Institute of Freshwater Ecology

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The ecology of young stages of salmonid fish and the implications for practical river management

Final report for the period
1 April 1986 to 31 March 1990

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Report date:	March 1990
Report to:	Ministry of Agriculture, Fisheries and Food
IFE Report Ref:	LL/T11050e5/1
TFS Project No:	T11050e5

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CONTENTS

THE ECOLOGY OF YOUNG STAGES OF SALMONID FISH AND THE IMPLICATIONS FOR PRACTICAL RIVER MANAGEMENT - FINAL REPORT FOR THE PERIOD 1 APRIL 1986 TO 31 MARCH 1990.

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SUMMARY

1. During the period 1 April 1986 to 31 March 1990 this contract has been responsible for the publication of seven papers. A further three papers are "in press" and five more are at a late stage of preparation for publication.

2. One paper deals with the general environmental requirements of trout and with the impact of human activities on the environment of trout.

3. Data on fish populations in Cow Green Reservoir have been processed and written up to give a detailed account of changes occurring as a result of impoundment.

4. Attention has been given to water temperatures in the free stream water and in gravel beds used as spawning sites by salmonids. Equations have been developed to predict intragravel development of salmonid eggs and alevins from temperature. The period required in a north Pennine stream is about twice as long as in a southern chalk stream.

However, the hatchery fed fry attain a rather smaller weight at the end of ten weeks than do those stocked as unfed fry.

9. Most of this work is highly relevant to problems relating to the enhancement of salmonid stocks in places where numbers of 0 group fish are often sub-optimal. It is also important in gaining more information about the dispersal of young salmonids during the first few months of free-swimming life.

I INTRODUCTION

The studies covered by this contract nearly all relate to the general theme of the title but they comprise several sub-projects some of which began during previous contract periods and were funded by several customers, including, latterly, MAFF. The present contract term, therefore, covered the following three types of activity:

(i) Processing and writing-up data from previous contract terms.

(ii) Continuation of long-term experiments and observations relevant to river management.

(iii) Extension of various short-term experiments of immediate relevance to, and complementary to, various MAFF/DAFS "in-house" researches.

During the period of funding ten papers have been published or are in press and two reports have been produced. All of these are relevant to the present contract and most arise directly from either it or its predecessor. Most of the present report is a brief summary of the main contents of these papers and reports. Another five papers are either submitted or are at a late stage of preparation and brief reference is made to their contents.

In addition, this report describes on-going aspects of the research and the probable timing of completion and of publication of results.

Finally, there are notes on possible activities for future support during the period 1 April 1990 to 31 March 1993.

II BACKGROUND

Salmon and trout deposit their eggs in the autumn or winter in gravel beds in rivers or streams. The female fish excavates a pit by repeated flexure of her body and a heap of spoil ("the tail") accumulates downstream. Eggs are deposited in the bottom of the pit and are then covered by the spoil from further excavations immediately upstream. This process is repeated until one or more pockets of eggs are buried in the tail of the structure. The whole structure is termed a "redd". The eggs incubate within the redd and hatch to produce an "alevin". The alevin remains in the gravel, subsisting upon the yolk sac. When the yolk in the sac is almost all gone, the alevin emerges from the gravel and becomes a free-swimming "fry".

The rate of incubation is related to water temperature, salmon eggs hatch in about 90 days at 5°C and about 48 days at 10°C, the additional times between hatching and emergence of the fry from the gravel are about 69 days and 34 days respectively. The young stages are, therefore, incubating in the gravel for relatively long periods of time (5–7 months in the northern Pennines, 3–4 months in southern chalk streams). During this period they may suffer mortality as a result of:

1. Scouring of the redds by spates. This can lead to physical damage to the young stages as a result of the grinding effect of the moving gravel and also to displacement of the young stages to sites unsuitable for continued developemnt.

2. Deposition of silt during low flows. This infills the spaces in the gravel and may cause death of young stages either by reducing their oxygen supply or by trapping fry seeking to emerge from the gravel.

3. Reductions in water level can lead to exposure of the young stages above water level. They are then vulnerable to drying out or freezing.

All of these causes of mortality can occur in natural flowing waters but their severity can be substanially increased by human activities. Some of the more important ones are:

1. Impoundment and regulation of rivers. Sudden and large releases of water from impoundments may lead to increased scour of gravel beds. The imposition of unnaturally low flows upon a river can lead to compaction of the bed and infilling of the spaces in the gravel with silt. Sharp reductions in river flow can lead to exposure above the water level of salmonid eggs.

