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FRESHWATER BIOLOGICAL ASSOCIATION

TEESDALE UNIT

Report to:	Northumbrian Water Authority Department of the Environment Natural Environment Research Council
Date:	2nd September, 1981.

Effects of flow regime on the young stages of Salmonid fishes - Conclusions based on results for 1977-1981.

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PROJECT 73

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CONTENTS

SUMMARY

1. The report briefly describes the life cycle of British salmonid fishes and indicates the main ways in which this life cycle is influenced by discharge and related effects.

2. Some highlights of the research results for 1977 - 1981 are briefly stated and proposals for future research are listed.

3. Some practical implications of the results are discussed.

INTRODUCTION

The detailed results of this project are available to customers as a series of offprints of primary publications, photocopies of the manuscripts of papers "in preparation" or "in press" and unpublished reports to customers. These documents form Appendix 2.

The interim version of the terminal report was a lengthy review of the material in Appendix 2, and of information from other sources, followed by attempts to answer detailed specific questions raised by customers towards the end of the contract period. The present version is briefer and less detailed. It views the project within the context of the questions asked in the original contract (see Appendix 1) and concentrates largely upon the scientific highlights of the work. It is important to note, however, that in a project of this type the exact form and emphasis of the basic questions will change as the project develops.

Relatively little work of a detailed, critical and quantitative nature has been done on this topic. Most of what has been done deals with species of _Oncorhynohus_ (Pacific salmon) which differ in some aspects of their life histories and behaviour from the two British species of the genus _Salmo_. Moreover, comparatively little work has been done on the composition and structure of the beds of upland streams in Britain. Such studies as have been made suggest that the British upland streams are more complex (in terms of bed material and hydraulics) than the salmonid rivers of North America. For these reasons a substantial amount of effort has been expended during the original contract period on literature survey (Milner _et al_. in press), the development of field and experimental methodology (Ottaway, 1981; Carling & Reader, 1981; Carling, in press a; Carling 1981 b) and in obtaining relatively basic background data (Carling & Reader, in press; Carling, 1981 a; Ottaway, 1979; Ottaway & Forrest, 1981).

Most of the work has, so far,, been done in Teesdale, chiefly on brown trout. Its most direct relevance is to the River Tees and other rivers (e.g. the Tyne) with similar geology and climate. However, the general aim of the project is the acquisition of knowledge of general principles which, with some input of local detail, will he of wider application. During the first contract period the work has begun to take in sea trout and salmon. We would expect this trend, together with the inclusion of a wider variety of stream/river types in other parts of Britain, to continue in the future. Such developments would accord with both the customer needs and the expenditure of Science Vote funds within the project.

The questions originally asked by the customers are given in Appendix 1, expecially in section 1.4. The priorities are defined in section 1.5.1. where three of the initial approaches were identified as being of high priority and likely to yield conclusions and publishable results by September 1981. These three are:

1. Field surveys to examine redd site selection relative to current speed, gravel size and stability and intragravel water movement (Appendix 1, section 1.4.2.1).
2. Studies on the subsequent fate of selected redds and the eggs therein (Appendix 1, section 1.4.2.2).
3. Intensive study of populations of young trout in selected streams, relative to flow regime (Appendix 1, section 1.4.3.1).

In practice, the studies on redd selection and the fate of redds and eggs have not proceeded to the point of firm conclusion but they have covered a broader field than was originally envisaged and a lot of effort has been expended in developing a preliminary model to relate *egg* burial depth to female fish size, with the ultimate aim of bringing together the physical and biological sides of the project towards prediction.

The studies of young free-swimming stages began as a widespread electro-fishing survey, but it soon became clear that this alone was not sufficient, chiefly because the effects of flow were confounded by population density effects. This led to the development of the Grassholme channels to facilitate an experimental approach under semi-field conditions in which population density and water velocity could be controlled. Additional work has been done within the areas outlined in sections 1.4.2.3, 1.4.2.4, 1.4.3.2, 1.4.3.3 and 1.4.3.4 of the contract (Appendix 1). During the initial contract period the approach has, therefore, been on a broad front and so, inevitably, at a rather superficial level. We have achieved rather fewer sound data and firm conclusions than had been hoped and this, in part, reflects the reliance of much of the work upon natural fluctuations in discharge and the seasonal nature of many of the topics being examined. Nevertheless, sound foundations for the future have been laid in the development of methodology, the acquisition of vital background data and in assessing the problems most worthy of detailed follow-up.

