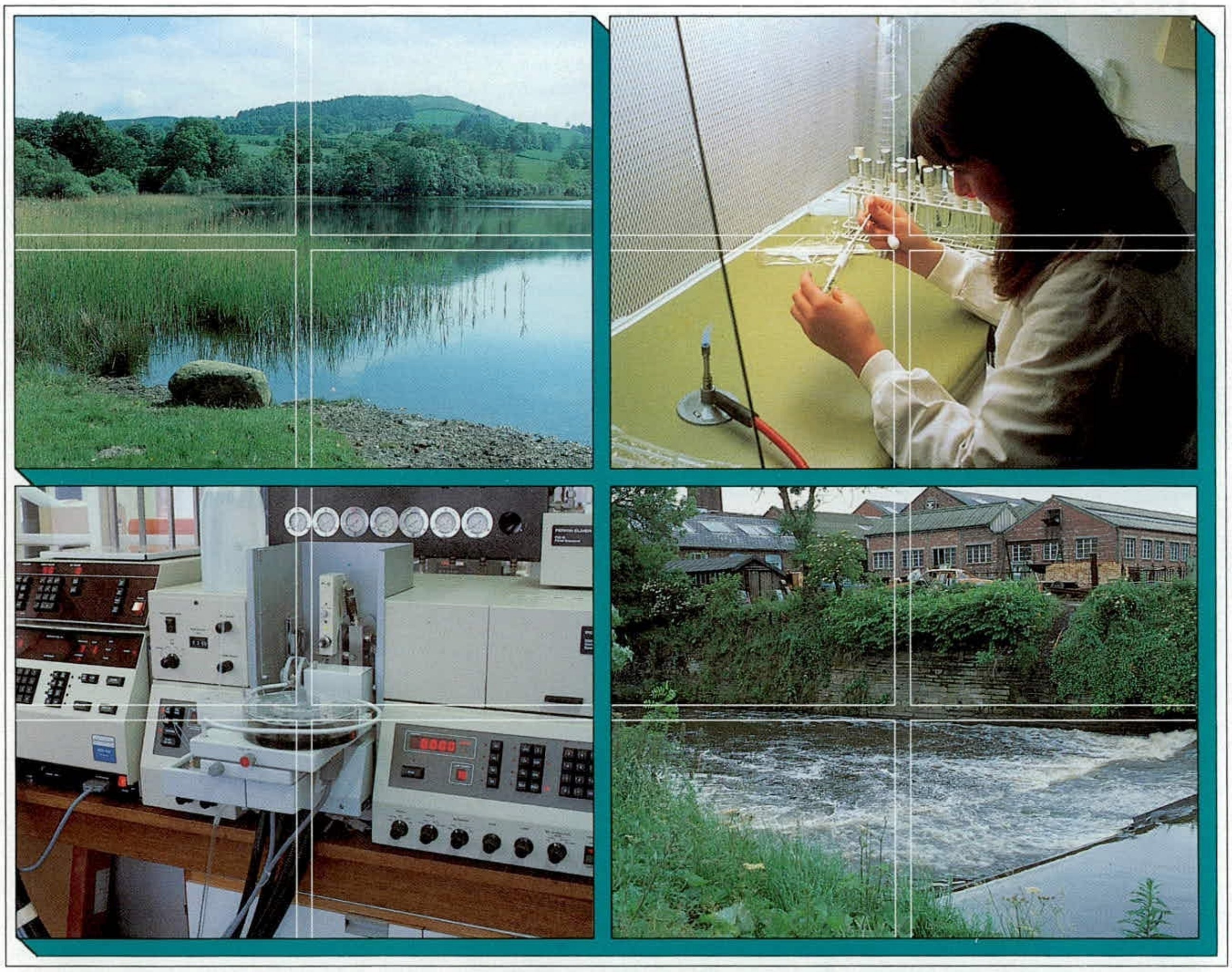
Institute of Freshwater Ecology

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

Final report for the period 1 April 1991 to 31 March 1994

D.T. Crisp, BSc, PhD, DSc, FIBiol

March 1994



Natural Environment Research Council

CONFIDENTIALITY STATEMENT

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Project Leader:	D.T. Crisp
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CONTENTS

SUMMARY

1. The main aims during the period under review were:

   (a) to complete various long-term and short-term field studies and experiments on the ecology of young salmonids. These studies are directly relevant to river management practices.

   (b) To write up this work as scientific papers and other publications.

2. Between April 1986 and March 1994, this contract, or its predecessors, have been responsible for nineteen publications, one paper "in press", four papers "in preparation" (drafts available) and six customer reports.

3. During the present contract a guide to the measurement of water temperature, with aids for the application of biological temperature models, has been published as an "F.B.A. Occasional Publication". In addition, a popular account of the habitat requirements of salmonids in fresh water has been published in "Freshwater Forum".

4. Work on the effects of Cow Green Reservoir (upper Teesdale) upon fish populations has now been written up and most of it has been published. The final output is a paper "in press" which compares the reproductive investment of female trout which disperse downstream to the reservoir and of those females which remain resident in the afferent streams.

5. Long-term (20 years +) studies on the brown trout in afferent streams at Cow Green in the northern Pennines and a 10 year investigation of juvenile brown trout and sea trout were completed in 1990 and 1993, respectively. The Cow Green results are published and those from the Afon Cwm are in the form of a draft paper. These studies have yielded valuable information on the relationships between the initial population density of swim-up fry, subsequent growth and losses by mortality and downstream dispersal.

