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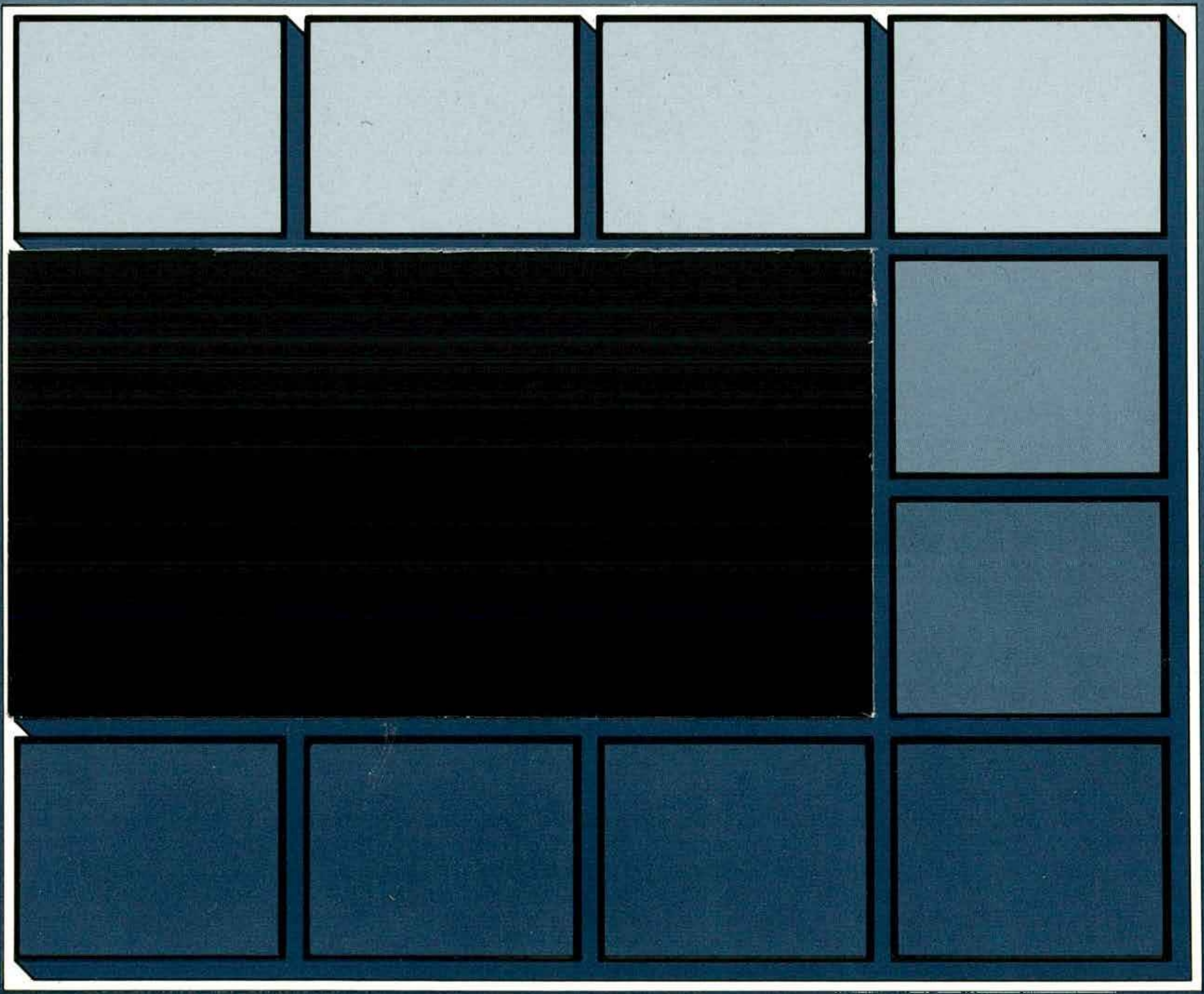

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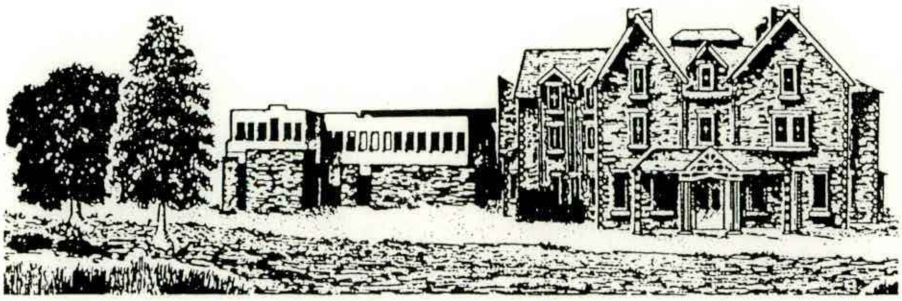

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Recent contracts have involved a wide variety of topics including biological monitoring, environmental impact assessment, fisheries problems, salmon counting, ecological effects of reservoirs and other engineering works, control of water weeds, control of insect pests and effects of chemicals on plants and animals.

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FRESHWATER BIOLOGICAL ASSOCIATION

TFS PROJECT T O 4009 - 5

Report to: Ministry of Agriculture, Fisheries and Food,
Northumbrian Water Authority,
Natural Environmental Research Council.

Date:

The effects of a sand layer upon swim-up success in U.K. salmonids.