THE LIFE-CYCLE OP BRITISH SALMONID FISHES

There is a large and scattered literature on this subject and on relevant physical factors. Much of this is summarised by Milner & Scullion (1980) and Milner et al.(in press). There is much less information on the physical and biological effects of impoundment, regulation and transfer schemes in the U.K. (Armitage, 1980). A general review of effects of impoundment is given by Brooker (in press) and more detailed accounts of effects of regulation are given by Edwards & Crisp (in press) for the Rivers Tees and Wye and by Edwards (in press) for the Wye.

Both the British salmonid species; the Atlantic salmon (Salmo salar L.) and the trout (Salmo trutta L.) in its resident (brown trout) and migratory (sea trout) forms; spawn in gravel beds. The female cuts a hole in the gravel. Eggs are deposited in the hole. The female then moves slightly upstream and cuts another hole and the spoil from this excavation covers the eggs laid in the first hole. This process is repeated until all the eggs have been deposited as a series of egg pockets within the redd. The *egg* develops within the gravel and hatches to give an alevin. The alevin lives within the gravel feeding upon the food reserves in its yolk sac. When the yolk sac is nearly depleted the alevin emerges from the gravel, fills its swim-bladder to achieve neutral buoyancy, becomes a free-swimming fry and begins to feed. The rate of development from oviposition to this "swim-up" stage is governed chiefly by water temperature.

Within a few weeks of emergence from the gravel the fry become aggressive and take up territories. As a consequence of this behaviour, supernumerary fry die or are dispersed, chiefly in a downstream direction and, in populations at high densities, the rate of mortality and/or dispersal is density-dependant.

When they reach an age of 1-3 years (the age varies with species and from river to river and is dependent, in part at least, on the growth rate of the fish) the young salmon and sea trout become smolts and migrate to sea. Brown trout remain within the river system throughout life.

When they reach sexual maturity the adults of both salmon and sea trout return to freshwater. The adults of both migratory and resident salmonids usually seek to spawn in their natal river system, often in the individual tributary of their origin. The spawning migration is influenced by discharge and the homing mechanism has been shown to operate through the sense of smell. There appears to be some discrimination in the choice of sites for redd construction and this appears to be linked to the pattern of flow through the gravel, though there is some conflict of evidence about the exact nature of the cues required to initiate spawning.

POSSIBLE EFFECTS OF DISCHARGE AND RELATED FACTORS UPON THE LIFE-CYCLE.

This topic is covered in some detail by Milner _et al_.(in press). The major likely effects of discharge upon the life-cycle are listed briefly below.

1. _Intragravel stages:_
    a. Washout.

High discharges can cause movement of gravel beds and consequent washout of eggs or alevins or damage of these stages by crushing or abrasion. There is some evidence that movement and shaking can kill eggs, especially during the period from a few hours after oviposition to the time when the eyes of the embryo become visible within the egg ("eyeing").

b. Siltation

The flow of water through the gravel is important as a vehicle to carry oxygen to the young stages and waste products away. Deposition of gravel and infilling of the gravel pores by finer materials could influence the rate of oxygen supply. The accumulation of organic silts could act as an oxygen sink and modify oxygen concentration.

c. Exposure

Large recessions of water level during incubation can lead to exposure of redds. The young stages are then vulnerable to drying-out or freezing.

2. Swim-up:

a. Siltation and/or gravel compaction.

Discharge will influence the compaction of the gravel and the rate of infilling of the gravel interstices by finer materials. In fine or compacted gravels there can be substantial mortality through entrapment of alevins (Koski 1966, 1975).

b. Water velocity.