This has important applications in the management and possible enhancement of trout populations in sub-optimal habitats

6. Experimental "point stocking" with unfed salmon fry gave survival to September of 15-20%. Of these survivors, 20-25% were found up to 50 m upstream of the release point and others were found up to 500 m downstream, but most were found close to the release point. These observations support the conclusions from several published studies that the movement from the release point is limited and that, where movement does occur, downstream movements are more extensive than upstream movements. The present work also showed substantial spatial variation in growth to September and this could be related to population density towards the end of the growth period. "Scatter stocked" salmon fry showed much less spatial variation in either population density or growth. The data suggest, but do not prove, that survival to September from scatter stocking was higher (27% c.f.15-20%) than from point stocking. Other experiments examined the results, at ten weeks after swim-up, of releasing young salmon as unfed fry and after retention and feeding for six weeks in a hatchery. The former treatment gave higher mean growth rate to ten weeks of age than did the latter, but resulted in only half the population density. For trout there was a similar effect upon growth but no demonstrable effect on population density. These two pieces of work relate to MAFF "In House" research programmes and are of value in devising the most cost-effective tactics for stocking young salmon or trout.

7. An outline research programme for future studies in the Afon Cwm is presented.

1. INTRODUCTION

The studies covered by this contract all conform to the general theme of the title "The ecology of young stages of salmonid fish and the implications for practical river management", but comprise several sub-projects, some of which began before 1991. Progress to the start of the present contract term has been summarized in Crisp (1991c).

The present report refers to four main activities:

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

(ii) Completion and writing up of long-term experiments and observations which are relevant to practical river management.

(iii) Completion and writing up of short-term experiments which complement various MAFF/SOAFD "In House" research programmes.

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

During the total period of MAFF funding (April 1986 to March 1994) nineteen papers have been published, one is "in press", four are "in preparation" (drafts available), and six reports have been produced. Much of the present report is a brief summary of the contents of papers published or prepared since 1 April 1991 (see Appendix 1).

The report is concluded by an outline of possible research activities for future support.

2. BACKGROUND

The present report covers the final three years of a programme which has been funded by MAFF over several contract terms since 1986. Much of the previous report (Crisp, 1991c), deals with aspects of the ecology of the intra-gravel stages of salmonids. In contrast, the present report is largely concerned with the ecology of the free-swimming stages.

Salmonid eggs are laid in nests in the riverbed gravel which are termed "redds". Each egg hatches to give an "alevin" (Plate 1). The alevin remains within the gravel and is sustained by its yolk sac. When the supply of yolk is almost exhausted, the alevin emerges from the gravel ("swim-up"), swallows a bubble of air to fill its swim bladder and attain neutral buoyancy and begins to take external foods. This free-swimming stage is called a "fry". Soon after emergence from the gravel, each individual seeks to establish and defend a territory. It is then termed a "parr". Any fish which is unable to acquire a territory is likely to be displaced downstream.

In the UK there have been two published studies on population regulation in benign habitats of young salmon, *Salmo salar* L. (Buck & Hay, 1984; Gardiner & Shackley, 1991) and one on sea trout *S. trutta* L. (Elliott, 1984). Normally in such places an excess of eggs is deposited and this gives rise to an excess of fry. Territorial behaviour during the early weeks of free-swimming life leads to density-dependent mortality which brings the population density down to approximate the "carrying capacity" of the habitat (BC on Figure 1). Two important points must be noted, however:

(a) In such populations there is year by year fluctuation about line BC by a factor of c.2.