D.T. Crisp

NOTE: This report is not a publication and should not be quoted without permission.

WIT/T04009-5/2

CONTENTS

SUMMARY

1. Laboratory studies on the entrapment of alevins by gravel fines are briefly reviewed.

2. Apparatus is described for use in studies on the effects upon fry emergence of a sand layer deposited on the gravel surface.

3. Fry of brown trout and Atlantic salmon emerged through layers of sand up to 8 cm thick but the percentage emergence, even from the controls with no sand, was relatively low (5 - 68%). There was no firm evidence that the experimental treatments influenced percentage emergence, timing of emergence or weight of fry at the time of emergence.

INTRODUCTION & BRIEF REVIEW

There are two main ways in which gravel composition and changes therein arising from siltation, can influence the survival of young salmonids. First, the composition of the gravel will affect its permeability and, hence, may influence the survival of eggs and alevins through its effect upon the rate of supply of oxygen and the rate of removal of metabolic products. This problem is usually studied in the field by attempting to relate measured values of intragravel flow and oxygen concentration to egg survival; or in the laboratory by use of controlled simulations of the field conditions. Second, the composition of the gravel may affect the ease, or otherwise, of emergence at the time of swim-up and alevins may become trapped in the gravel and perish. This aspect is the main concern of the present report. Entrapment of alevins has been studied in the field mainly by means of alevin traps (Phillips & Koski, 1969). Koski (unpublished theses) used them to show that heavy deposits of silt could cause substantial entrapment mortality of alevins of coho (Oncorhynchus kisutch (Walbaum)) and chum (O. keta (Walbaum)) salmon.

There have been a number af attempts to examine various aspects of survival and emergence relative to gravel composition under laboratory and semi-laboratory conditions and twelve representative studies are listed in Table 1. Two of these studies (Dill & Northcote, 1970; Mason, 1976) were concerned with behaviour as well as, or rather than, survival. The work of Godin (1980) was concerned with temporal aspects of emergence relative to temperature. The study by Marty et al.(1986) was conducted in experimental stream channels. The other eight studies were concerned with the effects of gravel size/composition on survival and emergence and used a wide variety of experimental designs and types

REFERENCE	SPECIES	STAGE AT START	GRAVELS USED	QUESTION(S) ASKED
1. Dill & Northcote (1970)	*O. kisutch*	"Eggs"	"Large" and "small"	Effects of depth, gravel composition and density upon movements and survival.
2. Mason (1976)	*O. kisutch*	Alevins, 10 days after hatch.	2 - 5 cm pebbles.	Effects of light and flow on behaviour, length, weight and yolk reserves.
3. Hausle & Coble (1976)	*Sa. fontinalis*	Alevins	0-25% sand in standard gravel.	Survival to swim-up relative to gravel composition.
4. Godin (1980)	*O. gorbuscha*	5 days after hatch.	A standard gravel mix.	Effects of temperature on temporal aspects of emergence.
5. Witzel & MacCrimmon (1981)	*S. gairdneri*	Eggs	2-26.5 mm gravel	Survival to swim-up relative to gravel composition.
6. Peterson & Metcalfe (1981)	*S. salar*	Water hardened eggs.	Gravel base, plus varying proportions of fine and course sand, burial at 16.5 cm & c. 25 cm depth.	Survival to swim-up relative to gravel composition.

TABLE 1. Brief summary of published results of laboratory studies on emergence/swim-up in salmonids. Note that, throughout the table, *Oncorhynchus* is abbreviated as "O", *Salmo* is abbreviated as "S" and *Salvelinus* is abbreviated as "Sa".

REFERENCE	SPECIES	STAGE AT START	GRAVELS USED	QUESTION(S) ASKED
7. Witzel & MacCrimmon (1983)	*S. trutta*	Fertilised eggs.	Gravel 4-16 mm, sand 0-80%, burial at 13 cm depth.	Survival to swim-up relative to gravel composition.
8. Tappell & Bjornn (1983)	*S. gairdneri*	Water hardened eggs.	0.42-50.8 mm in varying proportions.	Survival to swim-up relative to gravel composition.
9. Olsson & Persson (1986)	*S. trutta*	Fertilised eggs.	Gravel 1.5-32 mm, 0-60% peat.	Effect of gravel size and peat content on survival to swim-up.
10. MacCrimmon & Gots (1986)	*S. salar*	Eyed eggs.	Various gravel sand mixes, burial at 16 cm depth.	Survival to swim-up relative to gravel composition.
11. Marty, Beall & Parot (1986)	*S. salar*	Eyed eggs.	Natural gravels.	Survival relative to gravel composition and oxygen.
12. Phillips *et al.* (1986)	*O. kisutch* & *S. gairdneri*	"Fry"	0-70% 1-3 mm sand in gravel, burial at 25 cm depth.	Survival to emergence relative to gravel composition.

TABLE 1. continued.

of apparatus. However, all but two of them measured survival from the egg stage through to emergence and, therefore, confounded the effects of oxygen supply rates and the physical difficulties of emergence. Hausle & Coble(1976) used alevins but did not state whether they used early or late alevins, though their introduction implied interest in the effects of both oxygen supply and entrapment. The study by Phillips et al. (1986) was specifically aimed at the effects of gravel composition on the physical process of emergence and alevins of coho salmon and steelhead trout were introduced to the gravel "several days prior to absorption of the yolk sac". The experimental design attempted to ensure that intragravel flow and oxygen concentration were adequate to support alevins. Sand of 1-3 mm was mixed with a standard gravel at volumetric percentages of 0 to 70% and the alevins were buried at 25 cm depth. Percentage emergence was high at 0% sand (96% for coho and 94% for steelhead) and low at 70% sand (8% for coho and 18% for steelhead). At the higher concentrations of fines coho fry emerged prematurely and the premature fry were smaller and had more residual yolk sac than fry emerging at normal times.