2. Land drainage can result in substantial increases in the quantity of suspended solids carried by streams and rivers. When these solids are deposited on or in the spawning gravels they can be harmful to young stages of salmonids.

3. Afforestation and deforestation (the former usually accompanied by land drainage) can modify the flow regime in streams and rivers. They also usually give rise to increases in the concentration of suspended solids in the water.

The studies on redds and eggs (see below) address some aspects of these problems.

Soon after young salmon and trout emerge from the gravel each individual seeks to establish a territory and defend it from others. The fish which cannot gain territories are displaced downstream. The rate of downstream dispersal is, therefore, related to the number of fish present.

The effects of water velocity upon the rate of downstream dispersal of young salmon and trout have been investigated by means of experiments in four artificial stream channels with controllable flow and the results have been written-up for publication during the present contract term.

Other aspects of survival and dispersal of free-swimming young stages form the subject of continuing long term field studies at Cow Green and of recent short term studies in a local stream and in the experimental channels.

III PUBLICATIONS AND REPORTS.

1. General considerations:

All relevant papers published or in press and all relevant unpublished reports are listed in Appendix 1. A further five papers have already been submitted to Editors or soon will be. These are listed in Appendix 2. The summary of contents of these papers, which follows, is arranged according to subjects rather than chronologically.

2. Environmental requirements of salmonid fishes:

Crisp (1989a) is a general scientific resumé of the environmental requirements of trout in the U.K.. As far as possible the requirements have been quantified. Other papers give additional information for salmonids on requirements for spawning sites (Crisp & Carling, 1989) and effects of temperature on rate of embryonic development (Crisp, 1988c).

3. Stream water temperatures:

A compendium of water temperature data for a variety of streams and rivers in N.E. England (Crisp, 1988b) and an analysis of simplified methods of estimating daily mean stream water temperatures (Crisp, in press b), are contributions to the general study of stream/river water temperatures. Such work provides fundamental information on water temperatures and also a basis for examination of the effects man's activities in modifying temperature regimes and of the consequent effects of those modifications upon salmonid fishes. (e.g. Crisp, 1989 a).

The prediction, from temperature, of hatching time for the grayling (Thymallus thymallus) and for the main U.K. salmonid species was facilitated by several publications (Crisp, 1981; Jungwirth & Winkler, 1984; Humpesch, 1985). Further analysis of published information (Crisp, 1988c) gave the ability to predict times of median eyeing and median "swim-up" (i.e. emergence from the gravel). These two stages mark the end of the period of maximum vulnerability to mechanical shock and the end of the period of intragravel life, respectively. Prediction of these two stages is crucial to the management of rivers so as to minimize damage to intragravel stages and is also important in the design and management of a range of field and laboratory experiments.

However, the predictions must be used with some caution because water temperature in the streambed gravel may differ somewhat from the temperature of the free water and little is known about this topic (Crisp, in press c).

4. Redds and intragravel stages:

Crisp & Carling (1989) made detailed studies of a number of redds of trout, salmon and rainbow trout in Dorset chalk streams, and in upland streams of S.W. Wales and N.E. England. Significant, positive relationships were established between the size of the female fish making the redd and variables which included (a) some major dimensions of the redd, (b) water velocity at the redd site, (c) water depth at the redd site, (d) egg burial depth. Additional information was gained on spawning behaviour and on the structure of redds. This information is of value in defining suitable spawning areas for fish of different sizes. It is also relevant to problems of vulnerability of eggs to washout (see below).

The duration of various stages within the period of intragravel life (from oviposition to swim-up) can be predicted from temperatures (see above). During this period the young stages are vulnerable to mechanical shock (e.g. disturbance by vehicles) and to washout during spates. Quantitative field study of these processes presents a number of difficulties. A certain amount of progress has, however, been made through use of artificial eggs in the field, through the use of the Grassholme experimental channels in semi-field studies, and through the use of a small hatchery at Lartington. Artificial eggs which could be batch marked or individually coded were devised by Ottaway (1981) and used in some pilot trials, but their adequacy as simulations of of real eggs was not tested. Comparisons of size, weight, density, rate of fall in a water column and pattern of settlement within an experimental channel showed that they were a useful simulation of natural eggs (Crisp, 1989b). Use of these eggs in one spawning area of a natural stream showed that washout can occur to depths of at least 15 cm in severe spates (return period 10-20 years) and may be almost complete at 5 cm depth in smaller spates. This implies that vulnerability to washout is related to egg burial depth. Eggs drifting in an experimental channel with water velocity c. 100 cm s^{-1} would make 1 to 2 bed contacts m^{-1} of travel and 50% would settle within 8 m of the point of release. However, in a natural stream, drift distances were much larger, probably several tens of metres (Crisp 1989c). Standard applications of mechanical shock (by dropping) were used to test the vulnerability of trout and salmon eggs to mechanical shock at various stages of development (Crisp, in press a). The results supported more detailed studies on Pacific salmon eggs (Jensen & Alderdice, 1983) which showed that sensitivity to shock increased rapidly after fertilization and then fell to a low value at about the time of eyeing. Trout eggs drifted 10 m along the Grassholme channels at 10-20% completed development to median hatch suffered mortality of c. 50%. This is comparable to the mortality (52-65%) suffered by eggs at a similar stage of development which were given a shock of c. 8000 ergs. This implies that the simple process of drifting downstream after displacement from a redd by washout can cause substantial mortality to eggs at a sensitive stage of development. There is some evidence that sublethal mechanical shock may modify hatching time by some days (or even weeks).