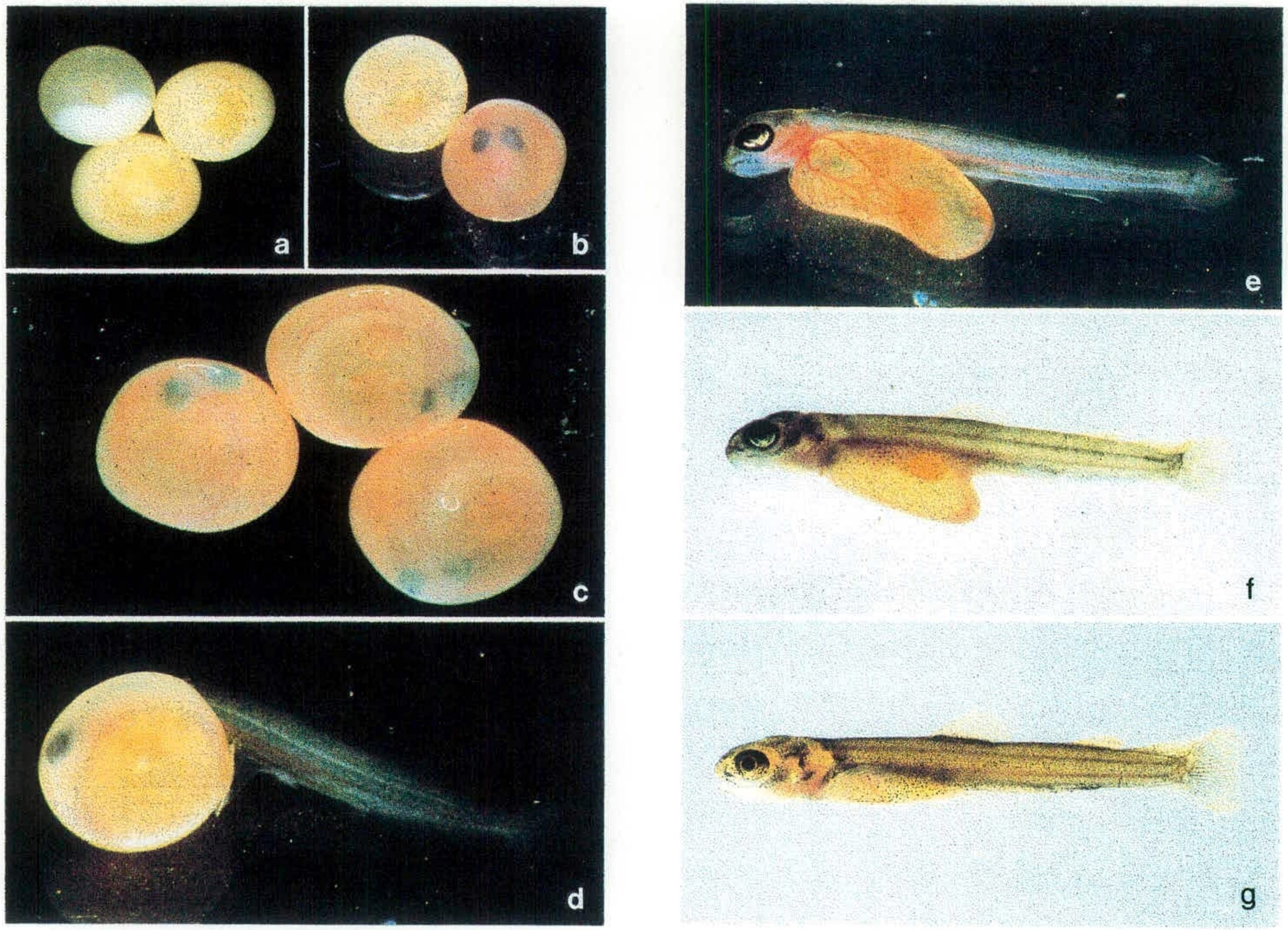

Fig. 1 Young stages of salmonid fish. a) Dead eggs. b) Living eggs; one is at an early stage of development and the other is "eyed". c) Eyed eggs with embryos clearly visible. d) An alevin in the process of hatching from the egg. e) A recently hatched alevin with a large yolk sac. f) An older alevin with a partly absorbed yolk sac. g) A fry shortly after emerging from the gravel. The diameter of the eggs is c. 5 mm. The lengths of the alevins and fry are 20 to 25 mm.

(b) Even in populations in benign habitats, the data point may occasionally fall on the ascending limb (AB) of the stock-recrutiment curve (see Fig.1). The reasons for this are not fully understood and the incidence of such years appears to be approximately 12%.

There have been few studies in the UK (or elsewhere) of the population dynamics of young salmonids in places where, as a result of severe climate or habitat degradation, survival to emergence from the gravel is low, there is proportionate mortality after swim-up and the data appear to fall on the rising limb (AB) of the recruitment curve. The available evidence suggests that amongst sea trout populations in England and Wales, populations (or sub-populations) of this type may be an important component of the total in 10-15% of river systems (Elliott, 1992). Enhancement or restoration work is more likely to be cost-effective in such populations than in those regulated by density-dependent mechanisms as the latter are likely to be already at "carrying capacity". The present project contains two long-term field studies on trout populations regulated by density-independent mechanisms. One of them examines in detail the effects of initial fry population density on downstream dispersal, mortality and growth.

In addition, short-term studies, using experimental stream channels and experimental stocking in a natural stream have shed light upon the relationships between initial density and dispersal, survival and growth of young salmon. They also provided information relevant to the practicalities of stocking young salmon in natural streams.