In the absence of any information on Salmo trutta L. or S. salar L. from experiments designed to test the effect of fines specifically upon the emergence process, suitable experiments on these species were made and are the subject of the present report. It was decided that the equipment used should, as far as possible, meet the following conditions:

(a) The artificial redd chambers should be large, so as to minimise edge effects.

(b) There should be some sort of non-return outlets to give an objective assessment of swim-up.

(c) There should be a good flow of clean water at adequate oxygen concentration, to eliminate any possibility of death by asphyxiation.

(d) The alevins should be introduced shortly before swim-up so that the study would, as far as possible, be concerned only with the process of emergence.

A modified version of the apparatus described by Godin (1986) met the first two conditions and details are given below. The experiment was so conducted that conditions (c) and (d) were met, apart from some difficulties in maintaining a clean water supply.

There are two ways in which fines may be deposited at salmonid spawning areas:

(1) Infilling of the void space by fines may occur from the bottom upwards. This is a common occurrence and the infilling may be surprisingly rapid (Carling & McCahon, 1987).

(2) Fines, especially sand, may be deposited as a layer on the gravel surface. This type of deposition occurs in gravel beds in some chalk streams of southern England and was the type simulated in the present experiments. The occurrence of sand layers on the surfaces of the redds was described by Chapman (1988) and the penetration of sand barriers by emerging sockeye salmon (Oncorhynchus nerka) alevins was described by Bams (1969).

APPARATUS, EXPERIMENTAL DESIGN, MATERIAL & PROCEDURES

The apparatus used consisted of twelve plastic emmergence boxes whose general layout is shown in Figure 1. Some details are illustrated in Plates 1-3.

Twelve such boxes were used and this gave three replicates of each of four experimental treatments. The boxes were arranged in four banks of three and the treatments were distributed in the form of a Youden square. The four treatments were to have 0, 2, 4, and 8 cm depth of sand overlying the gravel so that, in each box, the total depth of sand plus gravel to be negotiated by emerging alevins was 30 cm.

Each emergence box was set up using dry gravel and sand. The perspex cover was then fitted and sealed using a combination of waterproof "Sellotape" and silicone rubber. When the silicone rubber had set the water flow was turned on. The water supply passed to the emergence tanks from three header tanks and the rate of supply to each emergence tank was individually adjusted to give a nominal flow of 3 l min^{-1}. This gave a mean bulk velocity (apparent velocity) of 1.74 cm min^{-1} or 0.03 cm s^{-1} which is similar to the rate used by Godin (1980). The temperature of the water was continuously recorded. Dissolved oxygen determinations were made from time to time.

One experiment on trout and one on salmon was conducted in each of the years 1987 and 1988. The trout material was obtained by stripping wild brown trout taken from the upper reaches of the R. Tees.

