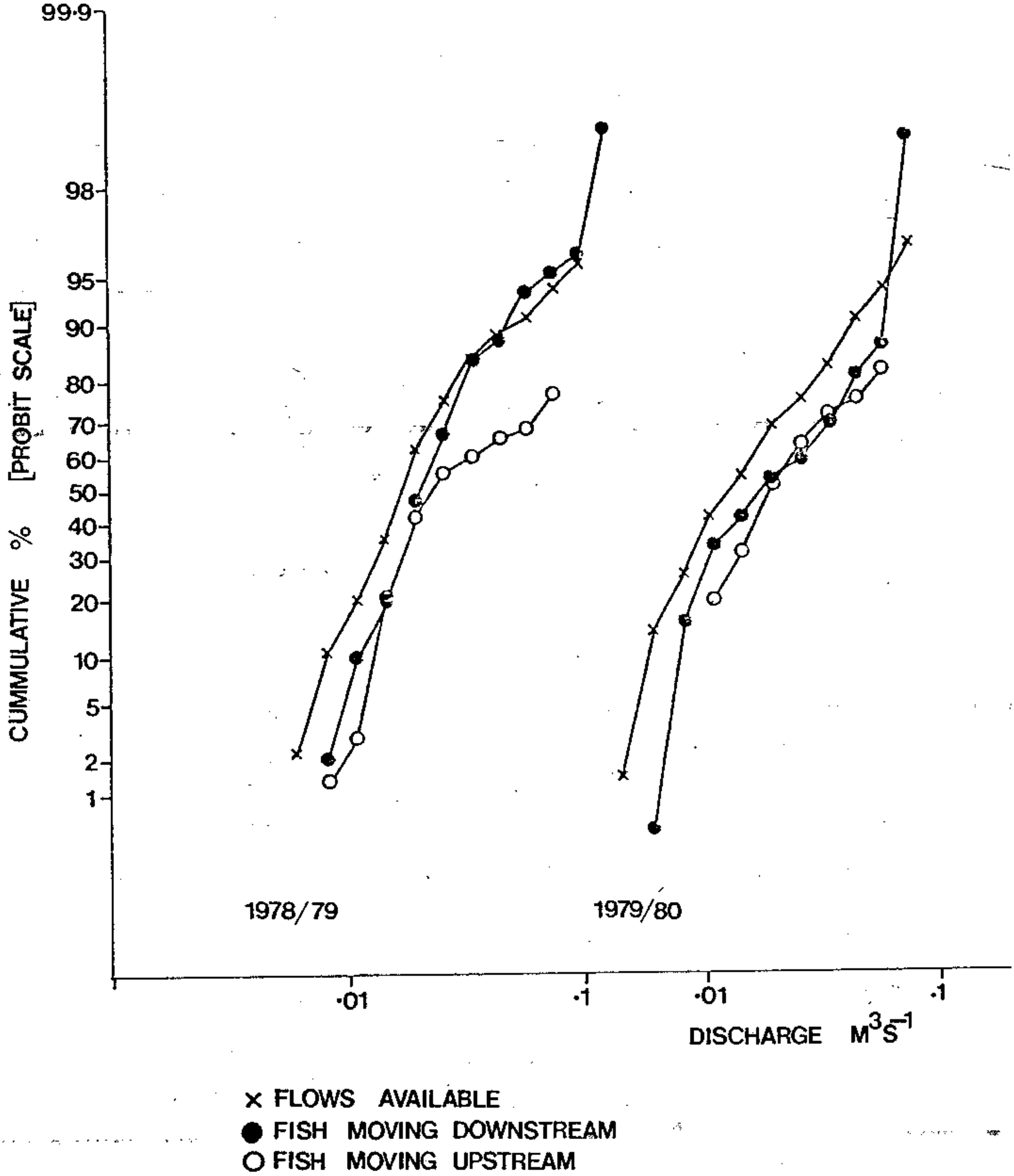


Fig.6. Cumulative probability distribution of available and utilised discharge for 1978/79 and 1979/80. Discharge = mean discharge between trap visits. Where discharge exceeded 0.2447 m^3 s^{-1} (trap overtopping level) the data were discarded. The utilised discharges were weighted according to Hellawell (1974) by using the sum of salmonids moving during these conditions.