When the alevin emerges from the gravel it has negative buoyancy and must fill its swim-bladder in order to achieve neutral buoyancy and become a free-swimming fry. At this point in its life it might be expected to be vulnerable to downstream displacement by high water velocities.

3. Free-swimming fry:

Some dispersal, chiefly downstream, is a normal feature of the behaviour of salmonid fry. It is probably influenced by population density acting through the territorial behaviour of the fry (Le Cren 1965, 1973). However, territory size is influenced by water velocity (Kalleberg, 1958) and it is, therefore, likely that the coefficients of the relationships between population density and dispersal and mortality will be modified by discharge.

4. Mature fish:

Discharge, acting through wetted area of stream will influence the area of spawning gravel available to fish and, hence, the loss of eggs through the superimposition of redds ("overcutting"). Acting through velocity it will also influence the availability and selection of redd sites.

RESEARCH RESULTS

The research results have been reviewed at some length in the interim version of this report and the present version will be confined to brief statements of some of the main findings.

1. Intragravel stages and emergence from the gravel:

Visual assessment of washout of marked redds in two streams suggested that in Eggleshope Beck 17% of redds (possible maximum of 51%) were washed-out within 63 days of oviposition and in Thorsgill Beck 30%(possible maximum of 58%) were washed out within 38 days of ovoposition. Similarly some 12% of Harris boxes (Harris, 1973) buried at redd sites and secured to metal stakes were washed out (Ottaway, Clarke & Forrest, 1981a; Ottaway & Clarke, 1981b). These results do not permit rigorous analysis or accurate quantification of losses by washout but they do show that it can be a substantial cause of mortality in the intragravel stages. The most promising line for future studies of washout is development and refinement of the simple model relating egg burial depth to the size of the female fish making the redd (Ottaway, Carling, Clarke & Reader, in press). In Teesdale and Weardale a simple regression of burial depth upon fish length can be used, although more data are needed to improve precision. For use at other sites it is likely that a more complex model incorporating such factors as water velocity and gravel composition will he required. If such models can be developed, they will provide a direct link to the physical side of the project (Carling, in press b; Carling & Reader, in press) which is working towards the prediction of gravel movements from discharge data. Preliminary trials using artificial eggs (Ottaway, 1981) strongly suggest that vulnerability to washout is influenced by the depth of burial (Ottaway, Clarke & Forrest, 1981).

Studies on planted eggs (Ottaway & Clarke, 1981) demonstrated substantial variation in survival (excluding washout losses) between streams and sites. Survival to eyeing varied between sites from 84.9 ± 8.8 (S.E.)% to 54.9 ± 11.2% and survival to hatching from 71.3 ± 5.6% to 15.9 ± 3.3%. Survival to swim-up varied between sites from 11.9 ± 7.6% to 0.3 ± 0.3%. Preliminary observations suggest that some of the intragravel mortality may reflect intragravel oxygen concentrations, though more detailed investigation is required to confirm and quantify this. Certainly, the survival rates to hatching are low relative to others reported in the literature. The low survival rate from hatching to swim-up further implies that the effect of flow regime upon the quality of the intragravel environment is important and requires further study.

Observations in Teesdale have shown that loss of intragravel stages through exposure by receding water levels can occur, though this is likely to he a minor cause of mortality in natural streams in most years.

2. "' Swim-up and free-swimming fry:

It is important to examine and, ultimately, to distinguish between, two aspects of the effects of discharge upon young salmonid fry:

i The effects of large discharges in physically displacing the newly-emerged fry from the sites at which they emerged.

ii The more subtle effects of discharge regime in modifying territory size and, hence, rate of density-related mortality and/or dispersal.

Data collected by Ottaway & Clarke (1981a) show that:

(i) The instantaneous rate of downstream movement of young trout and salmon fry was influenced by water velocity in some experiments, but in others there was relatively little movement. This suggests that there may particular stages in early fry life when velocity exerts its main influence.

