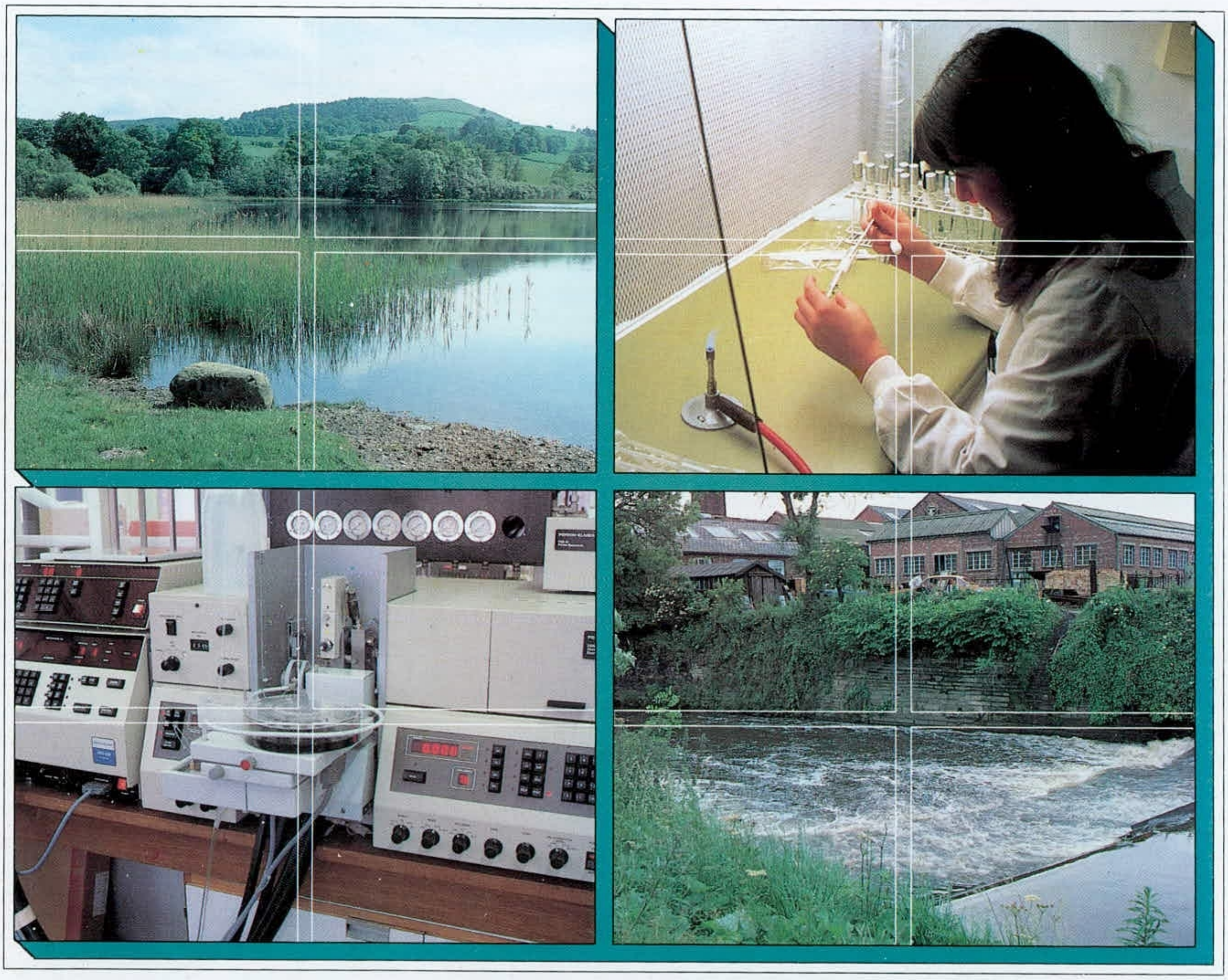
JULY
1997

Institute [of] Freshwater Ecology

REVIEW OF FLOW NEEDS FOR FISH AND FISHERIES

Progress Report



Natural Environment Research Council

INTELLECTUAL PROPERTY RIGHTS

CONFIDENTIALITY STATEMENT

Institute of
Freshwater
Ecology

River Laboratory
East Stoke, Wareham
Dorset BH20 6BB
United Kingdom

Telephone +44 (0)1929 462314
Facsimile +44 (0)1929 462180
Email

REVIEW OF FLOW NEEDS FOR FISH AND FISHERIES

Progress Report

A T Ibbotson PhD, Grad IPM, MIFM
M Ladle PhD

Project Leader:	M Ladle
Report Date:	July 1997
Report:	Environment Agency, Midland Region
IFE Report Reference Number:	T11068E7/1

Centre for Ecology & Hydrology
Institute of Freshwater Ecology
Institute of Hydrology
Institute of Terrestrial Ecology
Institute of Virology & Environmental Microbiology

Natural Environment Research Council

CONTENTS

1. PROGRESS

1.1 Objectives

1.1.1 Overall Objective

- To provide a standard methodology for analysing river flow in relation to fisheries' requirements in order to support development of River Flow Objectives.

1.1.2 Specific Objectives

- To review the current literature and knowledge concerning the relationship between river and upper estuary flows and fish migration (including an appraisal of unpublished work within the Environment Agency and its predecessor the NRA).

- To review existing literature and knowledge on the relationship between river flow, migratory and coarse fish stocks and potential for angling success. The literature should be reviewed to provide an understanding of the mechanisms by which flow can affect survival and reproduction.

- To review representative data from existing fish passes in the UK in relation to flows.

- To develop a standard methodology for statistical data analysis for relating flows to migration and to catch statistics taking into account existing methodologies, drawing on data from specific fish counters, various catch return statistics and flow gauges.

- To define flow needs (by species/lifestage/river type grouping) as far as practicable from existing data.

- To identify gaps in knowledge and to provide proposals to address these gaps in the form of a programme of work with indications of cost and duration.

1.2 Review of scientific literature

The scientific literature has been reviewed and a draft review is included as part of this progress report. The review covers three aspects:

- The relationship between river flow and fish migration

- The relationship between river flow and spawning and stock levels

- The relationship between river flow and fish catches

1.3 Review of Environment Agency data and methodologies

Excluding fish pass and counter data (see section 1.4), positive responses to the initial letter sent to all Area Offices have been received from 17 Agency staff. Of these 7 state that they had nothing of any value, 7 sent some information or reports and 3 state that they have large amounts of information that may or may not be relevant, but that it is too much to send in the post. Two offices have been visited, in Thames and Southern Region and in one of these cases reports that were promised have not yet materialised. All the information received to date has been collated on an ACCESS data base.

It is likely that there is not much more information that is directly relevant to this project, but having identified 150 separate Agency fisheries staff we need to continue our enquiries to make sure that is the case.

1.4 Review of representative data from existing fish passes in the UK

A copy of R&D note 110 'Fish Pass Design and Evaluation' has now been obtained. There was a delay in getting access to this document despite repeated requests to Environment Agency HQ at Bristol. However, from reading the report it is apparent that the Regions that have most fish counters, Southern, North West and South West did not respond to the questionnaire sent as part of that study and information from these Regions is not documented in R&D note 110. A letter has been sent to Dr Miran Aprahamian asking for help in identifying which counters have sufficient data to relate fish passage to flows.

2. REVIEW OF FLOW NEEDS FOR FISH AND FISHERIES

2.1 Relationship between river flows and fish migration

2.1.1 Introduction

The factors that control the movement of migratory fish are important to fishery managers. In particular, salmon *Salmo salar* and sea trout *Salmo trutta* stocks are dependent on the ability of the adults to move from the sea through estuaries and up natal rivers (Milner, 1989) to reach their spawning grounds at the correct time and with sufficient reserves to complete the act of spawning (Bjornn and Reiser, 1991). Thus stream discharge, temperature and water quality have to be at acceptable levels for at least part of their migratory period.

Native salmonids usually have enough flexibility in their migration, maturation and spawning schedules to survive natural fluctuations in flow (Bjornn and Reiser, 1991), but with the natural flows of rivers being increasingly changed and manipulated for water resource purposes it has become increasingly important to understand the migration process (Milner, 1989) and its response to flow.