Table 5. Equations obtained by regressing (number of fish in the traps +1) = y against (maximum discharge between trap visits $m^3\ s^{-1}$) = x. Equations take the form $y = ae^{bx}$. Data points where discharge exceeded the "overtopping value" of 0.2447 $m^3\ s^{-1}$ were excluded. SP = spawners, IMM = immature fish, + = fish in upstream trap, + = fish in downstream trap, r^2 = coefficient of determination, P = significance level of correlation coefficient, n.s. = not significant, n = number of pairs of data considered.

Category	Period	Year	r^2	P	a	b	n
SP ↑	Autumn	1978	0.28	< 0.001	1.38	7.79	49
	Autumn	1979	0.08	< 0.05	2.08	4.68	70
	Autumn	1980	0.42	< 0.001	1.17	11.30	35
IMM ↓	Autumn	1978	0.11	< 0.05	1.57	5.01	56
	Autumn	1979	0.05	< 0.05	2.04	4.03	76
	Autumn	1980	0.24	< 0.001	1.36	12.07	56
IMM ↓	Spring	1979	0.27	< 0.01	3.28	9.94	26
	Spring	1980	0.10	< 0.05	1.98	6.42	42

Table 6. Analysis of the percentage of R. Lune brown trout population that had passed through the Carl Beck fish trap.

Age of fish at time of survey	FISH TRAP (a) Nos. released	(b) Nos. still in R. Lune	ELECTROFISHING SURVEY (c) Total nos. in R. Lune	(d) % Carl Beck fish
1979 survey				
0+	2	2	365	1
1+	333	230	1267	18
>1+	392	288	1261	23
1980 survey				
0+	69	62	966	6
1+	225	144	1253	12
>1+	503	723	1008	72

(a) Numbers of fish passing through the downstream fish trap at Carl Beck into the R. Lune during the year preceding the electrofishing survey.

(b) Estimated number of (a) still present in R. Lune at time of survey assuming an annual Instantaneous Mortality Rate of 0.69.

(c) Total numbers of fish present in the whole regulated R. Lune at time of survey (August) - estimated from electrofishing data.

(d) Estimated percentage of R. Lune fish originating from Carl Beck = b/c x 100%.

there. The surveys were of, a limited nature and the sites fished are shown in Fig. 2. Very few Carl Beck fish were caught so that it was considered better to deduce the % of Carl Beck fish in the River Lune from the trap records and the R. Lune population densities rather than by expressing the number of Carl Beck fish found in the River Lune as a % of the total fish caught. The presence or absence of a single recaptured fish could make a large difference to the estimated percentages using the latter method. The % of 1+ fish in the River Lune originating from Carl Beck was estimated at 12% and 18% in 1979 and 1980 respectively (Table 6). Estimated values for 0+ and >1+ fish varied between years at 1-6% for 0+ fish and 23-72% for >1+ fish (Table 6).

Discussion

The immigration rates calculated from the electrofishing data, together with fish trap records both indicate that there is a downstream movement of juvenile brown trout in these becks in the spring and autumn. Trap-overtopping in Carl Beck meant that the exact numbers of fish moving were not known. Salmonids are however thought to avoid moving in the peak of spates (Stuart, 1.957; Stewart, 1968) so that the number of fish not trapped was possibly quite small.

In the autumn of 1978 in Thorsgill, the fry moving downstream were smaller in size than the 'resident' fish. Size is usually considered to be an advantage in the acquisition and defence of territories of salmonids (Chapman, 1966; Allen, 1969). It is suggested that these fish were supernumerary fry being displaced downstream.