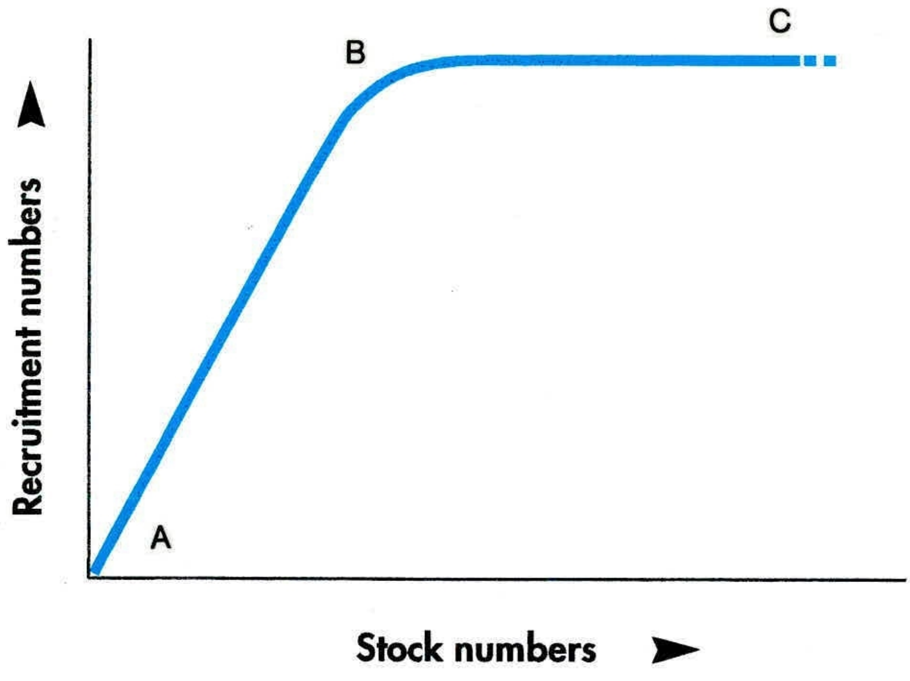

Fig. 2 A typical stock-recruitment curve. "Stock" may be the number of spawners or the number of eggs laid. "Recruitment" is the number of resultant progeny at some defined stage in the life cycle. See text for explanation of A, B and C.
In the present report "stock" is the number of spawners or the number of eggs and "recruitment" is the number of survivors at some later stage.

3. PUBLICATIONS & REPORTS

3.1. General considerations

All relevant papers, published or in press, are listed in Appendix 1. A further three papers are in preparation and have reached the stage at which typescripts are available. These are also listed in Appendix 1. The following summary of this material is arranged according to subject rather than to chronology.

3.2. Stream water temperatures

A general guide to the methodology of measuring stream temperatures has now been published (Crisp, 1992). This includes ready-reckoners for estimating, from temperature, the growth and rations of trout and the rates of incubation of the eggs of salmonid fishes and of dace.

Water temperature data from the Afon Cwm (see 7, below) and from afforested and clear- felled catchments in mid-Wales have been collected throughout the contract term (at no extra cost to the project) using loggers originally provided by the Welsh Office. A summary of the Afon Cwm data is included in Crisp & Beaumont (in prep.).

3.3. Habitat requirements of salmonids in fresh water.

A popular account of the habitat requirements of salmonids has been published in "Freshwater Forum" (Crisp, 1993c). The original version also contained practical guidelines for the managers, developers and users of watercourses and adjacent land. The editor did not consider this appropriate for "Freshwater Forum" and it is held by the author in typescript form. This publication, plus additional information on grayling (Crisp, 1991a), was used as the basis of an unpublished paper presented to the EIFAC Working Group on River Restoration (Lyon, France, 1993) entitled "Habitat Requirements of Fish - salmonids". A summary of this paper is likely to appear in the EIFAC handbook. A longer review on both salmonids and coarse fish is being drafted (in conjunction with Mr R.H.K.Mann) and is expected to be submitted to a review journal in late 1994 or early 1995.

3.4. Alevin emergence

A short paper (Crisp, 1993a) refers to the ability of alevins/fry of the two commonest UK salmonid species to emerge from spawning gravel which has been covered by a layer of sand.

3.5. Free-swimming stages and water velocity

The results of a series of studies in experimental channels have now been published (Crisp & Hurley, 1991a, b; Crisp, 1991b). A summary was given by Crisp (1991c) and will not be repeated here.

3.6. Effects of a river-regulating reservoir

An account of the effects of Cow Green Reservoir upon the biology of bullhead (*Cottus gobio* L.) and minnow (*Phoxinus phoxinus* (L.)) has been published (Crisp & Mann, 1991).

Information from previous publications (Crisp *et al.*, 1974; Crisp *et al.*, 1990) was used to compare the reproductive investment of female trout which dispersed downstream to Cow Green Reservoir and those which remained resident in afferent streams. The results (Crisp, 1994) showed that a cohort of 2000 female stream residents would produce more eggs during its lifetime, by a factor of c.3, than would a similar cohort of reservoir females. Despite this, most females disperse into the reservoir. This leads to the hypothesis that the smaller lifetime egg output of the reservoir cohort is more than offset by survival advantages which accrue to their progeny as a result of the much larger size of the female parent. Such advantages are likely to have two aspects. First, the eggs of larger females are buried more deeply and, therefore, are less prone to washout by spates. Second, larger females lay larger eggs which, in turn, give rise to larger alevins with a higher probability of survival.

3.7. Long term studies on trout populations in streams

i) In the Pennines

A routine thrice-yearly electrofishing census of a marked reach in each of four small streams began in the late 1960s and was completed in 1990. In addition, two streams were furnished with traps to capture downstream moving 0-group trout and, over a ten year period which ended in 1990, were stocked at a different known population density each year with unfed trout fry of local provenance. This work yielded information on the effect of initial stocking density upon mortality, downstream dispersal and growth.

The results have been published (Crisp, 1993b) and lead to the following general conclusions and hypotheses:

(a) For emergence densities of 0 to 10 fry m^{-2}, survival (including the results of loss by downstream dispersal) to August was proportionate (c.10%), regardless of initial density. Survival from August to early October was also proportionate (30 to 65%). However, for densities in August of the first year of 0 to 0.9 parr m^{-2} (i.e. emergence densities of c.0 to c.9 fry m^{-2}) the estimated mean instantaneous loss rate from August of the first year to age 40 to 65 months showed a positive curvilinear relationship to August population density. During this later part of the lifetime the loss rate was, therefore, density- dependent.

(b) For emergence densities of 0 to 10 fry m^{-2} the estimated instantaneous growth rate day^{-1} of 0-group trout from swim-up to August and from swim-up to October was inversely related to the natural logarithm of August population density and this was most apparent for August densities of < 0.15 parr m^{-2} (= initial densities of c.1.5 fry m^{-2}).