2.1.2 Methods of relating salmon migration rates to flow

Many of the methods for recording salmonid migration are complementary and are usually selected for their attributes regarding objectives, location, time and resources. The method used to measure salmonid migration is important in interpreting the impacts of flow, since migration and flow may be measured independently. Whilst salmon may be observed migrating by some method it is not always certain what flow event actually initiated the migration.

Additionally, methods that count salmon at the site of traps or weirs may bias results because movement may be influenced by the presence of the obstruction (Hellawell, 1976).

Milner (1989) lists the methods used under five headings:

- visual observation
- sonar surveys
- the use of fishery statistics
- fish counters and
- fish tracking.

Direct observation tends to be limited to behavioural studies from the bankside or good viewing points (e.g. Webb and Hawkins, 1988), although video footage is used to study passage over weirs or to verify counts through counters. Milner (1989) states that sonar surveys have apparently not been used much in UK fresh water and there are no other reported studies using this method since then.

Catch statistics are widely collected and provide valuable information for assessing the fishery response to changes in flow. These are generally regarded as acceptable indices of stock that has recently entered the river and this is corroborated by studies using tracking data (Milner, 1989). However, without knowing the availability of stock in the estuary and river and because of the varying catchability of stock with the length of time the salmon are in the river they may not accurately reflect the movement of salmon with flow.

Resistivity counters are now installed in several rivers and river types. These have the advantage of recording data automatically and all year round. Over the period of a year the whole count of salmon for any river can be accounted for over a wide range of flows (Milner, 1989). Although staff costs are cheap per salmon observed, installation costs can be high. There is an inability to distinguish between fish species, in particular between salmon and sea trout where there is an overlap of sizes. This problem can be partially overcome by the use of video cameras, provided visibility is acceptable.

In relating actual counts to the influence of flow on migration, the same problem that applied to catch statistics applies to remote counters. That is, there is no indication of fish availability and it is hard to assign any flow to the initiation of migration. The use of two counters would allow operators to account for salmon between them and help provide availability data for the higher counter (Milner, 1989).

In recent years the use of telemetric tags have dramatically improved the study of fish movements of individual fish (McCleave, Power and Rommel, 1978). Data accumulation is much slower because of the small sample sizes that are typical of tracking studies and the inherent variability of fish behaviour requires a large number of relatively labour intensive observations before relationships between fish movement and flow can be determined. However, the initiation of migration can be assigned to particular flows for individual fish accurately. This is because tagged fish can be located precisely and observed continuously.

Fixed receiving stations can monitor fish movements past them and some tags are capable of recording activity, such as tail beat frequency, physiological condition, such as respiration and heart rates as well as the environmental conditions outside the fish, such as salinity and hydrostatic pressure. Acoustic transmitters are used in salt water and radio transmitters in freshwater, although combination tags and transmitting systems are available (e.g. Solomon and Potter, 1988)

2.1.3 Units of measure

Bjornn and Reiser (1991) have reviewed some of the techniques for estimating flow requirements for upstream migrating salmonids. It would be helpful if all studies which discuss flows at which salmonid migration is initiated provided the same information with regard to flow. Apart from information on absolute flows at which migration took place this should include the flow characteristics of the river itself. This would allow absolute flows to be related to benchmark type flows such as average daily flows (e.g. Baxter, 1961), daily or monthly mean discharges (e.g. Smith, Smith and Armstrong, 1994) percentage exceedance flows or discharge per unit width of river (e.g. Stewart, 1969, 1973 and 1975).

For example, Baxter (1961) set out to establish the minimum residual flows for migratory fish and to correlate these with the incidence and duration of natural flow, by studying the flow records of 15 rivers, including the River Severn. As a common measure between rivers he used average daily flow and proportions of flow to this figure, arguing that absolute values of flow are meaningless when comparing runs of fish between rivers. Thus flows close to average daily flow are equivalent to a minor spate and flows which are 1/8 of a.d.f. are dry weather conditions. However the relationship between a.d.f. and other flows varies with size of river, so that recession in the amount of river bed covered by water occurs at about 1/2 a.d.f. in small streams but does not occur until 1/8 a.d.f. in large rivers.

Whilst recommending the use of freshets for inducing salmonid migration, in streams with only residual flow, Baxter (1961) went on to describe general rules for the magnitude of these temporary increases in flow. He estimated that salmon would ascend most rivers in flows varying from 30-50% of a.d.f. in the lower and middle reaches of rivers and at 70% of a.d.f. in the upper reaches. This was for rivers with gradients of 1:90 to 1:300 in upper reaches and 1:400 to 1:700 in middle to lower reaches. Rivers outside this range may require differing amounts of flow which he stated could be estimated from observation. However, spring fish (February - April) or the larger salmon that run in the early part of the year required more water than summer run fish at 50 - 70% of a.d.f. This was attributed to the effect of the lower temperatures on fish activity.

Rather than expressing flows as percentages of average daily flows, Stewart (1969, 1973 and 1975) expressed flows as a function of unit width. Cragg-Hine (1985) found that migration was initiated at a similar flow per unit width in different rivers. If such relationships hold for several rivers it might be possible to develop general rules for the flows required for migration that could be transferred to rivers where no actual measures have been made. These would be simple to understand, easily tested with current data and thus defensible as well as being relatively cheap to apply.

2.1.4 Methods for setting flows for salmon migration

The behavioural responses of salmon to different flows have, in the past, been used for setting minimum flow rates in different rivers. Often these were set in terms of an absolute discharge rate at which salmon migration would commence (Fraser, 1975). An example of this is Baxter (1961) who estimated that salmon would ascend most rivers in flows varying from 30-50% of a.d.f. in the lower to middle reaches of rivers and at 70% in the upper reaches. Stewart (1969, 1973, 1975) stated that salmon would not migrate below flows of 0.03 $m^3 s^{-1}$ per m width of river.

Lawson *et al.*, (1991) describe how a programme of monitoring movements of salmon with traps and telemetry in respect to flows helped to refine operating rules for abstraction on the River Tamar. This resulted in 'spate-sparing' rules where small summer spates were allowed without abstraction and this protection flowed for five days after the spate to allow fish to use the falling water.

These methods identify and protect a range of flows that are associated with the majority of salmon migration activity and these have been termed the 'gateway' flows (Millichamp, 1976). Cragg-Hine (1989a) describes a system on the River Lune where flows below a certain level are left unabstracted and some small summer spates are left unabstracted for a 36 hour period.

However, because flows associated with salmon entry vary both seasonally and annually minimum flow requirements for salmon have been difficult to quantify (Alabaster, 1970; Hellawell, 1976). The relationship between flow rate and salmon entry varied between years depending on prevailing flow conditions (Smith, 1991). On the Aberdeenshire Dee during a low flow year in 1989 the flows used for entry to the river were much lower than for previous years. Similar observations were made by Sambrook and Broad (1989) on the River Tamar where salmon were observed to enter the river at low flows. Thus the predictive power of any analysis based on absolute values of discharge and migration rates or catches will be weak (Smith, 1991), as will the predictive power of the effects of abstraction on salmon migration.

This view has been expressed previously by Dunkley and Shearer (1982) who found that movement into the river occurred in the reducing flow period after an increase that was associated with a decrease in flow from a flow peak. They concluded that models which relate river entry by salmon to absolute discharge rates on their own are unlikely to be reliable.

Although Frake and Solomon (1990) suggest that a minimum flow can be identified below which salmon show a marked tendency not to migrate. These apparent differences between studies may be related to river type with minimum flows being more readily identifiable where there is stable flow, such as in chalk streams, than in more variable spate rivers.

Despite this obvious difficulty in identifying 'gateway' flows Cragg-Hine (1989b) concluded that the 'gateway' concept remains the most useful method for dealing with abstraction problems.

Responses of salmonid migration to discharge variation have been modelled by Radford *et al.*, (1972), using discharge as the predictor and using availability of fish from records of their movement in rivers (Peters *et al.*, 1973). Radford *et al.*, (1972) found that statistical analysis of flow rates and the numbers of salmon migrating over a weir resulted in varying correlation coefficients between months and over complete years there was no significant relationship, although some degree of association was observed.