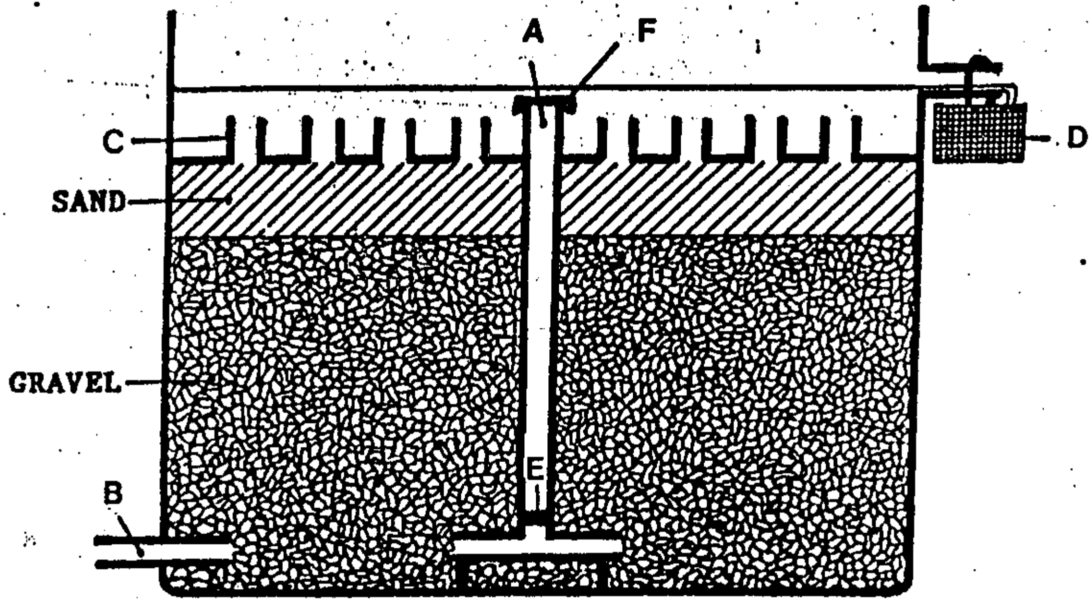

FIGURE 1. CROSS SECTION OF EMERGENCE BOX. PIPE B FEEDS WATER TO A MANIFOLD (NOT SHOWN). WATER UPWELLS THROUGH THE GRAVEL AND SAND AND OVERFLOWS THROUGH A MESH BASKET (D). A PERSPEX SHEET COVERS THE SURFACE OF THE GRAVEL OR SAND AND 48 PIPES, EACH 2 CM LONG & 1.5 CM INTERNAL DIAMETER (C) ACT AS NON-RETURN VALVES TO EMERGING FRY. ALEVINS ARE INTRODUCED DOWN THE STANDPIPE (A), FOLLOWED BY A WAD (E) AND THE TOP OF THE PIPE IS THEN SEALED (F). THE INNER DIMENSIONS OF THE BOX ARE 52x34 CM AND THE DEPTH OF GRAVEL + SAND ABOVE THE BOTTOM OF THE STANDPIPE IS 30 CM.

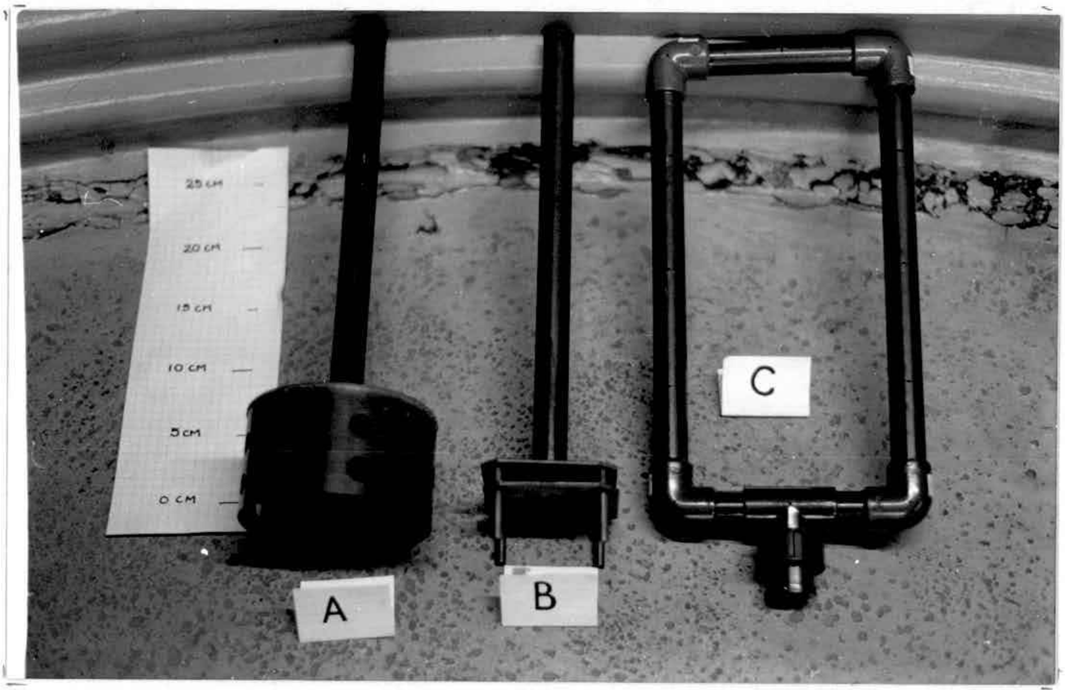

PLATE 1. DETAILS OF THE APPARATUS. A. THE TYPE OF STANDPIPE USED IN 1987. B. THE TYPE OF STANDPIPE USED IN 1988. C. INFLOW MANIFOLD, NOTE THE SMALL HOLES DRILLED IN THE PIPES.