(c) Although survival was proportionate (c.10%) from swim-up to August, for starting densities of 0 to 10 fry m^{-2}, the percentages of total loss attributable to mortality and to downstream dispersal varied with starting density in a complex manner (Figure 2). At starting densities of 4 to 5 fry m^{-2} dispersal was negligible. As initial density rose above 4 to 5 fry m^{-2} and towards 10 fry m^{-2}, the percentage of loss attributable to dispersal rose towards 30%. As initial densities fell from 4 to 1.4 fry m^{-2}, the percentage rose to c.20%. Below a starting density of 1.4 fry m^{-2} the percentage decreased.

(d) These observations are consistent with the following hypotheses: At initial densities below c.4 fry m^{-2}, the parr have few encounters with one another, do not show marked territoriality and forage widely. This has two consequences. First, the increased activity and wandering leads to a predominantly downstream shift of population and to relatively high downstream dispersal. Second, foraging, especially at densities below c.1.5 fry m^{-2},

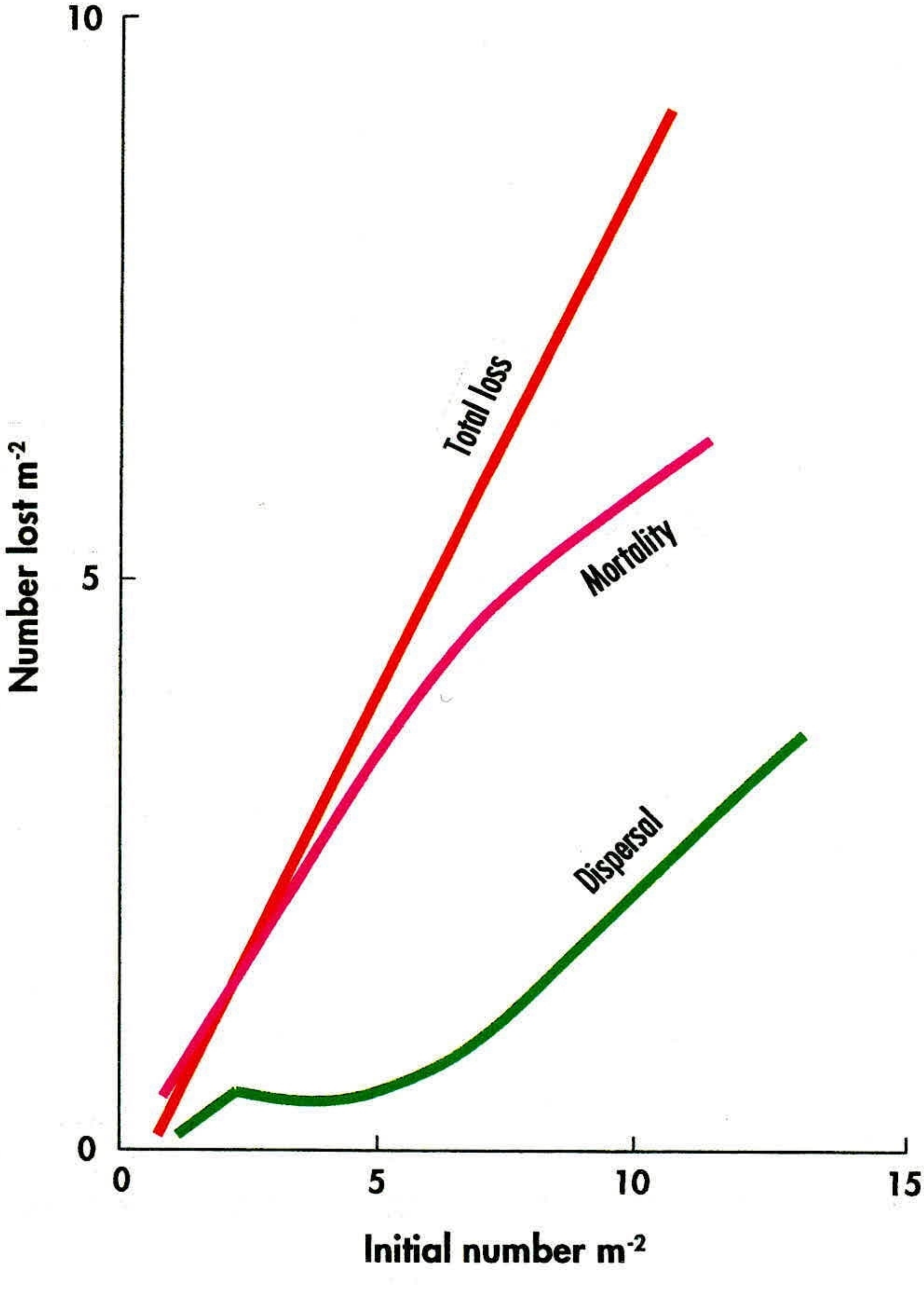

Fig. 3 Relationship between number of swim-up trout fry and total number lost by August of the first year. The distribution of "loss" between mortality and downstream dispersal is also shown.

is highly effective and gives high growth rates. At some higher density (probably between 3 and 5 fry m^{-2}) the fish become increasingly territorial and become limited, in terms of food supply, to that produced in or drifting through their territories. Growth rates then vary little with population density, unless or until, density becomes so high as to produce a significant shortage of food or some other essential resource. There is no evidence of this latter effect in the streams studied, at least up to population densities of 10 swim-up fry m^{-2}. As initial population density increases, downstream dispersal occurs earlier so that the dispersed fish are healthy and able to establish themselves elsewhere.