Inclusion of other variables resulted in similar results. Some months revealed significant correlation between numbers of salmon and a variety of factors such as flow but other months did not. This results from varying availability of fish to migrate and varying responses of these fish to flow. A model was then developed to analyse the basic data on the movements of fish, river flows and the seasonal arrival of fish to the estuary. To estimate the number of salmon in the estuary and therefore the number available for migration the monthly average of the daily rate of salmon migration past the weir for the three year period 1964-1966 was calculated and expressed as a proportion of the annual average run. From this the mean daily value for each month was assumed to be the actual value at the middle of the month. Rates of influx were thus obtained for twelve dates during the year and rates for all other days were calculated by linear interpolation between these points.

The model assumed that the effects of netting and angling broadly followed the same seasonal curve. However it was discovered later that the effects of fishing had a profound effect on the availability of fish, and the estimation of the number of fish available for migration had to be adjusted to take account of this. Using this data it was possible to identify the lowest flow at which a high rate of migration occurred and a flow below which large accumulations of salmon did not move. However on testing the model it was found that salmon were observed to migrate in significant numbers at flows which were half the predicted minimum flow for migration. This was partly attributed to flow acclimatisation by the salmon and its effects on migration.

There were considerable differences in the predicted migration rates and observed migration rates on all the rivers that the model was tested on, which were the Leven, Coquet and Lune. This was thought probably due to acclimatisation of the fish to previous flows, and the differing physiological conditions in the fish.

Peters *et al.*, (1973) found that their model of salmonid migration in the River's Coquet and Lune suggested that salmon did not move into freshwater from the estuary below flows which approximated 10% of average daily flows, but that in the river Leven this value fell to 4%. This difference between rivers was thought to be due to the regulating influence of Lake Windermere and fish were moving in response to rainfall itself which then had less effect on the river level because of the storage capacity of Lake Windermere.

Milner (1989) has stated that effective schemes for protecting flows for migratory fish will include:

- prescribed minimum flows,
- identification of migration bands making allowance for seasonal requirements,
- protection of summer spates with prescription for intensity and duration,
- use of tops of spates for storage of water,
- protection of spawning flows to maximise use of headwater streams and
- consideration of other ecological impacts.

Further Milner (1989) went on to say that in many rivers a variable proportion of salmon stray in from neighbouring catchments and the behaviour of these fish in response to flow may be significantly different to those entering for spawning and this may affect the performance of rod fisheries in response to flow changes.

2.1.5 Salmon migration patterns

In any consideration of the impacts of flow on salmon migration it is important to consider the seasonal, physiological and behavioural aspects of salmon migration during their life history.

Hellawell *et al.* (1974) and Hellawell (1976) emphasised the importance of the seasonal pattern of migration. He found from three years of salmon migration over a counter on the River Frome a chalk stream that the most important factor driving migration rates was the numbers of salmon available in the estuary and that this was a seasonal factor. The secondary importance of discharge is confirmed by seasonal movement of fish over fish passes (Gardner, 1976) and during constant or regulated flows (Pyefinch and Mills, 1963; Mills, 1968).

Thus the timing of entry to the river shows seasonal differences and although salmon can enter freshwater throughout the year, the seasonal differences are usually associated with the arrival of migrating salmon at the coast. Most rivers have summer and autumn runs, comprising 2 and 1 sea-winter fish and some rivers also have a significant spring run comprising 3 and older sea-winter fish (Saunders, 1967; Milner , 1989). Variations in flow may act to alter these seasonal patterns by restricting movement in to freshwater from the estuary.

Patterns of migration occasionally vary between rivers, this is manifested as different behavioural strategies which optimise energy expenditure, but evidence from radio tracking studies (e.g. Clarke and Purvis, 1989; Webb, 1989) suggest a recurrent pattern with the division of upstream migration into three distinct phases (Milner, 1989). These being:

- rapid river entry,
- quiescent phase,
- spawning run.

Post spawning there is a fourth downstream migration phase for kelts. Each of these phases needs to be considered in water resource issues.

Once salmon enter the river from the estuary they typically move rapidly upstream at a rate of up to 30 km per day on the River Dee (Hawkins *et al.*, 1989). This is followed by a period of discontinuous movement with fish primarily moving at night. Those entering the large rivers earlier tend to migrate further upstream on the first phase compared with the later running fish which remain in the lower reaches where they spawn. On smaller rivers the majority of fish held up within the lower reaches (e.g. Frake and Solomon, 1989).

After this initial migration stage the fish can remain in the same location for several months apart from a varying proportion, usually small, which make slower discontinuous progress upstream usually associated with increases in discharge (Milner, 1989). Hawkins and Smith (1986) showed with radio-tracking that salmon may spend many months of the year at holding positions within the main branch of the River Dee.

However later in the year in autumn fish start to respond to increases in flow more readily and the discontinuous movement rate increases (Milner, 1989). Fish entering the river in autumn are not so dependent on increases in flow, suggesting that as spawning time approaches the physiological drive to migrate upstream begins to override the environmental cues.

As autumn progresses movement to spawning areas is rapid although entry into spawning tributaries is dependent on discharge level. Webb and Hawkins (1989) found that the use of small headwaters is very dependent on discharge. The determination of whether individual fish would enter a tributary was dependent on a threshold discharge, but above this experience of previous floods was also important; those fish that experienced fewer floods would enter tributaries with lower discharges.

Once spawning is completed salmon have been observed migrating downstream from the spawning grounds (Laughton, 1991). Webb and Hawkins (1989) found that females migrated downstream from the spawning grounds sooner after spawning than males.

2.1.6 Influence of flow on salmon migration behaviour

Once salmon arrive at the coast their behaviour in their natal river estuaries will probably be dependent on the shape, size and flow dynamics of the estuary itself (Allan, 1966).

Hayes (1953) suggested that strong onshore winds induced fish to concentrate in the estuary. Stasko (1975) tagged salmon in the Miramichi River and found that they moved up the estuary with the incoming tide and back down again on the ebb tide, although there were some variations in behaviour with some fish holding station in parts of the estuary. This behaviour was also observed by Brawn (1982) in the estuary of the East River, Nova Scotia and Jackson and Howie (1967) in the River Erne, Ireland. However, Potter (1988) found that fish spent large amounts of time outside the estuary in the sea. This suggests that the behaviour and response of salmon to freshwater flow will in part be dependent on the estuarine characteristics.

This is borne out by the variation in time that fish take to enter freshwater once they arrive in the estuaries. Brawn (1982) found that salmon remained in suspended migration in the estuary for between 7 and 108 days. Potter (1988) quoted figures of between 9 hours and 130 days on the River Fowey, whereas Webb (1989) following 22 tagged fish in the River Tay found that they all moved from the estuary into the main river within 24 hours of tagging at a variety of flows. Smith (1991) found that the elapsed time between tagging salmon and river entry on the River Dee was greater during periods when flows were lower than mean monthly flows in all periods between February and August.

Movement into freshwater coincided with increased river discharge at night, although on heavy floods it also occurred during the day. Welton *et al.*, (1990) found movement of fish during the day was restricted to spate conditions. However, Potter (1988) thought that some freshets and floods were missed by the salmon because they were too far down the estuary or out to sea to detect them.

However, size of flood is important and large floods can have negative effects. Menzies (1916) found strong floods moved salmon out of rivers and back out to sea and Huntsman (1948) found that salmon did not migrate upstream on the strongest floods suggesting that very high flows can result in a net downstream movement.

Milner (1989) concludes that the patterns of movement within the tidal limits seems to be unaffected by freshwater flow but is more dependent on the flood and ebb tides. The time spent in the estuary is variable between rivers and that the differences are the result of differing physical structure, dimensions and hydrography of the estuaries.

Day (1887) made early references to spawning migrations of salmon being associated with increased water flows. However there are many factors associated with increases in water flows such as water and air temperature, turbidity, atmospheric pressure, cloud cover, pH, and variations in concentrations of many ions. Banks (1969) states that presently we are only able to say that flow is an important determinant of migration, but behavioural response to flow could be modified by any of these other factors and that this modification could differ between river, season and species.