The influence of discharge on fish movement was demonstrated in both Thorsgill and Carl Beck. The stimulation of brown trout movement by increases in water level is a phenomenon previously noted by other authors including Arawomo (1980); Campbell (1977); Huet & Timmermans (1979) and Munro & Balmain (1956).

The data on the contribiution of the nursery stream Carl Beck to the brown trout population in the R. Lune are included in this report because little is known about the contribution of nursery streams to the fish populations of larger rivers. Carl Beck is the only tributary of any size on the regulated R. Lune between Grassholme reservoir and the R. Tees. The figures suggest that about 10% of juvenile fish (0+ and 1+) in the R. Lune do originate from Carl Beck.

References

Alabaster, J.S. (1970) River flow and upstream movement and catch of migratory salmonids. J. Fish Biol. 2, 1-13.

Allen, K.R. (1969) Limitations on production in salmonid populations in streams. pp. 3-18. In "Symposium on salmon and trout in streams" ed. T.G. Northcote. University of British Columbia.

Anon, (1978) Low flow study report No. 1. Institute of Hydrology. 33pp.

Arawomo, G.A.O. (1981) Downstream movement of juvenile brown trout (Salmo trutta L.) in tributaries of Loch Leven, Kinross, Scotland. Hydrobiologia 77, 129-131.

Beran, M.A. & Gustard, A. (1977) A study into the low-flow characteristics of British rivers. J. Hydrol. 35, 147-157.

Campbell, J.S. (1977) Spawning characteristics of brown trout and sea trout Salmo trutta in Kirk Burn, River Tweed, Scotland. J.Fish Biol. 11, 217-229.

Carling, P.A. & Reader, N.A. (in press) Structure, composition and bulk properties of upland stream gravels. Earth Surface Processes.

Chapman, D.W. (1966) Food and space as regulators of salmonid populations in streams. Am. Nat. 100, 345-357.

Egglishaw, H.J. (1968) -The quantitative relationship between bottom fauna and plant detritus in streams of different calcium concentrations. J. Appl. Ecol. 5, 731-740.

Hart, P.J.B. & Pitcher,T.J. (1969) Field trials of fish marking using a jet inoculator. J. Fish Biol. 1, 383-385.

Hellawell, J.M., Leatham, H. & Williams, G.I. (1974) The upstream migratory behaviour of salmonids in the River Frome, Dorset. J. Fish Biol. 6, 729-744.

Huet, M. & Timmermans, J.A. (1979) Mechanisms and results of a spawning brook for brown trout. Trav. Stn Rech. Groenendael Ser. D 48, 3pp.

Le Cren, E.D. (1969) Estimates of fish populations and production in small streams in England. pp. 269-280. In "Symposium on salmon and trout in streams" ed. T.G. Northcote. University of British Columbia.

Milner, N.J., Gee, A.S. & Hemsworth, R.J. (1979) Recruitment and turnover of populations of brown trout, Salmo trutta in the upper River Wye, Wales. J. Fish Biol. 2, 211-222.

Moore, W.H. (1967) A light-weight pulsed d.c. fish shocker. J. Appl. Ecol. 5, 205-208.

Munro, W.R. & Balmain, K.H. (1965). Observations on the spawning runs of brown trout in the South Quiech, Loch Leven. Freshwat. Salm. Fish. Res. 13, 17pp.

Seber, G.A.F. & Le Cren, E.D. (1967) Estimating population parameters from catches large relative to the population. J. Anim. Ecol. 36, 631-643.

Snedecor, G.W. & Cochran, W.G. (1967) Statistical methods (6th-edn) The Iowa State University Press, Ames, Iowa, USA.

Stewart, L. (1968) Salmon movement in rising, falling and steady river levels. Fish. Dep. Lanc. River Auth. 8pp.

Stuart, T.A. (1957) The migrations and homing behaviour of brown trout (Salmo trutta L.). Freshwat. Salm. Fish. Res. 18, 1-27.

Wolf, P. (1951) A trap for the capture of fish and other organisms moving downstream. Trans. Am. Fish. Soc. 80, 41-45.