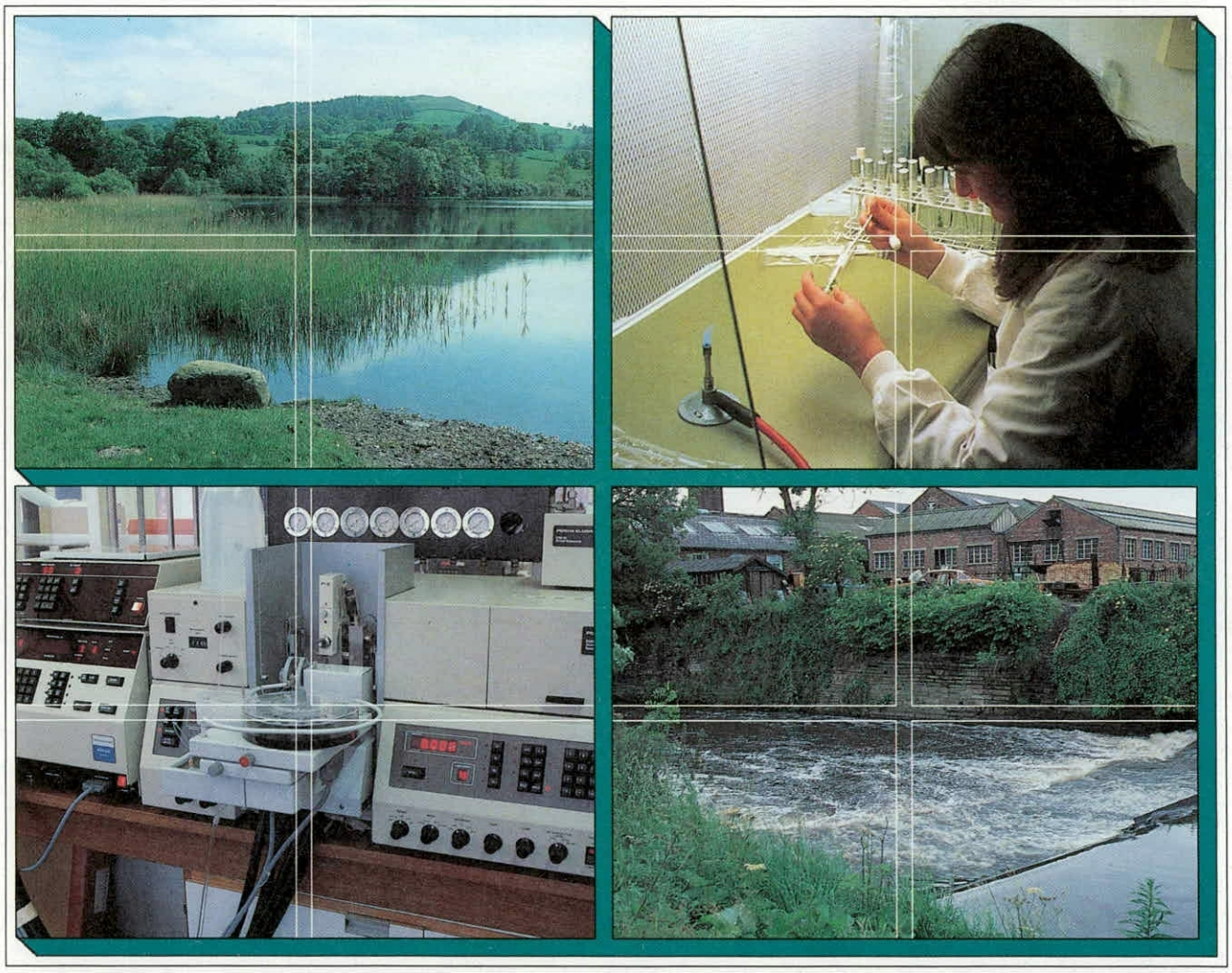
Institute of Freshwater Ecology

Institute of Freshwater Ecology

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

D T Crisp March 1991



Natural Environment Research Council

INSTITUTE OF FRESHWATER ECOLOGY
Teesdale Laboratory, c/o Northumbrian Water,
Lartington Treatment Works, Lartington,
Barnard Castle, Co Durham, DL12 9DW

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 1991

D T Crisp

Project Leader: D T Crisp
Report Date: March 1991
Report To: Ministry of Agriculture, Fisheries and Food
IFE Report Ref: LL/T11050e5/2
TFS Project No: T11050e5

The Institute of Freshwater Ecology is part of the Terrestrial and Freshwater Sciences Directorate of the Natural Environment Research Council.