The downstream dispersal of viable fry/parr is likely to be an important mechanism for maximising use of available habitat in populations where redds are widely scattered and/or where survival of the intragravel stages is low. In contrast, in streams where redds are close together and intragravel survival is high, displaced fry are unlikely to find territories and are, therefore, likely to perish.

It is not possible to be certain about the mechanism(s) by which, in most years, the population density of swim-up fry is held below the level at which density-dependent mortality comes into play. However, the most likely mechanism is by washout of intragravel stages during winter spates. This is consistent with the fact that the number of eggs laid m^2 $year^{-1}$ is comparable to the values observed in salmon populations regulated by density- dependent mortality (Buck & Hay, 1984; Gardiner & Shackley, 1991). Field experiments, using artificial eggs, have shown that such washout is likely to be appreciable in the northern Pennines (Crisp,1989).

(ii) Mid-Wales

A ten year study of the trout population of the Afon Cwm, a small tributary of the Afon Dyfi, mid-Wales, was completed in 1993. A draft paper (Crisp & Beaumont, in prep.), is available. The study was based on a thrice-yearly electrofishing census of a series of representative stations in the Afon Cwm. As in the Pennine streams, the mean population density of 0-group trout in late July was low and very variable from year to year (0.05 to 0.6 m^{-2}). Loss between July and September was proportionate at about 40 to 50% and, therefore, not density-dependent. However, from 5 to 53 months of age the mean instantaneous loss rate varied from 0.04 to 0.10 $month^{-1}$, was positively correlated with cohort number at 3 months of age and was, therefore, density-dependent.

Although some resident trout in the Afon Cwm become sexually mature, it is clear that the stream is also an important spawning and nursery area for sea trout. Extra MAFF funding in November 1993 (Crisp & Beaumont, 1994) facilitated an examination of spawners in the Afon Cwm. This showed that most of the sexually mature resident trout were males and that most of the egg input in most years is likely to be from sea trout. The generally low and very variable numbers of 0-group trout indicate the occurrence of some form of abiotic limitation of recruitment before the stage at which density-dependent mortality might be expected to act. This could result from washout of intragravel stages, as suggested for the Pennine streams, because Harris (unpublished thesis, Liverpool University, 1970) estimated that 0 to 58% (mean 27%) of sea trout redds in some tributaries of the Afon Dyfi were washed out. However, the Afon Cwm is less "flashy" (Base Flow Index =0.26) than the Pennine streams (Base Flow Indices often as low as 0.15 to 0.17) and a different flow-related mechanism seems more likely. Just downstream of the study area, the Afon Cwm flows over a metering structure and a weir associated with a water abstraction point. The ability of adult sea trout to pass upstream over these structures appears to be related to stream discharge and in years of low autumn/winter flow few, if any, may enter the study area. Variations in spawner access resulting from variations in stream flow may, therefore, be the reason for the observed fluctuations in recruitment.

The studies in the Afon Cwm give support to some of the conclusions from the longer and more intensive studies in the Pennine streams. They also provide a baseline for future studies on effects of afforestation upon salmonid populations and a starting point for possible future studies on sea trout population dynamics (see below).

Studies on sea trout population dynamics in marginal habitats is of particular importance at the present time in view of concerns about the well-being of UK sea trout.

3.8. Short term studies on salmon stocking (with some information on trout)

An opportunist study of the effects of "point stocking" and "scatter stocking" was made in Bollihope Burn, Co. Durham, between 1988 and 1993. (Crisp, in prep. a). Stocking took place in spring/early summer using 0-group salmon, usually unfed, from Kielder Hatchery. The distribution, numbers and weight of the survivors to September were examined by electrofishing census.

When fish were scatter stocked as evenly as possible over c.500 m of stream length, the estimated survival to September was c.27% and there was relatively little spatial variation in population density or fish weight in September.

Some fish from point stocking moved up to 50 m upstream or 500 m downstream of the stocking point but the majority stayed close to the point of release. This led to considerable spatial variation in population density and in fish weight in September. The inverse relationship between September population density and fish weight could be modelled by semi-logarithmic curves. Approximately 20 to 25% of the September survivors were found upstream of the release point. Survival to September was c.19% and c.14% in 1988 and 1989, respectively.

The Lartington, Co. Durham, hatchery and four experimental channels at Grassholme Reservoir were used in 1988 and 1989 to study the effects, upon survival and growth to 10 weeks after emergence, of either planting unfed salmon fry or of planting them after retention and feeding in a hatchery for six weeks. A similar study was made on trout in 1993 (Crisp, in prep. b). Salmon and trout released into experimental channels as unfed fry at densities of c.19 fish m^2 showed a rapid reduction in numbers, chiefly by downstream dispersal, accompanied by negligible growth. After this initial reduction in numbers, there was a reduced rate of loss and rapid growth. Salmon and trout retained in the hatchery at high density (80 to 200 fish m^{-2}) and fed for six weeks on proprietary food showed slow, but measurable, growth. After release into the channels, these fish adjusted their numbers and showed an increased growth rate. At the end of the ten week period, salmon introduced as fed parr had approximately twice the population density of salmon introduced as unfed fry. No similar difference in population density could be shown for trout. For both species, the fish introduced as fed parr had a significantly lower mean weight after ten weeks than had the fish introduced as unfed fry.