(ii) In those experiments where large numbers of fish did move, there were differences between trout and salmon. For trout the daily rate was low and variable at mean velocities of less than about $0.25\ m\ s^{-1}$ but at higher velocities the rate was positively correlated with mean velocity. In contrast, salmon fry showed high rates at low velocities and, as velocity increased, the rate was negatively correlated with velocity. There appear, therefore, to be important differences between the two species.

Further experiments on trout (Ottaway & Forrest, in prep.) in which eggs were hatched within four channels with different constant mean velocities (range 0.05 - 0.73 m s^{-1}) showed that the highest rate of downstream displacement occurred shortly after swim-up, the rate of dispersal was positively correlated with mean velocity and at the highest velocity (0.73 m s^{-1}) virtually all of the fish had left the channel within about 25 days of swim-up.

3. Mature fish:

Data from the literature show that brown trout and Atlantic salmon will spawn in a wide variety of water depths (0.15 - 0.61 m) and velocities (0.20 - 0.81 m s^{-1}) and there is some indication that the depth and velocity can be related to fish size (Milner et al., in press). Observations on brown trout, sea trout and salmon in Teesdale and Weardale cover a depth range of 0.03 - 0.215 m and a velocity range of 0.18 - 0.61 m s^{-1} for fish of 17.3 to 77.0 cm length (Ottaway, Carling, Clarke & Reader, in press). Both depth and velocity are positively correlated (P 0.001) with female fish length and both of these factors are, themselves, related to discharge.

There is a general consensus in the literature that salmonids exercise some selection in choice of spawning sites, generally in favour of areas of low silt content and high intragravel flows. However, there is considerable disagreement between authors about the cues which lead to this selection (Milner _et al._, in press). It has also been suggested that the internal structure of the redd and its surface contours influence the flow of water around the eggs, though there is little quantitative supporting evidence. Such site selection is not readily apparent in Teesdale streams and possible explanations are:

(a) The distinction between pools and riffles is not clear-cut in these streams.

(b) The gravels are poorly-sorted.

(c) Spates soon destroy at least the external structure of the redd.

(d) The identification of a pattern of location and structure probably requires a more detailed and statistically rigorous approach than has been possible so far.

4. Physical studies:

The results of the physical studies on gravel composition and structure (Carling, in press b: Carling & Reader, in press) have been summarised in the interim report. As indicated there, this work is breaking new ground within the field of river hydraulics in its attempts to characterise the gravel composition and to obtain means of predicting gravel movements within upland streams and rivers in the U.K. In addition, the importance of this work as an integral part of studies on biological effects such as egg washout, siltation of redds, and the quality of the intragravel environment cannot be overemphasised.

A considerable amount of staff time has "been spent in the collection of vital background information, especially in stream gauging (Carling, 1981 a) and operating thermographs (Ottaway & Forrest, 1981). Ideally ten or more years data are needed for adequate characterisation of stream discharge regimes. Therefore, routine gauging will continue during any extension of the project. Although the temperature regimes of natural and regulated streams were not specifically included in the contract, they are of major importance within that context because the rate of intragravel development of salmonids is closely related to temperature and there is a need to predict this rate in order to estimate the period for which the young stages are present in the gravel and at risk to washout or exposure. Also, engineering operations such as impoundment and transfer are likely to modify temperature regimes (Crisp, 1977). Therefore temperature data have been collected and analysed (Ottaway & Forrest, 1981) and approximate methods for predicting embryonic development from temperature have been developed (Crisp, 1980; Crisp, 1981) and tested (Crisp & Ottaway, 1981).

5. Miscellaneous

In addition to detailed studies in Teesdale and Weardale, some surveys have been made in the Kielder area.

A general survey of fish populations in the N. Tyne and its tributaries, upstream of the Kielder dam site (Ottaway, 1979) provided information for the Northumbrian Water Authority. It gave some indication of the number of salmon fry which the Kielder hatchery would need to produce in order to compensate for loss of spawning and. nursery area as a result of impoundment.