CONTENTS

SUMMARY

1. The general aims during the period under review have been:

   (a) to continue and/or complete various long-term field studies and to carry out various short-term experiments, all concerned with the ecology of young salmonids and relevant to the management of rivers.

   (b) to write up some of this work as scientific papers.

   (c) to produce first drafts of two documents of a practical nature (see 10 below).

2. Between 1 April 1986 and 31 March 1991 this contract was responsible for the publication of 11 papers. A further four are "in press" and two "practical summary accounts" are in first typescript.

3. One paper brings together information from our own studies and from the literature. It defines, as quantitatively as possible, the habitat requirements of trout. It then considers the impact of various human activities upon the aquatic environment and consequent effects upon trout populations.

4. Data on fish populations in Cow Green reservoir during a period of 10 years following impoundment have been published. One paper describes changes in trout growth, numbers, fecundity and production following impoundment. It also relates angling catches to recruitment. Another paper describes the changes in populations of bullhead and minnow.

5. Information has been gathered on the siting and structure of redds (spawning sites) of salmonids. Significant, positive relationships have been shown between the length of the female fish and the dimensions of the redds, water velocity and depth and egg burial depth.

6. Studies, using real and artificial eggs, have shown that salmonid eggs may be almost completely washed out at 5 cm depth by relatively small spates and that severe spates

disturb eggs to at least 15 cm. Displaced eggs probably drift, on average, for some tens of metres, making numerous contacts with the substratum before settling. Their vulnerability to death from mechanical shock varies according to stage of development. Sub-lethal mechanical stock may also modify the rate of embryonic development.

7. Studies have been made on effects of water velocity on downstream dispersal rates of young trout and salmon in experimental channels and of dispersal distances of young salmon in a natural stream. The channel experiments showed that young trout had low dispersal rates at intermediate velocity (c. 25 cm s^{-1} at 0.6 depth), rather higher rates at c. 7.5 cm s^{-1} and increasing rates at c. 40 cm s^{-1} and c. 70 cm s^{-1}. Young salmon had a high rate of dispersal at low velocity (7.5 cm s^{-1}). Both species dispersed more rapidly by day than by night and showed increased rates during changes in velocity. In stream experiments young salmon dispersed at least 50 cm upstream from the point of stocking. Downstream dispersal occurred over distances of at least 450 m in 1988 but only for about 200 m during the dry summers of 1989 and 1990.

8. Experiments on the relative value of stocking with fed and unfed 0 group salmon have been performed, using Grassholme experimental channels. These studies are complementary to MAFF "in house" work. They show that, ten weeks after feeding begins, salmon planted as five weeks fed fry have about twice the field population density of salmon planted as unfed fry. However, the hatchery fed fry attain a rather smaller weight at the end of ten weeks than do those 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.

10. During the period April 1990 to March 1991 much time was spent in the drafting of two documents described as "Practical Summary Accounts". One of these is a guide for foresters, farmers and other users/managers of land and water. It describes the habitat needs of salmonids in freshwater and the manner in which man can destroy, preserve or enhance the habitat. The other is a guide to the recording of water temperatures and a compendium of "ready reckoners" for assessing the effect of temperature upon a number of biological processes in freshwater, with particular reference to salmonid fishes.

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. Progress from 1 April 1986 to 31 March 1990 was the subject of a summary report to MAFF. Further funding for the period 1 April 1990 to 31 March 1991 was then provided by MAFF and a brief progress report was provided during March 1991.

The present report attempts to up-date the report of 31 March 1990 and refers to the following four types of activity:

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

(ii) Continuation and, where appropriate, completion 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/SOAF "in house" researches.

(iv) Preparation of two "popular accounts" which seek to bring aspects of the work to a wider audience within a practical context.

During the total period of funding eleven papers have been published, another four are "in press" and four reports have been produced. All of these are relevant to the present contract and most arise directly from it or its predecessor. Much of the present report is a brief summary of the contents of these papers and reports.