Indeed Brayshaw (1967) considered that the stimulus to start migration in the River Avon may have been some change in the quality of water associated with increased discharge rather than the discharge increase itself.

Alabaster (1970) analysed the monthly catches of salmon at a trap on the River Coquet. He thought that since no particular flow seemed to be equally associated with salmon movement it was possible that some other factor associated with higher than average flows stimulated migration. For example, short term changes in flow together with changes in concentrations of dissolved substance or suspended solids.

If there are cues, other than flows, involved in the initiation of migration then compensation flows or reservoir releases may need to be supplemented with water from natural spates to have the desired effects (Milner, 1989).

Smith, Smith and Armstrong (1994) radio tagged 109 salmon in the estuary of the Aberdeenshire Dee and recorded the times that fish entered the river. They found that the time taken between tagging and entering the river in all months was longer in periods when flow was lower than average.

It is thought that river entry from the estuary by salmon may be inhibited at low flows for several reasons and this may be adaptive to increase survival. At low flows subsequent upstream progress is likely to be impeded by shallow depths particularly at natural barriers (Stuart, 1962; Winstone, Gee and Varallo, 1985). Stuart (1962) observed that the passage of large salmon over falls only occurred at higher discharges. Salmon may also be vulnerable to predation in shallow or clear water (Smith, Smith and Armstrong, 1994), crowding may increase the potential for disease transmission and there may be extremes of water temperature (Roberts, 1978; Bjornn and Reiser, 1991) and reduced oxygen concentrations (Ellis, Roberts and Tytler, 1978; Shepherd, 1978). It is possible that the behaviour, and thus their response to flow changes, of stocks of homing salmon will be adapted to local flow regimes (e.g. Davidson, Vaughan and Hutchinson, 1943).

Once in the estuary salmon have been observed utilising a variety of flows for migrating into freshwater (Allan, 1966) and on the River Axe migration occurs at low flows, and in dry years they utilise lower flows than in wet years.

In general, in studies of the impacts of river flow on salmon migration, studies have concluded that high flow facilitates river entry, whereas low flows are associated with delayed river entry (Huntsman, 1948; Hayes, 1953: Brayshaw, 1967; Alabaster, 1970; Potter, 1988; Clarke, Purvis and Mee, 1991).

However, that is not always the case since Hellawell (1973) and Hellawell *et al.*, (1974) found that salmon in the River Frome, a chalk stream, appeared to migrate on flows lower than the flows that were generally available and this was thought to be due to the steady nature of River Frome flows in comparison to other rivers with more variable flows. However he did suggest that in drought years the behaviour of salmon in the River Frome may approach the behaviour of salmon in other rivers with variable flows.

Huntsman (1948) emphasises the importance of freshets for moving salmon from the estuary into the river. Baxter (1961) says to induce migration of fish into a stream with only residual flow there is a necessity to provide flows in the form of freshets and many authors report the use of these in initiating migration from the estuary. However, freshets require consideration of:

- their timing
- the amounts of water to be released
- the frequency of their release and
- their duration.

Baxter (1961) says that the amounts of water required for a freshet will vary with the size of the stream because of the relationship between a.d.f. and stream width.

Calderwood (1908) describes the use of an artificial freshet to bring salmon into the Grimersta River in Lewis. Salmon had congregated in the estuary during a dry period. Then a loch dam was broken and large numbers of salmon entered the river. In the subsequent week 400 salmon were captured by three rods. With the arrival of rains the fish moved further up river.

Huntsman (1948) used artificial freshets to bring fish into the river using a lake 8 miles upstream of the head of tide. Fish moved through a lower counting fence with the first freshet and the number that moved through the higher fence increased in the later sequence of freshets. No times are given for the duration of the freshets or their size which was dependent on the amount of water stored in the lake.

Hayes (1953) and Harriman (1961) have documented the effects of artificial freshets on the upstream movement of salmon. Harriman (1961) concluded from a comparison of the hydrographs and the daily rod catches over a 15 year period that freshets before 15 May did not start an early run of salmon but after that freshets would. During June a freshet would start the main run and an increase every few days will prolong it.

Hayes (1953) working on the Le Have River, Nova Scotia found that under natural conditions the river fell to 50 $ft^3\ sec^{-1}$ but found that 200 $ft^3\ sec^{-1}$ was needed to maintain a good run of fish. His general aim was to keep the river running at 400 $ft^3\ sec^{-1}$ for as long as possible and add freshets up to 1600 $ft^3\ sec^{-1}$ at intervals. After three years the author concluded that:

- large or small freshets are capable of moving fish,
- major runs can occur without the need for natural or artificial freshets and can be maintained by a steady flow of water during the run season,
- artificial freshets moved fish into the river from the head of the tide but were not sufficient to bring fish into the estuary,
- the reverse of a freshet which was to reduce the water and then increase it again could act like a freshet in bringing fish into the river and
- some freshets had no effect and it was concluded that there had to be a supply of salmon in the estuary if freshets were to work.

Hayes (1953) proposed a plan for water control based on his observations which included:

- maintaining flow at 400 $ft^3\ sec^{-1}$ for as long as possible, allowing natural freshets to take their course,
- not wasting water on large numbers of freshets,
- timing positive freshets to reach the head of tide at dusk during periods of spring tides and onshore winds and
- using inverse freshets when water resources are very low.

The occasional failure of freshets to bring salmon into the river has been confirmed by Mills (1968) who found that artificial freshets over a limited range of flows had little effect on the number of salmon coming into the river.

Baxter (1961) has addressed the issues of how much, how often and for how long. He says that the amounts of water required for a freshet will vary with the size of the stream because of the relationship between a.d.f. and stream width. However, his estimation was that salmon would ascend most rivers in flows varying from 30-50% of a.d.f. in the lower and middle reaches of rivers and at 70% of a.d.f. in the upper reaches. This was for rivers with gradients of 1:90 to 1:300 in upper reaches and 1:400 to 1:700 in middle to lower reaches. Rivers outside this range may require differing amounts of flow which can be estimated from observation.

However, spring fish (February - April) or the larger salmon that run in the early part of the year require more water than summer run fish and it is estimated they need 50 - 70% of a.d.f. (Baxter, 1961). This was attributed to the effect of the lower temperatures on fish activity. Sedgewick (1962) has said that naturally high flows were the norm at this time of year and so artificial freshets may not be needed but where rivers are heavily abstracted such flows may not be available early in the season and the early fish may be lost.

The frequency of the freshets will depend on the positioning of tributaries, the distance between the source of the freshet and the estuary and the location of the spawning grounds (Baxter, 1961). Where the residual flow is not supplemented by natural flow from tributaries it may be necessary to have frequent freshets to bring salmon into the river at regular intervals, or where the residual flow only affects spawning grounds they may only be needed later in the year to bring spawning salmon into the tributary.

The duration of freshets need not be more than 18 hours, 12 of which should be at the full rate. However it is advised that in order to maximise the attractive effects of freshets they should reach the mouth of the river at about half to full flood tide (Baxter, 1961).

Under natural conditions a number of authors have tried to measure the flows that salmon use for migration. For example on the River Avon Brayshaw (1967) observed peaks of migrating salmon appeared to occur at 75 - 100% of a.d.f. He thought that the establishment of a relationship between the extent and duration of a spate and the distance migrated by the salmon would be an important part of any river management.

Allan (1966) described the salmon counts at a counting fence on the River Axe and the frequency of counts at various flows. Most salmon ascended through the trap at flows between 28 and 243 $ft^3\ sec^{-1}$. Banks (1969) used Allan's data to calculate a figure for the number of salmon per flow day and found that the peak of this value occurred at between 147 and 267 $ft^3\ sec^{-1}$. This equates to the preferred levels of flow for migration.