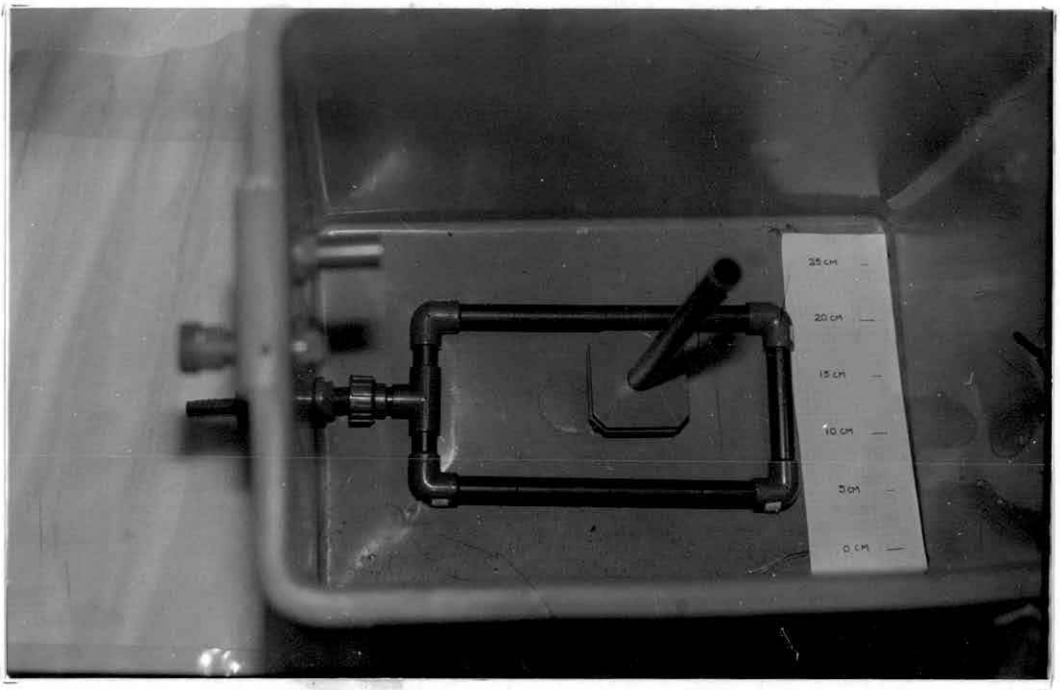

PLATE 2. VERTICAL VIEW OF EMPTY EMERGENCE TANK TO SHOW STANDPIPE AND MANIFOLD.

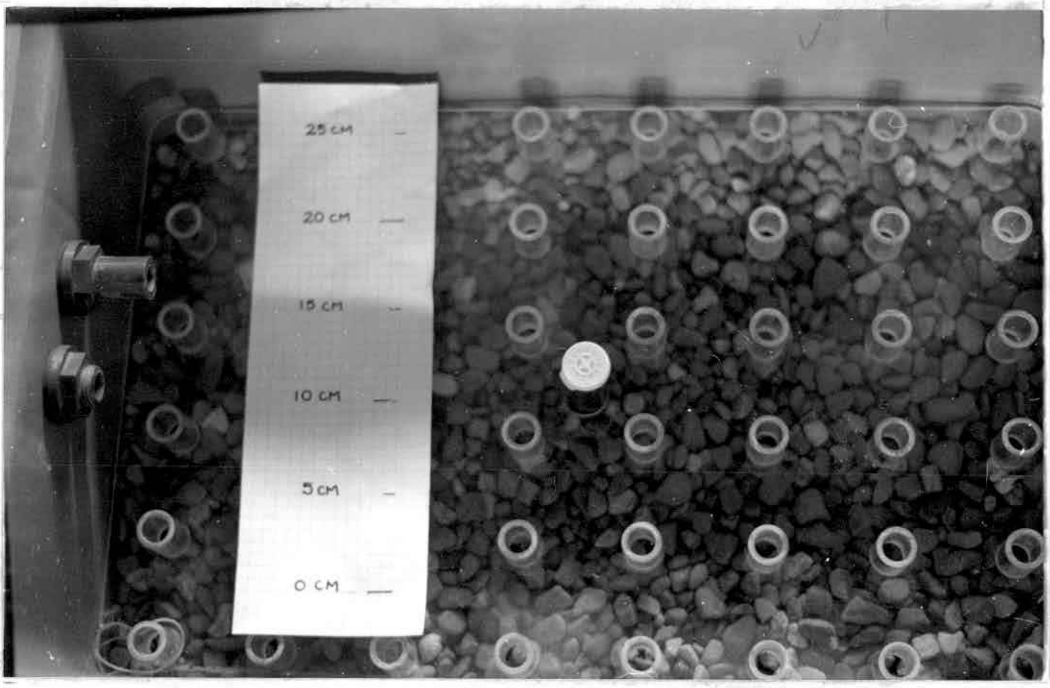

PLATE 3. VERTICAL VIEW OF EMERGENCE TANK TO SHOW GRAVEL, PERSPEX GRAVEL COVER, CAPPED TOP OF STANDPIPE AND OVERFLOW PIPES.

The salmon material was supplied by the Kielder hatchery of the Northumbrian Water Authority and had been obtained from R. North Tyne salmon. Each experiment in each year began with alevins which were predicted from their temperature history to be close to swim-up (152% to 167% of completed development to median hatch - see Crisp 1981 and 1988) and which were visually confirmed to have absorbed most of their yolk. In the salmon experiment of 1987 100 alevins were put in each box but in the other three experiments 200 alevins were put in each box. The alevins were introduced to the standpipe in each box via a funnel and a wad of pan-scrubber material was then pushed down the pipe to ensure that all the alevins entered the chamber at the bottom of the standpipe. The top of the pipe was then capped. Emerged fry were removed daily from the top of the perspex sheet and from the basket at the overflow. Each emerging fish was killed, measured and weighed. Each experiment was terminated when fry emergence ceased, usually between 238 and 297% completed development to median hatch.

At the end of each experiment the sand layer was scooped from the gravel surface and discarded and the gravel was washed for reuse, with new sand, in the next experiment.

GRAVEL & SAND COMPOSITION

A summary of the composition of the gravel and of the sand mixture used in the experiments is given in Table 2, together with estimates of porosity. For both sand and gravel the porosity was between 0.35 and 0.40 and this is rather higher than the values (0.1 to 0.3) observed in three Pennine streams by Carling & Reader (1982).

As the mean apparent velocity in the emergence boxes was c. 0.03 cm s^{-1}, the seepage velocity of the upwelling flow would be c. 0.076 cm s^{-1} in the gravel and c. 0.083 cm s^{-1} in the sand.

Sieve Aperture (mm)	Cumulative percentage not retained	
	Gravel	Sand Mixture
16.0	100.0	100.0
8.0	27.2	99.0
4.0	0.9	58.4
2.0	0.2	22.0
1.0	0.2	1.0
0.5	0.2	0.1
0.25	0.2	0
0.125	0.2	0
0.063	0.1	0
Porosity	0.393	0.362

TABLE 2. Size-frequency distributions of the gravel and sand used in the experiments, together with estimates of porosity. Analyses by Dr. P. A. Carling.