A detailed *survey* of the bathymetry and gravel composition in selected salmon spawning areas downstream of the Kielder dam site (Carling, 1979) showed that quantitative assessments of gravel composition agreed well with qualitative assessments by N.W.A. staff of the relative values of the different spawning riffles. The information on gravel composition and the measurements of river cross-sections have also been of value in assessing the likely washout and exposure impacts of changes in discharge variation in this part of the N. Tyne.

FUTURE PROPOSALS

Proposals for future work are listed below. The reasoning behind these proposals is presented more fully in the interim report. The aspects which we feel should receive the highest priority are marked with an asterisk.

1. Further siltation monitoring in natural streams.
2.* Controlled siltation experiments in channels. Ideally this would require a variable gradient channel. This topic and (l) above are closely interrelated.
3. Continued collection of hydraulic geometry data from natural streams.
4.* Continuation of bedload trapping. This is a rather routine operation, but very few data of this type are available for British upland streams.
5. Collection of hydraulic data from larger rivers such as the Wear, Tyne and Swale. This would facilitate wider application of the results obtained from smaller streams in Teesdale.

6.* Further studies on the structure and dimensions of redds, with special reference to gravel composition and egg burial depth. If possible, the egg burial depth model should be strengthened by the collection of more data from Teesdale/Weardale and extended by the collection of data from a wider variety of river types.

7.* Detailed quantitative studies of the gravel environment, with special reference to oxygen supply rate and embryonic survival.

8. Quantitative field studies on washout, using both real and artificial eggs.

9. Further development of studies on alevin entrapment and siltation.

10. Development of fish trapping techniques so as to assess downstream movements of young salmonids relative to discharge.

11* Further channel experiments, especially on young fry of trout and salmon.

PRACTICAL IMPLICATIONS

1. Introductory Comments

It is important to note that the main aim of the project is to obtain fundamental information and establish principles which are of general application, rather than to deal in detail with *ad hoc* problems at individual sites. For the latter type of application the general principles must be augmented by some information from the site(s) concerned. As the problem of biological impacts of flow regime is extremely complex, the project has not yet produced many firm conclusions, and we would not recommend long-term rule-of-thumb practice to be based on the present findings, unless accompanied by substantial safety margins.

Nevertheless, the results obtained can be used to make "best available estimates" of the likely impacts upon fisheries of given flow regimes in rivers such as the Tees, Wear and Tyne. These estimates will become more precise as the predictive models are improved and the approach will be of more general application as the models are extended to include more river types. Both of these developments are included in the future aims of the project.

The main practical applications of the work to date (in conjunction with information from the literature) are twofold. First, the results can be used to make very general recommendations on the likely hazards and benefits to salmonid fisheries resulting from changes in flow regime. Second, the results can be applied to specific proposals at named sites, provided certain basic background data from those sites are available or can be obtained. This is exemplified by the semi-quantitative estimates of the impacts of certain specified patterns of release from Kielder Water (Interim Report to N.W.A. by Carling & Crisp, 1981).

2. General recommendations

a. Water temperature.

A change of water temperature regime is an inevitable consequence of impoundment and regulation and may also result from some transfer schemes. Comparatively small changes in temperature regime can have disproportionate effects on the embryonic development, food requirements, growth and behaviour of salmonids. Therefore, though temperature effects were not included in the contract, they are an important consideration, especially because they act through rate of embryonic development to determine the period of time during which the intragravel stages and recently-emerged fry are vulnerable to discharge effects.

There is insufficient information on the effects of impoundment and regulation upon downstream water temperatures to allow quantitative prediction of the changes likely to be caused by any particular scheme. The magnitude of the effects at Cow Green is indicated by Crisp (1977) and the temperature changes observed there would delay the swim-up of both trout and salmon fry by several weeks.

There is little information on the likely attenuation of such effects with distance downstream of the release point, though such data as do exist (e.g. Edwards, in press) suggest that temperature equilibrium occurs within a few km of the release point. Temperature effects are, therefore, likely to be of little importance, relative to embryonic development, in those rivers where the major spawning and nursery areas are in unregulated tributaries or in the main river well downstream of the release point. However this would not be true at sites such as Kielder, where some prime salmon spawning areas occur within the critical few km. At such places, if local information on the spawning time of the relevant salmonid species and on the local water temperature regime were available, it would be possible to predict the approximate period during which the intragravel stages were at risk and, hence, to make recommendations on the timing of regulation releases so as to maximise their beneficial and minimise their harmful effects.

b. Washout of intragravel stages.