Stewart (1966, 1968 a,b,c,d,e,f, 1969) describes results for the River's Lune and Leven where fish moving upstream are automatically recorded together with fish size and a whole variety of other environmental factors. Stewart (1968 a, b) found on the river Lune that 80% of all salmon move upstream on flows equivalent to 190% of a.d.f. or 460 $ft^3\ sec^{-1}$. A peak of movement occurs at 400 $ft^3\ sec^{-1}$ (equivalent to 167% of a.d.f.) and a lesser peak occurs at 175 $ft^3\ sec^{-1}$ (equivalent to 73% of a.d.f.). These peaks correspond to movements of spring and summer fish. On the River Leven the peak of salmon migration occurred at a flow equivalent to 86% of a.d.f. However comparisons between the two rivers were difficult because the counter was 26 miles up river on the Lune and at the head of the tide on the Leven which was also partly regulated by Lake Windermere.

Swain and Champion (1968) found on the River Axe that appreciable numbers of salmon utilised flows less than 65% of a.d.f. for migration but this occurred at night. If fish were available in the estuary then an increase in flow after rain initiated a substantial migration. Higher flows are necessary to initiate migration in the spring than in the summer when low or medium flows are used. Once migration has commenced in response to an increase in flow the numbers of fish passing a fixed point tends to remain constant for up to two days regardless of subsequent changes in flow and then ceases before the river returns to its previous level.

Cragg-Hine (1985) observed that over several years, during the summer months, fish tended to utilise the higher flows but the migration flow range varied from year to year depending on prevailing flow conditions. He points out that a basic problem with observing salmon over a counter is that there is no information on the numbers of salmon available. Studies of fish counts over a counter on the River Lune between 1974 and 1979 showed very great variation in the flow utilised for migration from year to year depending on the flows that were available. In general fish utilised flows that were slightly higher than those available but in 1979 when the water level was consistently higher the mean migration flow was less than the mean available flow. The summer migration flow range was approximately 10 - 82% of a.d.f. for that river. By dividing the number of fish moving at a particular water level by the number of days that water level existed it was possible to determine the flow at which fish preferred to migrate.

This observation of fluctuating relationships between flow and salmon movement between years was noted by Smith (1991) who stated that it would alter depending on prevailing flow conditions. On the Aberdeenshire Dee during a low flow year in 1989 the flows used for entry to the river were much lower than in previous years. A similar observation was made by Sambrook and Broad (1989) on the River Tamar where salmon were observed to enter the river at low flows.

In relation to available flows entry into the river was not dependent on flow higher than the long term mean in April/May but was in June/July and August. During periods of lower than average seasonal flow, river entry was closely associated with days when flow had increased since the previous day, but during periods of higher than average flow river entry was not associated with such periods of increased flow. Thus the predictive power of any analysis based on absolute values of discharge and migration rates or catches will be weak (Smith, 1991), as will the predictive power of the effects of abstraction on salmon migration.

Webb (1992) states that the behaviour of salmon in relation to environmental factors such as flow will be dependent on the date they enter the river and the position in the river system in which they eventually spawn.

Thus movement into freshwater is dependent on river flow but in most rivers it has not been possible to identify a threshold level which can be applied from year to year. At times of low flow fish accumulate in estuaries. It is not known how acclimatisation to river flows and the length of time spent in the estuary effects the subsequent migration into fresh water (Milner, 1989).

Migration in respect to stages of flow increase is important for management of flows. The problem with fixed location counters is that it is not possible to know at what flow the salmon was motivated to move.

Allan (1966) observed that during flood events some fish ran on rising water levels but more on falling water levels. However because of the static nature of the trap he was not certain what part of the flood initiated movement of the salmon, because there was a time delay between the onset of the flood and the salmon reaching the trap. On some flood events no fish ran and it was thought this was because no fish were available in the estuary.

Similarly Huntsman (1948) found that although the rising portion of the freshet stimulated some salmon to migrate the majority of the salmon moved on the falling part of the freshet. Other authors record movements on falling water levels and on the peak of an increase in water levels (Huntsman, 1939, Hayes, 1953, Stewart 1968f, Dunkley and Shearer, 1982).

Trepanier *et al.*, (1996) correlated the number of migrants with changes in flow from one day to the next and found that there was a negative correlation suggesting that most fish migrated on falling water levels not rising ones. This was with landlocked salmon which only migrated on a spawning run equivalent to the third migratory stage of sea run salmon.

This phenomenon (of lag between initiation of movement and counts) further confounds the ability to predict the impact of flow on migration because freshets that instigate migrations consist of a wide range of flow rates and since fish move on the falling part of the hydrograph the counts of salmon at various flows will often include flows which are quite low (Banks, 1969). It may be more valuable to relate the peak value of the flood and the duration of the falling water stage with the numbers of salmon that migrate in the following days.

Once in the river progress upstream can be rapid. Hawkins and Smith (1986) measured rate of progress upstream as between 2 and 22 km day^{-1}, although there was insufficient data to relate rate of progress or swimming speeds to water flow.

During the quiescent phase (Milner, 1989) most fish remain static and do not respond to spates. Clarke and Purvis (1990) found that, following this phase, movement of fish over distances greater then 2 km were associated with increases in flow. Similarly, Laughton (1991) analysed movements of 69 salmon and grilse in the River Spey with respect to mean daily flows, and found that following the quiescent phase the stimulus required to move salmon was increased flow.

Discontinuous movements during this phase are likely to be more independent of spates in larger rivers (Milner, 1989). Once autumn starts these discontinuous movements seem to increase in rate (Milner, 1989). Fish entering the river later in the season appear less dependent on increases in flow.

Nearer the spawning grounds movement appears to be very dependent on flow rate with entry of tributaries associated with higher flows (Webb, 1992). Laughton (1989) tagged 24 salmon at the bottom of the River Spey and found that movement was often associated with increases in river discharge and this was most noticeable in the vicinity of tributaries. Movement during the day was restricted to spate conditions.

Webb and Hawkins (1989) trapped fish at the lower part of a tributary of the Aberdeenshire Dee during October and November for a study of salmon spawning in one tributary. They found that most fish entering the tributary coincided with the occurrence of spates. Burn entry was extremely dependent on these. However a relationship between river flows and salmon entry did not suggest any minimum flow requirement or threshold level of flow. They postulated that entry may depend on the pattern of flow during the summer and the acclimation of the fish to earlier rates of discharge. Thus after periods of low flow the increase in flow required to initiate movement may be smaller than in high flow years. However this behaviour is probably mediated by the reproductive state of the fish since entry to the spawning tributaries usually occurred in October and November despite there being floods in September. Despite the above statement a minimum flow of $0.1 m^3 sec^{-1}$ was thought necessary to stimulate entry to this burn, since only one fish entered it at a flow below this level.

The size of floods after spawning may influence survival of kelts, Huntsman (1945) found that large floods moved kelts further out to sea.

There are potentially some important indirect considerations of the flow requirements for fish as changes in flow rate will undoubtedly impact on the concentration of oxygen and toxic pollutants as well as having an indirect effect on temperature.

Alabaster (1990) has suggested that temperature plays an important part in determining the tendency of salmon to migrate. On the River Dee the numbers of salmon migrating reduced considerably as mean weekly maximum temperatures reached 21.5°C. Similarly the numbers of grilse migrating in the Miramichi River declined at high temperatures (Alabaster *et al.*, 1971). Inhibition of migration is also thought to occur at temperatures lower then 5°C (Milner, 1989).

Jensen, Heggberget and Johnsen (1986) tried to correlate a variety of physical and environmental variables with the numbers of salmon passing through a fish pass between June and September. They found that in addition to flow, temperature showed a significant relationship with the number of migrants.

2.1.7 Impacts of annual variations in flow on numbers of salmon migrating

As well as the behavioural responses to flow variation some authors have reported changes in the number of migrants with changes in flow.

Huntsman (1948) found that when artificial freshets were used on the Moser River, Nova Scotia more than twice the number of salmon entered the river then in the previous three years. They suggested that this resulted in salmon from neighbouring rivers coming up the Moser River in response to the freshets. All smolts in this river had been marked as they left the river and the artificial freshets appeared to result in 25 - 50% of grilse being unmarked or thought to be from foreign river systems. They also reported many more large salmon entering the river than usual although they don't comment on whether these are from other catchments or not.

Saunders (1960) attributed the total number of salmon ascending the Ellerslie Brook a small stream on Prince Edward Island to annual variations in discharge.