4. RELEVANCE AND APPLICATIONS

4.1. General comments

This section considers most of the items mentioned in the previous section and seeks to indicate their relevance to the interests of MAFF and their application in practical river management.

4.2. Stream water temperatures

The measurement of stream water temperature is an important adjunct to any study of salmonid population dynamics because fish are poikilothermic and, therefore, temperature plays an important part in controlling various behaviour patterns and in regulating the rate of vital processes. The relationships between temperature and processes such as growth are often curvilinear. The present project has contributed to the effective measurement of water temperatures through the publication of a general guide to methods (Crisp, 1992). This publication also contains ready reckoners to facilitate the practical application of several published biological temperature models.

4.3. Habitat requirements of salmonids in fresh water

The popular account of the habitat requirements of salmonids (Crisp, 1993c.) was intended to serve an educational purpose in giving those who use and manage rivers and adjacent land a clearer view of the needs of the fish and the manner in which their biology can be upset by the actions of man.

River restoration work can be successfully achieved in an empirical or intuitive manner. The success of this type of approach depends upon the local knowledge and the subjective judgement of those doing the work. Without quantitative criteria as a basis, however, it is difficult to predict the likelihood of success or the validity of the methods when applied at other sites. The preparation of a critical review of quantitative information on the habitat needs of salmonids in fresh water is an attempt to bring together the information needed to make informed decisions in this sphere. It will also help to indicate any important gaps in our knowledge.

4.4. Effects of a river-regulating reservoir

The work at Cow Green Reservoir is the only long-term (20 years +) quantitative "case study" in the UK of the effects of a new impoundment upon fish populations within the reservoir, in the afferent streams and in the river immediately downstream. The recent analysis of the reproductive strategies of stream and reservoir female trout illustrates the very plastic nature of trout behaviour and performance (Crisp, 1994).

4.5. Long term studies on trout populations in streams

The long term studies in north Pennine streams (Crisp, 1993b) give a quantitative description of the influence of numbers of swim-up fry upon subsequent growth and upon the probability of loss by mortality or downstream dispersal. It is also clear that, in these Pennine streams, density-dependent population regulation in the early months of free-swimming life is irrelevant, at least up to swim-up fry densities of 10 m^{-2}. It is also clear that in these streams, the conventional stock/recruitment curve (Figure 1) is not an appropriate model because the estimated annual egg output should be sufficient to give high fry densities (values on part BC of the curve), provided that there was adequate survival of the intragravel stages. It follows, therefore, that there must be heavy mortality during the intragravel stages and that the stock/recruitment curve is only applicable to this data set if the "x" axis refers to numbers of swim-up fry rather than to numbers of spawners or of eggs.

In contrast, the conventional stock/recruitment curve may be applicable to the Afon Cwm population (Crisp & Beaumont, in prep.) because it is likely that in this stream, the number of spawners (hence of eggs) may be limited by access problems and this may lead to a low mean population density of eggs in most years. In the 1993 spawning season the input of eggs by resident females in the Afon Cwm was c.0.5 m^{-2} and a minimum estimate of the input by sea trout was 2.0 m^{-2}. The total of 2.5 eggs m^{-2} falls well short of the values indicated in the literature as being the lowest starting densities at which density-dependent mortality has been observed to operate in the early months of life. Values for UK streams are: > 12 eggs m^{-2} (Buck & Hay, 1984 - salmon), > 20 eggs m^{-2} (Elliott, 1984 - trout), > 7 swim-up fry m^{-2} (Gardiner & Shackley, 1991 - salmon) and > 10 swim-up fry m^{-2} (Crisp, 1993b - trout). However, it is important to note that the input of eggs by sea trout in 1993 is only a minimum estimate. The mean population density of parr in the Afon Cwm in late July varied between years from 0.05 to 0.6 m^{-2}. If survival from swim-up to late July is taken as 10% (Crisp, 1993b), then these values represent swim-up fry densities of c.0.5 to 6.0 m^{-2}, which are low relative to the published density values necessary to initiate density-dependent mortality amongst fry/early parr. These considerations suggest, but do not prove, that the trout population of the Afon Cwm gives a data point, in most years, which falls on part AB of the curve and that this arises because the access of adult sea trout is limited by obstructions and that the severity of the effect of those obstructions varies from year to year in response to hydrological conditions.

Populations such as those observed in the northern Pennines could best be enhanced by hatchery rearing of eggs obtained from wild trout attempting to spawn in those streams. A much higher survival to swim-up could be obtained in a hatchery or some other incubation facility and the resultant fry could then be planted in their native stream. This traditional philosophy in justification of hatchery operations is difficult to defend when applied to streams whose salmonids show density-dependent mortality early in free-swimming life. Laying aside genetic considerations, it can be justified, in biological terms in these Pennine streams and in similar streams elsewhere. Economic justification of such measures in places of this type might, however, be more difficult.

Should subsequent investigation confirm that spawner access is the main limitation on recruitment in the Afon Cwm, then the obvious solution in this and similar streams would be the removal or modification of the obstructions or the provision of fish passes.

These two studies, taken together, give two reasons for the exercise of caution in managing wild salmonid populations :

(a) The Pennine streams and the Afon Cwm showed similar "symptoms" in that the population density of 0-group trout in mid-summer was low and very variable from year to year in both places. Nevertheless, it is probable that the causes and best remedies differ between these two areas.