Our present understanding of bed movement can be used to estimate the water velocities over spawning riffles which are likely to result from various discharges. Given knowledge of the composition of the gravel beds, it is then possible to predict the minimum discharge at which appreciable gravel movements will occur. This can be used, in conjunction with the length-frequency distribution of the spawners and the relationship between fish size and egg burial depth, to predict egg loss through washout. Such predictions require some information gathered on-site, especially on the gravel composition and the length-frequency distribution of the spawners. Clearly, such predictions are very approximate, but their precision might be expected to improve as more data are gathered and the models are refined.

Regulation releases are generally smaller than natural spates and they are, therefore, likely to cause less washout than natural spates. However, the frequency of occurrence of large regulation releases may be greater than that of natural spates and this should be borne in mind.

c. Exposure of intragravel stages and availability of spawning area.

If the composition (species and size) of salmonid spawners is known, the depth of burial of their eggs can be predicted. Moreover, if the spatial distribution of redds and the hydraulic geometry of the river at these sites are known — and these can be obtained relatively easily - then it is possible to estimate the relative areas of potential spawning gravel immersed and exposed above water level at any given discharge value. In conjunction with knowledge of the timing of spawning and of emergence of fry from the gravel, such estimates can he used to recommend the optimum timing and size of releases to ensure*

i. Maximum availability of spawning gravel at spawning time.

ii Minimum loss of intragravel stages as a result of sudden reductions in river level which can lead to exposure of the young stages above water level and thus render them vulnerable to drying-out or freezing.

d. Siltation and Intragravel flow.

These are both influenced by discharge regime. They can influence the survival of intragravel stages. Our studies in both these areas are at an early stage and we are not able to outline a scheme for prediction. However (see pp. 14, 15) more detailed studies of these topics are high on the list of future proposals.

e. Discharge and water velocity and their effects on free-swimming salmonids.

The effects of discharge upon the spawning movements of adult salmonids were specifically excluded from the contract and will not be discussed here.

Salmonids spawn in a wide variety of water depths and velocities (pp. 11, 12) and it is unlikely that the depths and velocities produced during normal regulation or transfer releases will cause problems. Guidelines were indicated by the MAFF/NWC Joint Study Group (1976).

The results of the preliminary channel experiments (Ottaway & Clarke, 1981a; Ottaway & Forrest, in prep.) show clearly that water velocities do influence the rate of downstream dispersal of recently emerged salmonids, though the response appears to differ between species and may occur during only a small portion of the weeks following emergence. Further work on this topic is a high priority for the future (p. 15).

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APPENDIX 1. SCIENTIFIC PORTION OF THE ORIGINAL CONTRACT BETWEEN CENTRAL WATER PLANNING UNIT AND FRESHWATER BIOLOGICAL ASSOCIATION

SCHEDULE 1. Programme of Research on the Effects of Flow Regime on the Recruitment of Salmonid Fish.

1.1 Objectives To determine the effects of different natural and artificial flow regimes on the spawning success and survival of the eggs and young stages of salmonids up to the time of recruitment. Particular emphasis will he laid on identifying guidelines for the operation of the Kielder scheme and similar projects elsewhere.

1.2 Relevant markets and potential applications

1.2.1 Possible effects of water transfers between rivers on the survival of redds and natural recruitment of salmonids has been identified as a research topic of high priority.

1.2.2 Water authorities are required to conserve fish stocks and improve fisheries; the results of this project should assist them to regulate river flows and manipulate water transfers in ways that will minimise possible damage to fish stocks and perhaps enhance natural recruitment.

1.2.3. Specifically, it is intended to obtain information on rates of discharge and rates of change in discharge that will damage salmonid eggs and young for example by disturbance of redds, or silting of redds or removal of young fish.