Alabaster (1970) found a direct linear relationship between the total numbers of salmon migrating up the Coquet River and the mean average daily flow for the river, both for salmon and sea trout. The relationship was much steeper for salmon. This implies that there is a surplus of salmon in the estuary which does not enter the river in years of low flow and are therefore subsequently lost to the system. When this was broken down into individual months it was shown that months with high catches often came after months with low catches implying that fish are held up in periods of low flow.

This straying of salmon between catchments has been corroborated by studies with radio tags. For example Solomon (1988) tagged 261 salmon captured near the mouth of the Avon. If the salmon are destined to move up the Avon they usually enter freshwater within 12 - 36 h. About 10% of the fish are not detected in the River Avon and whilst some of this may be due to tag loss, some others were subsequently detected in other neighbouring catchments.

The proportion of straying fish probably varies between rivers systems, but this behaviour is important because their number could have a significant impact on the fish available to the angler (Milner, 1989).

2.1.8 Other salmonids

Banks (1969) says there is very little data on the migratory responses of sea trout to flow. Allan (1966) found they tended to move through the trap at low flows more readily than salmon but in general behaved very much like salmon. Baxter (1961) thought that flows for salmon would be sufficient for sea trout migration, but says sea trout enter the river at lower flows than salmon and probably only require 20 - 25% a.d.f. in large rivers and 25 - 30% a.d.f. in small rivers.

Migrations of adult brown trout from Loch Leven into the spawning streams were always associated with increases in water levels (Munro and Balmain, 1956). Adult brown trout on spawning runs were found to respond to freshets in much the same way as salmon (Arnekleiv and Kraabol, 1996).

2.1.9 Eels

Martin (1995) found that early elver (*Anguilla rostrata*) migration into the river was increased by reduced flows, but later in the year tidal stage was more important.

Gandolfi *et al.*, (1984) found that under low flow conditions elver (*Anguilla anguilla*) migration into the river seemed inhibited and a positive relationship was found between number of elvers captured and river flow. However, the changes in flow over the study period was rather uniform and small, and therefore it was not possible to determine whether flow had any influence on migration or whether there was some other direct influence.

2.1.10 Coarse fish

This group of fish contains a large number of species. Whilst there are reports of seasonal migration patterns in many of these species (e.g. whole coarse fish communities Linfield, 1985; barbel *Barbus barbus*, Baras, 1995; Lucas and Batley, 1996; Lucas and Frear, 1997; dace *Leuciscus leuciscus* Clough and Beaumont, *pers. comm.*), there is no published information on the responses of migration to flow for individual species.

3. RELATIONSHIP BETWEEN RIVER FLOW AND SPAWNING AND STOCK LEVELS

3.1 Introduction

Flow regulates the amount of spawning area in a stream by affecting the velocity and depth, the area of river bed covered and the type of substratum available. It also regulates the amount of space and habitat quality available to juveniles and parr and plays some part in the migration of smolts.

3.2 Salmonid spawning

Substratum composition, cover, water quality as well as water quantity are important habitat elements for successful salmonid spawning. The amount of area available for spawning varies with the size of the stream or amount of water flowing in it Bjornn and Reiser (1991). Boehne and House (1983) found that first order streams were not used by salmonids for spawning, second order streams were used by non-anadromous ones. Third order streams contained a few anadromous fish, but they mostly spawned in the fourth and fifth order ones.

There are a wealth of studies which have characterised the habitat requirements of salmon and brown trout for spawning in terms of substratum size, velocity, depth and cover (reviewed by Mann and Winfield, 1992). However, in the published literature, the quantity and quality of these locally measured variables are not routinely compared to levels of flow in the river. Indeed the relationships between flow and the distribution of these habitat variables locally will be dependent on the characteristics of the channel, that is, its shape, gradient, width, geology etc.

Survival from egg to alevin stage seems to be very dependent on the accumulation of fine materials in the redd (e.g. Lisle and Lewis, 1992) and although flow may have some influence in maintaining the quality of redds through its effects on velocities, the process of entombment of embryos may not necessarily be related to surface water velocities (Ottaway and Forest, 1983).

Baxter (1961) has attempted to make some general rules about the amount of flow required for spawning. He considered that smaller rivers would require a larger proportion of a.d.f. than the larger ones. He suggests that from observations in the River Tweed where width varies from 15 - 70 ft about 25 - 30% a.d.f. may be required and in the lower reaches between 12½ - 20% a.d.f. For the survival of the ova he recommends between 10 - 17% a.d.f., although in the middle to lower reaches 10 - 12½% would normally provide enough..

3.3 Post-emergent fry

As with spawning there is little published information on the effects of flow on post-emergent fry. However, velocities will obviously be mediated by flows. Young salmonids pass through a short stage at emergence (just before the swim up stage) when they are very vulnerable to high flows (Heggenes and Traaen, 1988), particularly to rapid increases in flow. Salmon, however, showed a negative relationship between velocity and movement which is the converse of trout (Elliott, 1987).

3.4 Parr and non-anadromous adults

As with spawning habitat there is a wealth of literature on the habitat requirements for resident salmonid populations (reviewed by Mann and Winfield, 1992). The important habitat features which are usually listed as depth, velocity, substratum and cover are all effected by the flow rate in the river. Thompson (1972) developed a procedure for estimating minimum flows on the basis of minimum depths and maximum velocities and measurements in critical reaches and similar methods are described by Fraser (1975). With the advent of models that predict the frequency and distribution of these local habitat features a great many papers have begun to relate stock levels to local habitat availability and not flow itself.

However, there have been some studies on the impacts of flow regulation, patterns or variability on the stock levels in some rivers.

In common with other life stages Baxter (1961) gives a minimum flow rate for the maintenance of aquatic river life including salmon parr. He estimates it to be 1/8 a.d.f., but states that long periods at this level will need to be broken with the use of freshets.

Cowx, Young and Hellawell (1984) found that a drought resulted in the total elimination of one year-class of salmon parr and thought it was probably due to prolonged high water temperatures. Cowx and Gould (1989) found that the sudden release of water from Llyn Clywedog caused repeated displacement of salmon and trout and a reduction in the population, to the point that salmon were completely eliminated. Conversely, Heggenes (1988) thought that large substrate size played a part in brown trout holding station during hydropeaking.

An experimental approach to studying the reductions in flow in artificial channels resulted in some movement of salmon parr out of shallow water into deep water at very low flows (Debowski and Beall, 1995).

Solomon and Paterson (1980) found a clear relationship between the number of surviving 0+ brown trout and mean April flow in a chalk stream. White (1975) observed increased trout recruitment in response to increases in flow the previous winter.

Crisp, Mann and Cubby (1983) found flow regulation improved conditions for brown trout below a reservoir by stabilising the flows, whereas Cowx and Gould (1989) found that the sudden release of water from Llyn Clywedog caused repeated displacement of salmon and trout and a reduction in the population.

Reductions in flows below dams in the French Pyrenees resulted in reductions in brown trout densities and biomass, because of a reduction in habitat (Baran *et al.*, 1995). Conversely, Harris and Hubert (1991) found no significant increase in catchable brown trout after the minimum flow was increased in Douglas Creek, Wyoming, although this appears to disagree with Wolfe *et al.*, (1990) who did find some increase in brown trout standing stock.

3.5 Smolts

Smolt migration occurs in the spring, the exact timing depending on the geographic area. It's seasonal occurrence is further influenced by a variety of factors including discharge (Berry, 1932; 1933; White and Huntsman, 1938; Solomon, 1978a and b; Rottiers and Redell, 1993; Hvidsten *et al.*, 1995) or rainfall and thus probably discharge (Allen, 1938).

3.6 Coarse fish

As previously stated this group of fish consists of a large number of species all of which will respond differently to flow rates. There is very little published information relating stocks of coarse fish to flows, primarily because coarse fish abundance is technically difficult to estimate.