(b) In both places there is evidence of density-dependent loss operating over a period of time which begins during the latter half of the first year of life and extends over several years thereafter. The full implications of this are not clear but are worthy of further investigation.

4.6. Short term studies on stocking

(a) "Point stocking" versus "Scatter stocking"

Though some salmon fry from point stocking may disperse several hundred metres downstream and several tens of metres upstream, most remain close to the point of release. This gives rise to considerable spatial variation in population density and growth between the time of release and September. In terms of natural redds, this implies that, when survival within the gravel is low or when redds are widely spaced (i.e tens or hundreds of metres apart), there will be appreciable dispersal of fry to fill any suitable nursery ground which is initially vacant. In terms of artificial stocking, the results imply that, to obtain maximum use of available space, point stocking should occur at points no more than 500 m apart, preferably less. Such stocking, in suitable habitat, is likely to give 10 to 20% survival to September. In contrast, scatter stocking gives a more even dispersal and growth of the stocked fish and the present data suggest that survival to September will be higher (c.27 % ?) than from point stocking.

(b) Stocking with "fed" and " unfed" fry/parr

The results suggest that stocking with six weeks fed trout parr gives a smaller mean size at ten weeks of age and no significant increase in population density close to the point of stocking, relative to stocking with unfed fry. This indicates that there is little return for the added costs of retention in the hatchery

The results clearly show that stocking with fed salmon parr gives higher population densities close to the point of stocking but a smaller mean size than can be attained by stocking with unfed fry, though a large proportion dispersed downstream and their fate in a natural stream would not be known. There is a trade-off between population density and size amongst salmon and this must be taken into account, along with the relative costs of the two approaches. Larger parr tend to give larger smolts.

(c) General points

Studies on coho salmon (*Oncorhynchus kisutch* (Walbaum)) have shown that faster freshwater growth gives larger smolts within a year class and these have a greater likelihood of returning from the sea as "jacks" (grilse) rather than as fish of two or more sea winters (Bilton *et al.*, 1982; Mundie *et al.*, 1990.). Should this also be true of Atlantic salmon, then the uneven distribution given by point stocking may give a smaller proportion of grilse amongst the returning fish. Some form of trade-off of quantity against quality might then be necessary in deciding upon the best stocking strategy in any given stream.

Application of a similar argument suggests the possibility that stocking with fed salmon fry, giving a higher density and smaller mean size, might also give larger average size amongst returning adults.

These experiments, particularly those in the experimental channels, give clear-cut conclusions on some issues but are open to the criticism that they were conducted in contrived circumstances and, hence, the results are difficult to apply in the "real world" of natural streams. It is important to note, however, that these experiments were run in conjunction with field observations in natural streams (MAFF "In House" research). When the results of these field studies are available, it will be possible to bring together the results of these two complementary approaches. Information available to date indicates good agreement between to two.

5. FUTURE PROPOSALS

We already have ten years' data on trout populations in the Afon Cwm. This gives a basis for future studies on the effects of afforestation at the time of canopy closure in ten to fifteen years' time. The data have been written up for publication but, in addition, the raw data are being fully documented and archived for possible future use.

In the meantime, the Afon Cwm offers the opportunity for detailed studies on the relationships between trout spawning stock, egg input, recruitment and hydrological fluctuations. The value of the data from such a study would be greatly enhanced by the fact that the NERC Institute of Hydrology and the NERC Institute of Terrestrial Ecology are using this stream in a long term study of water quantity and quality and this give a good opportunity to link the trout population dynamics to these physical and chemical variables. The funding of an appropriate five year programme is currently being considered by MAFF.

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REFERENCES (ADDITIONAL TO THOSE IN APPENDIX 1)

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APPENDIX 1. PAPERS AND REPORTS PUBLISHED OR DRAFTED DURING THE PRESENT CONTRACT TERM.

1. Papers published

Crisp, D.T. (1991a). *Habitat requirements of the grayling. *Journal of the Grayling Society*. Autumn 1991 15-19.

Crisp, D.T. (1991b). Stream channel experiments on downstream movement of recently emerged trout, *Salmo trutta* L., and salmon, *S. salar* L., III.-Effects of developmental stage & day and night upon dispersal. *Journal of Fish Biology*. 39, 371-381.

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2. Reports

Crisp, D.T. & Beaumont, W.R.C. (1994). Observations on the sizes and sex ratios of spawning trout in the Afon Cwm, mid Wales, in November 1993. *I.F.E.Report to MAFF*. 1-8.

3. In preparation for submission to a journal, typescript available.

Crisp, D.T. (in prep. a). Dispersal and growth of 0-group salmon (*Salmo salar* L.) from "point stocking" and "scatter stocking".

Crisp, D.T. (in prep. b). Experimental studies on the relative effectiveness of planting streams with unfed and six weeks fed salmon (*Salmo salar* L.) fry/parr, with some comparable information on trout (*S.trutta* L.).

Crisp, D.T. & Beaumont, W.R.C. (in prep.). The trout (*Salmo trutta* L.) population of the Afon Cwm, a small tributary of the Afon Dyfi, mid-Wales.

*An item written by the Editor of the Journal of the Grayling Society, based on notes and illustrations from a lecture by D.T.Crisp to a meeting of the Society in Wharfedale during 1991.

NOTE; Reprints of all published papers are held by C.S.G. Fisheries.

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