1.2.4 The results should also contribute to the better management and improvement of fisheries in rivers subject to largely natural fluctuations in discharge.

1.3 Background

1.3.1 Present understanding (based largely on work done outside the U.K., much of it some while ago) suggests that evolutionary selection has led salmonids to spawn in carefully chosen sites. Under favourable conditions in clean rivers the survival of eggs is high and may not limit recruitment. Losses may be caused by such factors as the lack of suitable spawning gravel, and overcrowding of spawners, the movement of redds in high flows or exposure in low flows and the deposition of silt. These factors urgently require re-appraisal and investigation in the U.K., and especially important are the possible deleterious and beneficial effects of river regulation and water transfer. An understanding of the manner of operation of factors affecting egg survival should lead to the manipulation of water-resource operations in a way optimal to fish egg survival.

1.3.2 There is evidence (some of it from FBA studies at Cow Green) that the post-hatching survival of young salmonids is affected by flow regime. In rivers such as the Tees, it appears that much of the spawning and early rearing of trout takes place in the tributaries; the main river may be less suitable. Research is needed on the factors that render one stream more suitable than another as a nursery and how the year-to-year variations in recruitment in any one stream operate, with particular reference to the role of flow regime and related factors. An understanding of the effects of river regulation and water transfer on juvenile survival should enable the actual manipulation of flows to he done in a manner which will cause the least detriment and even, possibly, benefit to fish stocks.

1.3.3 The current development of water resources in the Rivers Tyne, Wear and Tees render these systems admirable sites for observational and experimental work on these problems. The FBA studies on fish populations in the Cow Green basin (which have been in progress for nearly ten years) are an added reason for carrying out these studies in that area. Especially valuable is the wide range of tributaries available with different natural and artificial flow regimes and the possibility of experimental releases in some of these.

1.4 Approaches

1.4.1 The detailed approach to the project will be the responsibility of the staff appointed to carry it out, and only an outline of suggested work can be given at this stage.

1.4.2 The study on eggs and redds would involve:

1.4.2.1 Field surveys to identify the factors that lead fish of different sizes (and species) to spawn in particular sites. These surveys would note where redds were made and examine such criteria as current-speed, gravel size and stability, intra-substratum water movement, and compare these with other sites avoided by spawning fish. A series of spawning streams exhibiting a range of such factors would be surveyed.

1.4.2.2 The subsequent fate of selected redds and the eggs therein would he determined.

1.4.2.3 These observations, while initially confined to brown trout should later be extended to sea trout and salmon.

1.4.2.4 Some of the conclusions derived from these observations might then be tested a) by observing the survival of eggs planted in artificial redds, b) by artificial releases of water and/or sediment and observations of the effects of these (e.g. in the Rivers Balder or Lune); and c) by observations on rivers elsewhere.

1.4.3 The study on the population dynamics of post-larval young stages would be carried out in parallel to the study on eggs. It would also be based on, and carried out in close correlation with, the existing FBA studies on streams in the Cow Green basin.

1.4.3.1 It would census (by electrofishing) the young trout populations in a range of tributary streams and then select a small number for more intensive study. These would be chosen to exhibit a range of flow regimes and related factors, and would include one with regulated flow.

1.4.3.2 The population-dynamics in the streams of this series would then be studied in detail by regular censusing and e.g. with the aid of traps. Attempts would then be made to relate survival and emigration to such factors as flow regime and initial population density.

1.4.3.3 Although the main work would probably he done on brown trout in the Tees system it might be possible to carry out some observations on salmon and sea-trout and on other rivers such as the Tyne, Rede and Wear.

1.4.3.4 Attempts would also be made (e.g. by marking) to assess the contribution of the streams studied to the overall natural recruitment to the trout population in the main River Tees, though this may prove to be impracticable in other than very approximate terms.

1.5 Points to be taken into account

1.5.1 The programmme will be planned to last four years and priority will be given to achieving conclusions and publishable results on the initial approaches (1.4.2.1, 1.4.2.2, 1.4.3.1) by September 1981. The possibility of obtaining results on the other approaches by that time will depend upon success with the earlier aspects and of the weather conditions actually experienced and especially the flow regimes during the periods of active field work.