5. Free-swimming young stages:

The Grassholme channels were used in a series of pilot experiments on the downstream dispersal of young salmonids (Ottaway & Clarke, 1981; Ottaway & Forrest, 1983). These early experiments were, however, open to substantial criticisms of their experimental design and data presentation. Therefore, in 1983 a large programme (unpublished) was carried out to calibrate the channels and further experiments, with improved design and management, were performed from 1983 to 1987. These have now been written up as three papers which are in the process of submission for publication (see Appendix 2, items 3, 4 & 5). General conclusions are:

(a) Trout show a low rate of downstream dispersal in water velocities at 0.6 depth of c. 25 cm s^{-1}. The rate is higher at low (7.5 cm s^{-1}) velocity and increases at higher (40 cm s^{-1}, 70 cm s^{-1}) velocities. Salmon show a high rate at low velocities (7.5 cm s^{-1}) and much lower rates at velocities of 25 cm and above.

(b) Dispersal rate was higher by night than by day.

(c) Dispersal rates were greatly increased by increases and decreases of velocity for trout but only by decreases of velocity for salmon.

(d) Salmon fry appear to actively avoid low velocity (7.5 cm s^{-1}) and disperse until very low densities are attained. For trout at all velocities and salmon at higher velocities, velocity appears to have little effect on final population density, but it does influence the rate at which that density is approached.

This work has relevance to the management of rivers, with particular reference to flow regime and its manipulation by man (e.g. regulation releases from reservoirs) and to consequent effects in modifying the relative balance of favourability of flow conditions to trout or salmon.

6. Effects of a river regulating reservoir:

Studies on the effects of Cow Green Reservoir (dam closed 1970) upon fish populations in the downstream river, the afferent streams and the reservoir basin began in 1967 and continued until 1985. Accounts of stream/river populations were given by Crisp et al., 1974 ; Crisp et al., 1983; Crisp et al., 1984. Accounts of fish populations within the reservoir have been difficult to prepare but are now ready for submission to a journal (see Appendix 2, items 1 & 2).

IV ON-GOING STUDIES

1. Long-term studies at Cow Green.

(a) Trout populations in four marked reaches of streams.

Thrice-yearly census work has been done in four marked stream reaches since the late 1960s. The data show evidence of an inverse effect of population density upon growth rate of first year trout. There is also some evidence of population cycles. It is proposed that these observations shall cease in the autumn of 1990 and the work will then be written-up.

(b) Mortality and downstream dispersal of 0 group trout, relative to initial stocking density.

Two streams have been furnished with traps for downstream moving 0 group trout. These are being used to examine the effects of initial stocking density, not only upon total rate of loss between spring and early August, but also the apportionment of that loss between mortality and downstream dispersal. At the end of the 1990 season we will have 10 data points for each stream and the work will then be written up.

(c) Both of these studies have relevance to MAFF's interest in streams/rivers which appear to have sub-optimal population densities of 0 group salmonids. If the reasons for this can be understood, some remedial measures might be devised.

2. Short-term studies on the practicalities of stocking with 0 group salmon.

(a) Stocking experiments in Bollihope Burn (see "Reports" Crisp, 1988).

An experiment in 1988 showed substantial dispersal from a single stocking point. Upstream dispersal was appreciable and occurred for at least 50 m, despite a minor obstruction. Downstream dispersal was substantial for a distance of at least 450 m. A similar experiment in 1989 gave similar results, except that downstream dispersal occurred only over a distance of 100-200 m. This probably reflected very dry conditions during 1989. In both years, the dispersed fish were of larger size in September than were those which remained close to the point of release.

(b) Experimental channel studies on the relative effectiveness of stocking with unfed and five weeks fed salmon fry.