RESULTS

1. Water temperatures.

A summary of water temperatures during each experiment is given in Table 3. In order to achieve one experiment with each species in each year it was necessary to accelerate the development of the trout by rearing them, prior to the experiment, in relatively warm spring water. As a consequence the trout experiment preceded the salmon experiment in each year and was, therefore, conducted within a lower temperature range.

2. Water flow.

The upwelling flow in each emergence tank was set at a nominal mean value of 3 l min^{-1} (50 ml s^{-1}) at the start of each experiment. In the trout experiment of 1987 the mean flow was actually 2.98 ± 0.04 l min^{-1} (95% C.L.) at the start and 2.44 ± 0.04 l min^{-1} at the finish. Corresponding values for the 1987 salmon experiment were 3.16 ± 0.01 l min^{-1} and 2.94 ± 0.07 l min^{-1}. During each experiment there was a decrease of 7 - 18% in the flow. This mainly reflected gradual sag of the feed pipe walls at the points where screw clips were fitted to regulate the flow. However, even the flows at the conclusions of the experiments were ample for the intended purpose. No detailed flow measurements were made at the end of the 1988 experiments but, as the control of flow in that year was by means of taps rather than screw clips, no major drift in value would be expected.

TROUT 1987

March	(23-31)	2.7	(2.1-3.3)
April	(1-30)	5.6	(3.1-10.2)
May	(1-19)	9.3	(8.9-10.5)

SALMON 1987

May	(21-31)	9.7	(8.8-10.7)
June	(1-30)	10.5	(8.8-11.8)
July	(1-6)	13.3	(12.7-13.9)

TROUT 1988

Feb.	(29)	2.4	
March	(1-31)	3.3	(1.5-4.8)
April	(1-30)	6.7	(4.4-8.4)
May	(1-11)	8.4	(7.8-9.2)

SALMON 1988

May	(16-21)	11.2	(10.3-11.8)
June	(1-30)	13.5	(12.0-14.8)

TABLE 3. Mean water temperatures (°C) for months or parts of months during emergence experiments. The days of each month which are included in that month's mean are shown in parentheses after the name of the month. The lowest and highest daily means recorded during each month or part-month are shown in parentheses after the monthly mean.

3. Dissolved oxygen concentration.

The dissolved oxygen concentration of the water feeding the experiments was measured at irregular intervals. Concentrations of 9 to 13 mgl^{-1} were usual, though values as low as 7 mgl^{-1} sometimes occurred during July. A relatively high dissolved oxygen concentration would be expected because, prior to being supplied to the emergence boxes, the water was fed as a high speed spray into the header tanks.

4. Timing of swim-up.

The timing of swim-up is best examined by comparison of either the date of median swim-up or the percentage completed development towards median hatch on the date of median swim-up. Relationships in Crisp (1988) indicate that at the time of median swim-up the percentage development to median hatch (as computed from daily temperatures) will be c. 200% for material incubated within gravel. In all four experiments the results (Table 4) are reasonably close to this expected value and in the 1987 trout and 1988 salmon experiments the observed and predicted values were very similar.

Within treatments variation was high relative to between-treatments variation and no significant effect of treatment upon time of swim-up could be shown.

5. Survival to swim-up.

The percentage of input fry emerging from each box in each experiment is shown in Table 5. In each experiment the mean percentage emergence was higher in the boxes without sand than in the remainder. However the within-treatments variation was high relative to the between-treatments variation and no statistically significant differences between treatments could be shown.

SAND DEPTH (cm)	TROUT (1987)	SALMON (1987)
0	206.5, 206.5, 193.2 (202±19.1)	224.8, 219.3, 219.3 (221± 7.9)
2	208.7, 202.6, 213.0 (208±13.0	219.3, 222.0, 211.1 (218±14.1)
4	208.7, 198.0, 198.0 (202±15.3)	219.3, 219.3, 211.1 (217±11.8)
8	202.6, 202.6, 202.6 (203)	219.3, 219.3, 211.1 (217±11.8)
	TROUT (1988)	**SALMON (1988)**
0	218.2, 218.2, 230.2 (222±17.2)	201.0, 212.3, 198.7 (204±18.1)
2	211.0, 230.2, 225.1 (222±24.7)	212.3, 221.6, 196.4 (210±31.6)
4	223.4, 225.1, 230.2 (226± 8.8)	212.3, 212.3, 196.4 (207±22.8)
8	225.1, 221.7, 225.1 (224± 4.9)	198.7, 214.5, 196.4 (203±24.5)

TABLE 4. Percentage development towards median hatch at the time of median swim-up in each emergence box in each experiment. The treatment means ± 95% C.L. are given in parentheses.