1.5.2 There will be close liaison with the Northumbrian Water Authority. Their practical assistance ins

(a) permission to carry out research on fish in their area,

(b) sites for intensive work,

(c) experimental releases,

(d) access to data on discharges and other background data on the rivers, fish management operations and fishery catches etc.,

(e) advice,

(f) if possible, a site and/or building in Teesdale as a temporary laboratory,

is almost essential for the successful operation of the research programme.

1.5.3 There will he close co-ordination between this programme, and the fish project at Cow Green already in progress (FBA Project No. 18).

1.5.4 There will he liaison with work on salmonid populations in relation to flow going on elsewhere e.g., at the UWIST Field Station on the River Wye and at DAFS, Pitlochry. It might he desirable for the leader of the programme or the fish biologist working on eggs to visit British Columbia to see at first-hand the work there on artificial spawning channels.

APPENDIX 2.

CONTENTS

1. Offprints:

Crisp, D.T. & Robson, S. (1979). Some effects of discharge upon the transport of animals and peat in a north Pennine headstream. J. Appl. Ecol. 16, 721-736.

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

Carling, P.A. & Header, N.A.(1981). A freeze-sampling technique suitable for coarse river bed-material. Sedimentary Geology 29, 233-239.

Crisp, D.T. (1981). A desk study of the relationship between temperature and incubation time for a selection of salmonid fishes. Freshwat. Biol. 11, 361-368.

Milner, N.J.: Soullion, J.; Carling, P.A. & Crisp, D.T. (in press). A review of the effects of discharge on sediment dynamics and consequent effects on invertebrates and salmonids in upland rivers. Advances in Applied Biology 6, 153-220.

2. Photocopies of manuscripts:

Edwards, R.W. & Crisp, D.T. (in press). Ecological implications of river regulation in the U.K. In: Hey, R.D., Bathurst, J.C. & Thorne, C.J. (Eds.). Gravel Rivers. Fluvial processes, engineering and management. Wiley.

Carling, P.A. (in press a). Freeze-sampling coarse river gravels. Brit. Geomorph. Res. Group Technical Bulletin, Shorter Technical Methods. 29,

Carling, P.A. (in press b). Threshold of coarse sediment transport in broad and narrow natural streams. Earth Surface Processes and Landforms.

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

Ottaway, E.M.; Carling, P.A.; Clarke, A.; & Reader, N.A.(in press). Observations on the structure of brown trout (*Salmo trutta* Linnaeus) redds. J. Fish Biol.

Ottaway, E.M. & Clarke, A. (1981a). 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. J. Fish Biol. 19, 135-145.

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3. Unpublished Reports to Customers:

Carling, P.A. (1979). Survey of physical characteristics of salmon spawning riffles in the River North Tyne.

Ottaway, E.M. (1979). Report on two electrofishing surveys carried out between July 10-25 1978 and July 9-12 1979 in the vicinity of the proposed Kielder Water.

Crisp, D.T. (1980). Prediction of eyeing, hatching and swim-up times for brown trout and Atlantic salmon from water temperatures.

Carling, P.A. (1981a). Summary of gauging data for F.B.A. gauging stations in Teesdale, U.K. in relation to the prediction of scour.

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Ottaway, E.M.; Clarke, A. & Forrest, D.R. (1981a). Some observations on washout of brown trout (*Salmo trutta* L.) eggs in Teesdale streams.

Ottaway, E.M. & Clarke, A. (1981b). Survival of intragravel stages of brown trout (*Salmo trutta* L.) in Teesdale.

Carling, P.A. (1981b). The Grassholme Channels.

Ottaway, E.M.; Clarke, A. & Forrest, I.E. (1981b). Information collected in Teesdale concerning free-swimming stages of brown trout (*Salmo trutta* L.).

Ottaway, E.M. & Forrest, D.R. (1981). The temperature of four Pennine streams.