In addition there is a brief mention of on-going aspects of the research and of those sub-projects which have recently been completed but not yet written-up.

Finally there are notes on possible activities for future support.

II BACKGROUND

Salmon and trout deposit their eggs in the autumn or winter in gravel beds in rivers or streams. The female 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 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 development.
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 substantially 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 were the subject of 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 also listed in Appendix 1. 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 UK. 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, 1987, 1988b).

3. Stream water temperatures:

A compendium of water temperature data for a variety of streams and rivers in N E England (Crisp, 1988a) and an analysis of simplified methods of estimating daily mean stream water temperatures (Crisp, 1990b), 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. (eg Crisp, 1989a).

The prediction, from temperature, of hatching time for the grayling (Thymallus thymallus) and for the main UK salmonid species was facilitated by several publications (Crisp, 1981;

Jungwirth & Winkler, 1984; Humpesch, 1985). Further analysis of published information (Crisp, 1988b) gave the ability to predict times of median eyeing and median "swim-up" (ie emergence from the gravel). These two stages mark 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, 1990c).

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 SW Wales and NE 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 gaining 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 to 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 (eg 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 real eggs was not tested. Comparisons of size, 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, (1990a). 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 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 press". General conclusions are:

(a) Trout show a large 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}) 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 (eg 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 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 accepted for publication (Crisp et al., 1990; Crisp & Mann, in press).

These are the only detailed accounts of the long-term (5-10 years) effects of a new UK reservoir upon fish populations. The results should be useful in the future management of trout fisheries within reservoirs.

IV LONG-TERM STUDIES COMPLETED BUT NOT YET WRITTEN UP

(a) Trout populations in four marked reaches of streams at Cow Green. Thrice yearly census work has been done in four marked stream reaches since the late 1960s. Data collection ceased at the end of 1990 and preliminary analysis of the results is completed. The data show evidence of an inverse effect of population density upon growth rate of first year trout. There is also evidence of population cycles.

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

Two streams were furnished with traps for monitoring downstream movements of 0 group trout. All were 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. The study was completed at the end of 1990, when ten data points were available for each stream. The data are currently being analysed prior to writing-up.

(c) Both of these sub-projects 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.

V SHORT-TERM STUDIES ON THE PRACTICALITIES OF STOCKING WITH O 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 at least 450 m. Similar experiments in 1989 and 1990 gave similar results, except that downstream dispersal occurred only over a distance of 100-200 m. This probably reflected very dry conditions during 1989 and 1990. In all three 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 of MAFF and SOAF in the practicalities of salmon enhancement by planting fry. The Bollihope experiments parallel and complement similar studies being made by SOAF, 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 may be desirable to repeat the Bollihope experiment in one other year, to gain more insight into year-upon-year variations in dispersal distance. The channel experiments, or developments of them, could usefully be continued in future years.

VI 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. Seven years' data are now in hand. A further 3 years' 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. IFE has a small contract from Welsh Office to study effects of afforestation/deforestation on stream water temperatures at this and other nearby sites.

Data from the studies outlined in sections V and VI 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 1991-94. If three years continuation were provided for the Afon Cwm study, then the work could be prepared for publication and full documentation be placed in IFE library soon after the end of fieldwork.

VII "PRACTICAL SUMMARY ACCOUNTS"

(a) "The environmental requirements of salmon and trout in freshwater" is an expansion and extension of Crisp, 1989a. It attempts to show, quantitatively as far as possible, the manner in which man's activities can affect salmonids during their freshwater phase. It also attempts to give guidelines for good practice. It is intended for use by farmers, foresters and other users and managers of land and water. This document is now in first typescript. It follows the format of the "Blue Books" produced by the Atlantic Salmon Trust and it is hoped that, after suitable revision, it will be published as part of that series.

(b) "Measurement of stream water temperature and biological applications (including tables for easy estimation of rates of some biological processes, relative to temperature)".

This follows the format of the FBA Scientific Publications. It consists of two main parts:

(i) A general guide to the methodology of recording stream/river water temperatures.

(ii) A set of Tables for easy computation from temperature of such things as the embryonic development of salmonids, the food requirements of trout and the maximum swimming speeds of fishes. Appendices have worked examples.