SAND DEPTH (cm)	TROUT (1987)	SALMON (1987)
0	53.0, 33.5, 42.0 (43±24.3)	17.0, 19.0, 46.0 (27±40.2)
2	33.5, 31.5, -	5.0, 7.0, 17.0 (10±16.0)
4	19.5, 36.0, 52.0 (36±40.3)	10.0, 15.0, 28.0 (18±23.1)
8	37.0, 15.5, 24.0 (26±26.9)	10.0, 17.0, 22.0 (16±15.0)
	TROUT (1988)	SALMON (1988)
0	34.0, 30.0, 33.0 (32± 5.2)	41.0, 67.5, 55.5 (55±32.9)
2	17.0, 8.5, 26.5 (17±22.3)	35.0, 54.0, 45.5 (45±23.6)
4	23.0, 16.0, 26.0 (22±12.7)	34.0, 32.5, 56.0 (41±32.7)
8	18.5, 19.5, 37.5 (25±26.5)	50.0, 45.5, 45.5 (47± 6.4)

TABLE 5. Percentage achieving swim-up. Treatment means ± 95% C.L. are given in parentheses. Note: (a) The starting number in each box was 200 in each experiment except the 1987 salmon experiment which had only 100 per box.

(b) Most of the alevins in one of the 1987 trout boxes were accidentally trapped in the base of the standpipe and no results are given for that box.

Attempts to fit linear regressions after log-log and semi-log transformations of the data also led to non-significant results ($P>0.1$).

6. Mean weights at the start of each experiment and at the time of swim-up.

A summary of mean weights (Table 6) shows that the emerging fry had approximately 80% of the weight of the input alevins. This, presumably, represents consumption of material by metabolism during the process of emergence. Despite the fact that within-treatments variation was small in each experiment, the results give no clear-cut evidence that the mean weight of the emerging fry was influenced by experimental treatments.

As neither the time of swim-up nor the weight of the fry at swim-up could be related to the experimental treatments, data for all treatments were combined for analysis of the effect of time of swim-up upon fry weight. Within each experiment the weights of individual fry (y, g) were regressed upon time since the start of the experiment (x, days). Details of the correlation coefficients and probabilities are given in Table 7 together, where appropriate, with details of the corresponding linear regressions. No significant ($P<0.05$) relationship could be shown for salmon. In both trout experiments, despite considerable scatter of data points, there were significant negative relationships between date of emergence and fry weight. This could imply either that the later emerging fry had used more body weight in metabolism during the emergence process, or that they had commenced emergence at a lower mean weight and that these smaller fry took longer to emerge.

SAND DEPTH (cm)	TROUT (1987)	SALMON (1987)
0	0.087±0.002 (251)	0.094±0.004 (81)
2	0.083±0.002 (141)	0.099±0.007 (27)
4	0.082±0.002 (211)	0.102±0.005 (52)
8	0.080±0.002 (150)	0.094±0.005 (49)
START	—	0.124±0.007 (31)

	TROUT (1988)	SALMON (1988)
0	0.068±0.001 (195)	0.094±0.002 (319)
2	0.067±0.002 (101)	0.091±0.002 (258)
4	0.066±0.001 (130)	0.092±0.002 (241)
8	0.067±0.001 (145)	0.093±0.002 (274)
START	0.084±0.003 (30)	0.113±0.009 (30)

TABLE 6. Mean weight (g) of fry emerging from each treatment within each experiment ± 95% C.L. For three of the experiments the mean weight (g) ± 95% C.L. of the input alevins is also given. The numbers of fish upon which each mean is based is given in parentheses.

YEAR	SPECIES	n	$a \pm 95\%$ C.L.	$b \pm 95\%$ C.L.	r	P
1987	salmon	209	-	-	0.1318	>0.10
1988	salmon	1094	-	-	-0.1683	>0.05
1987	trout	753	0.124 ± 0.009	-0.00095 ± 0.00021	-0.3110	<0.01
1988	trout	575	0.096 ± 0.007	-0.00048 ± 0.00009	-0.4000	<0.001

TABLE 7. Summary of constants a & b in linear regressions of the form $y = bx + a$, when y = individual weight of emerging fry and x = days from start of experiment.

7. The alevins/fry which did not emerge.

After each of the 1987 experiments, as many residual alevins as possible were recovered during the process of washing the gravel. A total of 213 out of 1200 (18%) of the salmon had emerged and, of the 988 (82%) which did not emerge, 64 were found in the gravel and 47% of them were dead. It is likely that most of the 924 (77%) which were not recovered had died and become unrecognisable. In the 1987 trout experiment 767 (32%) of the input alevins emerged and 1633 (68%) did not. Of the latter, 630 were found in the gravel and 75% of them were dead.

This suggests that most of the material left in the boxes at the end of each experiment was either dead or moribund. It is far from clear why this mortality occurred, even in the controls.

DISCUSSION

Most previous studies have confounded the effects of egg/alevin survival relative to oxygen supply rate and alevin/fry emergence relative to gravel composition. The present experiments and those of Phillips *et al.* (1986) were concerned solely with the latter problem. Phillips *et al.* used gravel and sand mixtures. In controls which contained no sand they obtained nearly 100% emergence for coho salmon and steelhead trout, whereas at 70% sand emergence was less than 20%. This contrasts with data from the present experiments where the sand was laid in a discrete layer on the top of the gravel and the controls with no sand only gave emergences of 17 to 68% (Table 5) for brown trout and Atlantic salmon. The reasons for this difference are not clear but the following points are worth brief mention:

(a) In the present experiment the alevins had to emerge through at total depth of 30 cm of sand and gravel. In the experiments of Phillips et al. they had to negotiate only 25 cm of gravel/sand mixture.