These experiments have used the Lartington Hatchery and the Grassholme channels in small scale, semi-field experiments. The results show that, some ten weeks after they first begin to feed, fish fed in a hatchery for 5 weeks and then released in the channels will have approximately twice the population density of fish released as unfed fry. However, the overall growth rate of the 5 weeks fed fry will be less than that of the fish released as unfed fry.

(c) Both of these studies are relevant to the interests MAFF and DAFS in the practicalities of salmon enhancement by planting fry. The Bollihope experiments parallel and complement similar studies being made by DAFS, but with a slightly different experimental design. The channel experiments relate to field studies by Mr. Scott and it is hoped that they will be jointly published. It is desirable to repeat the Bollihope experiment again in 1990 and possibly in one other year, to gain insight into year-upon-year variations in dispersal distance. The channel experiments, or developments of them, could usefully be continued in future years. However, none are likely to be possible during 1990 because of Water Authority works interfering with the quality of channel water supply.

3. Base-line studies on a sea trout population in a stream which is being afforested.

This work consists of thrice-yearly fish census work on the Afon Cwm in mid-Wales. The catchment has recently been planted with conifers but their influence is likely to be negligible until the canopy closes. In the meantime background population data are being gathered. Six years data are now in hand. A further 3 or 4 year's data would give a reasonable picture of year-upon-year variation. Good background data on water quality are being gathered by the Institute of Hydrology. It seems likely that I.F.E. will get a small contract from Welsh Office to study effects of afforestation/deforestation on stream water temperatures at nearby sites.

4. Completion and publication

Data from all of these studies are now being processed as they are collected. Production of papers for publication could, therefore, rapidly follow the completion of field studies. The Bollihope and channel work could, therefore, be ready for publication during the period 1991-1993. If three years continuation funding were provided for the Afon Cwm study, then the work could be p epared for publication and full documentation be placed in I.F.E. library soon after the end of fieldwork.

I FUTURE PROPOSALS

A more detailed statement, with indications of timing, will be given to MAFF by Mr. A P Scott in the near future. The present account is simply a brief listing. It is based on the assumption of continued funding from 1 April 1990 to 31 March 1993.

1. Continuation, either as part of the main contract, or as a separate entity, of the fieldwork at Afon Cwm for three further years. This is an ideal opportunity to gain good base-line data accompanied by water quality information. The value of this work will be further enhanced by an expected Welsh Office input to study water temperatures in the general vicinity.

2. Completion of long-term field studies on trout at Cow Green by the autumn of 1990 and, subsequently, processing and publication of the results.

3. Continuation and development, as appropriate, of opportunist studies on young salmon, in conjunction with Mr. A. P. Scott of MAFF. Writing-up results.

4. Production of "practical summary accounts".

(a) Quantitative definition of the habitat requirements of salmon and trout, including practical application for use by fishery managers, forestry managers and farm managers. Possible publication as an Atlantic Salmon Trust "Blue Book".

(b) Practical guide to methods in studying stream water temperatures and a set of tables to aid simple estimation/calculation, from temperatures, of incubation times, growth rates, ration sizes and similar dependant variables. Possible publication as an F.B.A. Scientific Publication or Occasional Publication. Some MAFF sponsorship of publication costs would probably be needed to make this proposal viable.

RELEVANCE

There are a number of sites in various parts of the U.K. where population density of 0 group salmonids appears to sub-optimal in some or all years. In such places it seems unlikely that numbers are controlled by density dependant factors and some form of abiotic regulation seems probable either because the habitat is naturally severe, or because man has intervened in a damaging manner.

Any attempt to enhance salmonid stocks, either by supplementary stocking or by habitat improvements, will need to concentrate upon these sub-optimal populations. Understanding of the mechanisms operating in such populations and of the point(s) in the life cycle at which there are problems is of fundamental importance to the development of a rational enhancement programme. Most of the studies included in the present contract are relevant to these problems.

Most population studies on young stages of U.K. salmonids have concentrated upon the relationship between population density and mortality and have assumed that losses from a given area all represent mortality. This seems an unrealistic approach. Some dispersal would be expected. Collection of information on the amount and extent of dispersal which occurs and of the factors by which it is influenced is a central part of some aspects of the present contract.

REFERENCES (ADDITIONAL TO THOSE IN APPENDICES 1 & 2).

Crisp, D.T. (1981). A desk study of the relationship between temperature and hatching time for the eggs of five species of salmonid fishes. Freshwater Biology 11, 361-368.