Clark (1992) found that grayling recruitment was negatively correlated to flow during the first few weeks of life and this was thought to be due to downstream displacement and destruction of eggs and young fish. Similarly, Harvey (1987) has found that cyprinid fry less than 10 cm in length are exceptionally susceptible to downstream displacement during severe floods. Linfield (1985) reviewed data from a stock assessment programme in East Anglia and concluded that downstream displacement of cyprinids was negatively size related and thus very pronounced in the first year.

Where abundance is estimated relatively between year-classes a recurrent pattern occurs where individual populations are dominated by fish of one age. In other words that there is great variation in year class strength (e.g. Mann, 1979; Linfield, 1981; Goldspink, 1983). Mills and Mann (1985) have attributed a large portion of this phenomenon in flowing waters to warm years and the increases in growth rates associated with them. However, precipitation and therefore one would suppose flow, was negatively correlated with temperature. Thus it could be that flow and its indirect effect on temperature could influence coarse fish stock at least in some instances.

4. RELATIONSHIP BETWEEN RIVER FLOWS AND FISH CATCHES

4.1 Introduction

Aprahamian and Ball (1995) considered that river flow is an important factor in determining the catches of salmonid fish. However they felt that few studies detail the flows that are important for angling and the relationship between flow and catches is poorly understood. If the fishery itself is to be protected then discharges that facilitate the availability of fish may not be sufficient. It is necessary to also consider the impact of flow on the performance of the fishery through catches. Thus the environmental conditions necessary to protect the performance of the fishery need to be assessed.

Huntsman (1939, 1948) found that not surprisingly angling on the Margaree River, Cape Breton improved dramatically when salmon were in the river. Angling improved once a large freshet had brought salmon into the river and as the freshet subsided large numbers of salmon were taken and this effect gradually increased in an upstream direction. Indeed angling in this river seemed dependent on freshets. However, on the neighbouring Cheticamp River the angling was less dependent on freshets. This was explained by differences in the shape of the estuary, with a shallow mouth in the Cheticamp estuary and a deeper one in the Margaree estuary.

However, angling also improved once river levels were increased locally when a freshet high up the river improved angling locally even though there was no change to angling or discharge downstream (Huntsman, 1939). He concluded that an increase in water level locally increased the salmon activity and led to increased catches.

Hayes (1953) released freshets to try and increase the numbers of salmon coming into the river. During periods of high salmon counts through traps there was an improvement in the numbers of salmon captured by anglers, but the freshet programme did not result in a significant improvement in the numbers of salmon captured throughout the year.

In the Narraguagus River, Maine Harriman (1961) showed that over a 15 year period the rod catches of salmon became negligible once the river dropped below 200 ft^3 sec^{-1} as the fish in the river became inactive and no others migrated in.

Several authors have stated that salmon catches increase with increasing flows. Alabaster (1970) found that salmon are more frequently captured in flows higher than the mean daily flow during the year in the River Coquet. Similar results were found for the River Towy (Neville-Jones, 1968), River Avon (Brayshaw, 1966) and River Usk (Millichamp and Lambert, 1966).

Alabaster (1970) found that the number of salmon captured increased with increasing flow, but that the efficiency of capture decreased as flow increased. It was not known whether this was due to the development of poor fishing conditions in periods of high flow or whether fishing effort was reduced. Similarly, Peterman and Steer (1981) found that the catchability coefficient for sport angled salmon is higher at lower levels of stock.

Neville-Jones (1968) found that the numbers of salmon captured in a year in the River Towy increased linearly with the mean daily flow in the year. Huntsman (1939) found that the number of salmon that were taken by anglers showed good correlation with the volume of water discharged.

Several authors have tried to relate catches to specific flow rates in an attempt to determine optimum flow rates for salmon angling. For example Stewart (1968, 1969) showed that optimum angling required 134% a.d.f. and 385% a.d.f. on the River Lune, with the two peaks relating to different migration seasons. Brayshaw (1967) showed that the best angling catches per day on the River Avon seemed to occur at 70 - 125% of a.d.f.

Baxter (1961) states that the minimum flow conditions required for successful angling is 25% of a.d.f. for small rivers and 20% for large rivers. Maximum flow conditions suitable for angling can approach 300% of a.d.f. in some spate rivers but normally it is up to about 100% of a.d.f. Generally he thought the most suitable conditions for spring angling were from 25 - 50% of a.d.f. and for summer angling 20 - 35% of a.d.f.

Millichamp and Lambert (1967) investigated the relationship between salmon catches and river flows in an attempt to determine an optimum flow for fishing on the river Usk. They found that in one year the rate of catch of fish was greatest at about 640 ft^3 sec^{-1} but developed a curve of fish captured per flow day and the different flow rates. Although this was only developed for one year the same relationship when applied to the flows experienced in previous years predicted with good accuracy which years were better for salmon fishing. This demonstrated that the durations of particular flows were important in determining the numbers of salmon caught in a particular year. Unfortunately this study was not adjusted for effort so it was not possible to say whether this was the result of angler behaviour i.e. fishing when conditions were perceived to be good or a genuine change in the angling quality.

This is important since Mills, Mahon and Piggins (1986) found that most of the changes in catches could be attributed to variations in effort on a lake fishery in Ireland. Effects of environment could mostly be attributed to variations in fishing effort attributed to these factors.

Potts and Malloch (1991) found good correlation between flow, on the day of capture as well as on the preceding days, and the number of salmon captured by anglers on the lower fisheries of the Aberdeenshire Dee, but this correlation broke down on the fisheries higher up the Dee. This was attributed to the numbers of salmon entering the river increasing with increasing flows and the time delay required for the fish to reach the individual fisheries from the estuary. This was in the months February to August when there are nets in the estuary taking salmon. However in September when the nets are taken off there is no such correlation and it was suggested that at low flows more salmon stayed in the estuary and were susceptible to capture by nets therefore reducing the catch available to the rod fishermen. But it may also be possible that salmon have stopped arriving at the estuary by this time and so the number of fish captured is less dependent on those coming from the estuary anyway.

Bunt (1991) reported that angling effort is greater in larger rivers. He states that river flow is a major stimulus to migration and catches of salmon. Mean monthly flow was found to be correlated with catches for rivers in Wales but this reflected river size. However on the River Teifi they calculated a flow index which was the mean monthly flow as a percentage of the long term average during the fishing season and between 1976 and 1988 they found that the number of salmon and sea trout captured was positively related to increases in this flow index.

Clarke, Purvis and Mee (1991) studied catches in the River Tywi during 1988 and 1989. They stated that previous authors have studied the relationship between flow and catch and catch effort and demonstrated an influence of flow in most cases. However it has not been possible to examine the mechanisms behind these relationships, in particular it has not been possible to distinguish between abundance and catchability. They tagged fish and studied their behaviour and related this to catches and flow rates. Most rod catches were taken during the active migration phase which lasted for 20 days. They found that flow was important in stimulating catches because both effort and catch per effort increased during and immediately flowing freshets in late July, August and September. Flow was also shown to be important in long term data with significant correlation between catches and mean monthly flows in all months. This relationship held despite evidence of long term population changes. Peaks in catch effort following freshets represented new fish entering the river. During the drought year of 1989 the rod catch was dramatically reduced probably because not many fish entered the river.

Gee (1980) analysed catch data from one year in 1977 from 10 private fisheries on the River Wye. He calculated the catch per hour per flowday for 5 $m^3 sec^{-1}$ intervals of flow. He found that median catch-flows were generally lower further upstream, ranging from 35 $m^3 sec^{-1}$ in the lowest fishery to 7.4 $m^3 sec^{-1}$ in the highest fishery equivalent to a range of 32 to 68% of a.d.f., although this observation was only based on one fishery high up and one low down, with the bulk of the fisheries in the mid reaches. Interestingly, only one fishery showed a significant relationship between catch per hour and flow. He stated that falling water level appears to be the most effective stimulant for a salmon to take an anglers lure although temporal changes in catches may be the result of angler behaviour.