(b) Phillips et al. ran their experiments at dissolved oxygen concentrations of 6.5 to 11.8 mgl^{-1}. They quoted no intragravel flow rates but considered that the values obtaining would be adequate. The dissolved oxygen values used in the present experiments compared favourably with those used by Phillips et al. and the intragravel flow was adequate relative to the specification given by Godin (1980).

(c) It seems unlikely that differences in burial depth (see a above), inadequacies in oxygen content or intragravel flow (b above), differences in species or differences in the quality of the experimental material are the explanation of the generally low rates of emergence observed in the present experiments. A possible reason is the occasional presence of relatively high concentrations of aluminium in the hatchery water supply during the two years of experiments. This was a rather unexpected consequence of drawdown of reservoirs during the two relevant winters. A high mortality of salmon eggs during the winter of 1986-87 almost certainly reflected an episode of high aluminium concentration in the hatchery water supply but this same episode had no obvious effect on young trout.

On a more positive note, the experiments did demonstrate that fry of both Atlantic salmon and brown trout can successfully negotiate bands of pure sand up to 8 cm thick during the course of emergence.

ACKNOWLEDGMENTS

The apparatus was developed and built by Mr P.R. Cubby. Dr P. A. Carling gave valuable advice on sand and gravel composition before the experiments and performed analyses afterwards. Mr M. Glaister transported the gravel to the site. Messrs. R.M. Murray, T. Gledhill, N. Shopland and M. Dipnall helped in the conduct of the experiments. Figure 1 is based on an original drawing by Mr Shopland. The photographs (Plates 1-3) were taken by Mr N. Cruddace.

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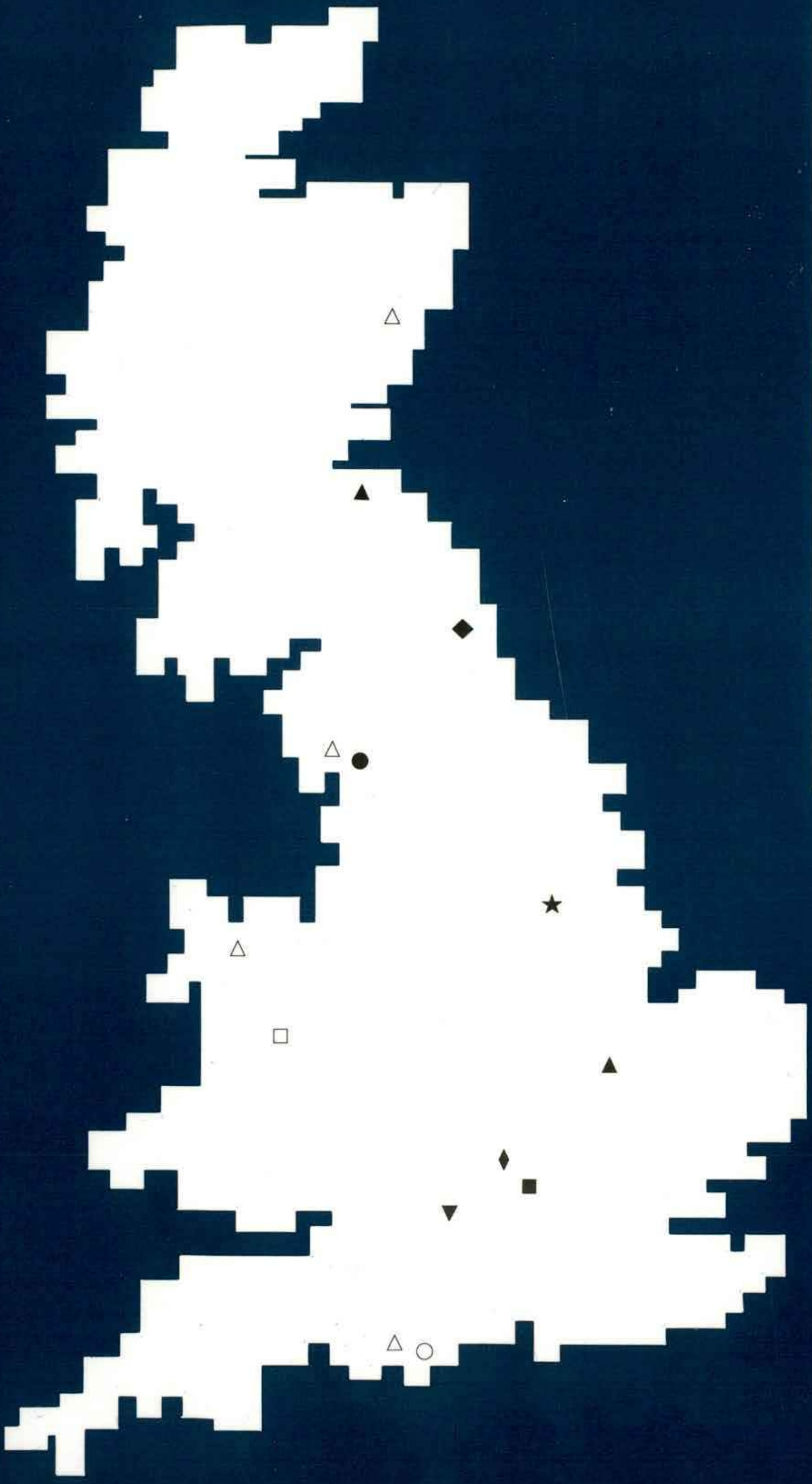

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