This document is intended for use by scientists, including those who lack elaborate computing facilities or who do not feel "at home" with complex mathematical equations. It is now in first typescript. There is now a need for thorough revision and to seek a suitable vehicle for publication.

VIII FUTURE PROPOSALS

This is simply a general indication of intent should MAFF funding be continued for the period 1 April 1991 to 31 March 1994.

1. Continuation, either as part of the main contract, or as a separate entity of the fieldwork at Afon Cwm for three further years followed by full documentation. This is an ideal opportunity to gather sound base-line data accompanied by good information on water quality and quantity (being collected by the Institute of Hydrology). The value of this work is further enhanced by a Welsh Officer input to study water temperatures.
2. Processing and preparation for publication of the results of the long-term field studies on O group trout populations and their dispersal at Cow Green.
3. Continuation and development, as appropriate, of opportunistic studies on young salmon and stocking strategies, in conjunction with Mr A P Scott of MAFF. Joint writing-up of past studies.
4. Production of "practical summary accounts". As promised in April 1990, first drafts of these two documents have been produced by 31 March 1991. Further work is now needed in polishing, revision and final preparation for publication.

IX RELEVANCE

There are a number of sites in the UK where population density of O group salmonids appears to be 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 attempts 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 UK 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 APPENDIX 1)

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.

Crisp, D.T., Mann, R.H.K. & Cubby, P.R. (1983) Effects of regulation of the River Tees upon fish populations below Cow Green reservoir. Journal of Applied Ecology 20, 371-386.

Crisp, D.T., Mann, R.H.K. & Cubby, P.R. (1984) Effects of impoundment on fish populations in afferent streams at Cow Green Reservoir. Journal of Applied Ecology 21, 739-756.

Crisp, D.T., Mann, R.H.K. & McCormack, J.C. (1974) The populations of fish at Cow Green, upper Teesdale, before impoundment. Journal of Applied Ecology 11, 969-996.

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 dependence 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 I PUBLICATIONS AND REPORTS

1. Papers published.

Crisp, D.T. (1987) 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. (1988a) Water temperature data from streams and rivers in north-east England. FBA Occasional Paper 26, 1-60.

Crisp, D.T. (1988b) 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.

Crisp, D.T. (1990a) Some effects of mechanical shock at varying stages of development upon the survival and hatching time of British salmonid eggs.

*Crisp, D.T. (1990b) Simplified methods of estimating daily mean stream water temperature. Freshwater Biology 23, 457-462.

*Crisp, D.T. (1990c) Water temperature in a stream gravel bed and implications for salmonid incubation. Freshwater Biology 23, 601-612.

Crisp, D.T., Mann, R.H.K., Cubby, P.R. & Robson, S. (1990) Effects of impoundment upon trout (Salmo trutta L.) populations in the basin of Cow Green Reservoir. Journal of Applied Ecology 27, 1020-1041.

2. Reports.

Crisp, D.T. (1988) Dispersal of salmon (Salmo salar L.) 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 UK salmonids. Report to MAFF, Northumbrian Water and NERC. 1-16.

Crisp, D.T. (1990) The ecology of young stages of salmonid fish and implications for practical river management. Final report for the period 1 April 1986 to 31 March 1990. Report to MAFF 1-18.

3. Papers "in press".

Crisp, D.T. & Mann, R.H.K. (1991, in press) Effects of impoundment on populations of bullhead (Cottius gobio L.) and minnow (Phoxinus phoxinus (L.)) in the basin of Cow Green Reservoir. Journal of Fish Biology.

Crisp, D.T. & Hurley, M.A. (in press 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. Journal of Fish Biology.

Crisp, D.T. & Hurley, M.A. (in press b) 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. Journal of Fish Biology.

Crisp, D.T. (in press) 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. Journal of Fish Biology.

4. First typescripts now available.

Crisp, D.T. The environmental requirements of salmon and trout in freshwater. 1-33.

Crisp, D.T. Measurement of stream water temperature and biological applications (including tables for easy estimation of rates of some biological processes relative to temperature. 1-39 (Also 54 Tables).

* Papers relevant to this contract but mainly or entirely funded by other contracts.


Natural
Environment
Research
Council