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Humpesch, U.H. (1985) Inter and intra-specific variation in hatching success and embryonic development of five species of salmonids and Thymallus thymallus. Archives für Hydrobiologie 104, 129-144.

Jensen, J.O.T. & Alderdice, D.F. (1983) Changes in mechanical shock sensitivity of coho salmon (Oncorhychus kisutch) eggs during incubation. Aquaculture 32, 303-312.

Jungwirth, M. & Winkler, H. (1984) The temperature dependance of embryonic development of grayling (Thymallus thymallus), Danube salmon (Hucho hucho), arctic char (Salvelinus alpinus) and brown trout (Salmo trutta fario). Aquaculture 38, 315-327.

Ottaway, E.M. (1981) How to obtain artificial brown trout (Salmo trutta L.) eggs. Fishery Management 12, 37-38.

Ottaway, E.M & Clarke, A. (1981) A preliminary investigation into the vulnerability of young trout (Salmo trutta L.) and Atlantic salmon (S. salar L.) to downstream displacement by high water velocities. Journal of Fish Biology 19, 135-145.

Ottaway, E.M. & Forrest, D.R. (1983) The influence of water velocity on the downstream movement of alevins and fry of brown trout, Salmo trutta L.. Journal of Fish Biology 23, 221-227.

APPENDIX 1 PUBLICATIONS AND REPORTS

1. Published

Crisp, D.T. (1988a) Thermal "resetting" of streams by reservoir releases, with special reference to effects on salmonid fishes. In: Craig, J.F. & Kemper, J.B. (Eds.) Regulated streams: Advances in Ecology. Plenum, New York. 163-182.

*Crisp, D.T. (1988b) Water temperature data from streams and rivers in north-east England. F.B.A. Occasional Publication 26, 1-60.

Crisp, D.T. (1988c) Prediction, from temperature, of eyeing, hatching and "swim-up" times for salmonid embryos. Freshwater Biology 19, 41-48.

Crisp, D.T. (1989a) Some impacts of human activities on trout, Salmo trutta, populations. Freshwater Biology 21, 21-33.

Crisp, D.T. (1989b) Comparison of the physical properties of real and artificial salmon eggs and of their performance when drifting in an experimental stream channel. Hydrobiologia 178, 143-153.

Crisp, D.T. (1989c) Use of artificial eggs in studies of washout depth and drift distance for salmonid eggs. Hydrobiologia 178, 155-163.

Crisp, D.T & Carling., P.A. (1989) Observations on siting, dimensions, and structure of salmonid redds. Journal of Fish Biology 34, 119-134.

2. "in press"

Crisp, D.T. (in press a) Some effects of mechanical shock at varying stages of development upon the survival and hatching time of British salmonid eggs. Hydrobiologia

*Crisp, D.T. (in press b) Simplified methods of estimating daily mean stream water temperature. Freshwater Biology 23.

*Crisp, D.T (in press c) Water temperature in a stream gravel bed and implications for salmonid incubation. Freshwater Biology 23.

REPORTS

Crisp, D.T (1988) Dispersal of salmon (Salmo salar L.) fry from the point of stocking - experiment in Bollihope Burn, Co. Durham, during 1988. Report to MAFF, Northumbrian Water Authority and NERC 1-7.

Crisp, D.T (1989) The effects of a sand layer upon swim-up success in U.K. salmonids. Report to MAFF, Northumbrian Water and NERC 1-16.

* Originally funded by another customer but relevant to the present contract.

APPENDIX 2 PAPERS SUBMITTED OR CLOSE TO SUBMISSION

1. Crisp, D.T., Mann, R.H.K., Cubby, P.R. & Robson, S. Effects of impoundment upon trout (Salmo trutta L.) populations in the basin of Cow Green Reservoir.
2. Crisp, D. T. & Mann, R.H.K. Effects of impoundment on populations of bullhead (Cottus gobio L.) and minnow (Phoxinus phoxinus (L.)) in the basin of Cow Green Reservoir.
3. Crisp, D.T. & Hurley, M.A. Stream channel experiments on downstream movement of recently emerged trout (Salmo trutta L.) and salmon (S. salar L.) - I Effects of four different water velocity treatments upon dispersal rate.
4. Crisp, D.T & Hurley, M.A. Stream channel experiments on downstream movement of recently emerged trout (Salmo trutta L.) and salmon (S. salar L.) - II Effects of constant and changing velocities and of day and night upon dispersal rate.
5. Crisp, D.T. Stream channel experiments on downstream movement of recently emerged trout (Salmo trutta L.) and salmon (S. salar L.) - III Effects of developmental stage and day and night upon dispersal rate.

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