Aprahamian and Ball (1995) attempted to examine how daily catch responds to flow using 27 years of catch data between June and October from one fishery on the River Derwent. Catches were standardised to reduce the bias of varying catches between years, and the data was calculated on a monthly basis to account for varying availability and behaviour of the salmon. They identified two levels of flow; one between 7 and 11 $m^3 sec^{-1}$ when salmon angling became successful; and another for each month when the standardised catch reached a peak around 40 $m^3 sec^{-1}$ (150 - 170 % of a.d.f.) in most months. In October the catch of fish seemed much less dependent on flow levels and a plateau of catches was reached once the flow reached 21 $m^3 sec^{-1}$ (83% of a.d.f.). Regression equations of standardised catch on flows was used to estimate the impacts of flow changes on catches of salmon. Thus in an average year it was predicted that in September reductions in flow would reduce catch by 0.14 fish per $m^3 sec^{-1}$ reduction. The figure at which salmon fishing became successful was approximately 9 $m^3 sec^{-1}$ cumecs and this was equivalent to 0.3 $m^3 sec^{-1}$ per metre width of river which agrees closely with Stewart (1969). The authors go on to discuss placing an economic value on cumecs of flow to salmon fishermen and the fishery. This is important in getting comparative values of water to fisheries and water users.

4.2 Brown trout

There is little information on the effect of flows on catches of brown trout. Obviously, catches can be mediated through two mechanisms, one is the direct impact of flow on fishing conditions and the other is the impact of flow on fish stock and thus the availability of fish. Most studies deal with the former not the latter mechanism. Alabaster (1986) and Alabaster and Reid (1988) analysed four years of angler returns from the River Don, Scotland. They found that the efficiency of anglers catches declined at high flows.

4.3 Coarse fish

As previously stated coarse fish consist of a large number of ecologically different species and therefore it should be expected that their response to and catchability at different flows will vary. The few studies that related angler catches to flow treat coarse fish as a single species.

North and Hickley (1977) monitored anglers catches for one season on the River Severn in response to complaints that releases of compensation flow from the upstream reservoirs reduced the anglers catches of coarse fish. They concluded that large scale releases reduced angling success in the upper and middle Severn but increased them in the Lower Severn. Small scale releases had some deleterious effect in March and October, but not in the summer.

Further analysis of the catches above by North (1980) showed that angling success was closely related to temperature. and the reason for the apparent impact of flow increases was its direct effect on temperature. Flow only had a negative impact in its own right above certain critical flows.

5. BIBLIOGRAPHY

Alabaster, J.S, Garland, J.H.N. and Hart, I.C. (1971) Fisheries, Cooling-Water Discharges and Sewage and Industrial Wastes. CEGB Symposium on Freshwater Biology and Electrical Power Generation. RD/L/M.

Alabaster, John S. and Reid, Graham A. (1988) Factors Affecting Angling Catches of Brown Trout in the River Don, Aberdeenshire. *Verh Internat Verein Limnol*, 23: 1715-1718.

Alabaster, J.S. (1970) River Flow and Upstream Movement and Catch of Migratory Salmonids. *Journal of Fish Biology*, 2: 1-13.

Alabaster, J.S. (1986) An Analysis of Angling Returns for Trout, *Salmo trutta* L, in a Scottish River. *Aquaculture and Fisheries Management*, 17: 313-316.

Alabaster, J.S. (1990) The Temperature Requirements of Adult Atlantic Salmon, *Salmo salar* L, during their Upstream Migration in the River Dee. *Journal of Fish Biology*, 37: 659-661.

Alabaster, John S. BSc, DSc, CBiol, FIBiol, FIFM. Habitat Modification and Freshwater Fisheries. *Proceedings of a Symposium of the European Inland Fisheries Advisory Commission.* Food and Agriculture Organisation of the United Nations. Butterworths, London.

Allan, I.R.H. (1966a) Counting Fences for Salmon and Sea Trout, and What Can be Learned From Them. *Salm Trout Mag*, 1965 London Conf Suppl, 176, 19-26.

Allen, K. Radway. (1944) Studies on the Biology of the Early Stages of the Salmon (*Salmo salar*). The Smolt Migration in the Thurso River in 1938. *The Journal of Animal Ecology*, Vol 13, 63-85.

Aprahamian, M.W. and Ball, M. (1995) Influence of River Flow on Rod Catch of Atlantic Salmon, *Salmo salar* L, from the Lower River Derwent, North-West England. *Fisheries Management and Ecology*, 2: 75-86.

Arnekeiv, Jo Vegar. and Kraabøl Morten. (1996) Migratory Behaviour of Adult Fast-Growing Brown Trout (*Salmo Trutta* L) in Relation to Water Flow in a Regulated Norwegian River. *Regulated Rivers: Research and Management*, Vol 12, 39-49.

Banks, J.W. (1968) A Review of the Literature on Upstream Migration of Adult Salmonids. *J Fish Biol* 1: 85-136.

Baran, Philippe., Delacoste, Marc., Dauba, Francis., Lascaux, J-Marc., Belaud, Alain. and Lek, Sovan. (1995) Effects of Reduced Flow on Brown Trout (*Salmo Trutta* L) Populations Downstream Dams in Fresh Pyrenees. *Regulated Rivers: Research and Management*, Vol 10, 347-361.

Baras, E. (1995) Seasonal Activities of *Barbus barbus*: Effect of Temperature on Time-Budgeting. *Journal of Fish Biology*, 46: 806-818.

Baxter, G. (1961) River Utilisation and the Preservation of Migratory Fish Life. *Proc Instn Civ Engrs*, 18: 225-44.

Baxter, George. River Utilisation and the Preservation of Migratory Fish Life. p 225-244.

Berry, J. (1932) Report of an Investigation of the Migration of Smolts in the River Tay during Spring 1931. *Fish Scot, Salmon Fish*, No. 6, pp 1-21.

Berry, J. (1933) Notes on the Migration of Salmon Smolts from Loch Ness; Summer 1932. *Fish Scot, Salmon Fish*, No. 1, pp 1-12.

Bjornn, T.C. and Reiser, D.W. Habitat Requirements of Salmonids in Streams. In *Influences of Forest and Rangeland Management on Salmonid Fishes and their Habitats* (Ed William R Meehan).

Boehne, P.L. and House, R.A. (1983) Stream Ordering: a Tool for Land Managers to Classify Western Oregon Streams. US Bureau of Land Management, Technical Note OR-3, Portland, Oregon.

Brawn, Vivien M. Behaviour of Atlantic Salmon (*Salmo salar*) during Suspended Migration in an Estuary, Sheet Harbour, Nova Scotia, Observed Visually and by Ultrasonic Tracking. *Can J Fish Squat Sci*, 39: 248-256.

Brayshaw, J.D. (1966) The Effect of River Discharge on Inland Fisheries. In *Symposium on 'River Management'*, pp 102-118 (Ed P.C.G. Isaac) London: McLaren.

Brayshaw, J.D. (1967) The Effects of River Discharge on Inland Fisheries. In *River Management* (Isaac, P.G. Ed) pp 102-118, London: MacLaren.

Brayshaw, J.D. The Effects of River Discharge on Inland Fisheries. In Isaac, Peter C.G. (Ed) River Management. *Proceedings of a Symposium Organised by the Department of Civil Engineering*, University of Newcastle upon Tyne, 20 and 21 September 1966.

Bunt, D.A. Chapter 2. Use of Rod Catch Effort Data to Monitor Migratory Salmonids in Wales. pp 15-32. In *Catch Effort Sampling Strategies. Their Application in Freshwater Fisheries Management*, Edited by I G Cowx, Humberside International Fisheries Institute, University of Hull. Fishing News Books.

Calderwood, W.L. (1908). The Life of the Salmon. London: Edward Arnold.

Clarke, D, Purvis, W.K. and Mee, D. (1991) Use of Telemetric Tracking Studies to Examine Environmental Influence on Catch/Effort Indices. A Case Study of Atlantic Salmon (*Salmo salar* L) in the River Tywi, South Wales. In *Catch-Effort Sampling Techniques and their Application in Freshwater Fisheries Management* (Cowx, I. Ed), pp 33-48, London: Blackwell.

Clarke, D, Purvis, W.K. and Mee, D. Chapter 3. Use of Telemetric Tracking to Examine Environmental Influences on Catch Effort Indices. A Case Study of Atlantic Salmon (*Salmo salar* L) in the River Tywi, South Wales. pp 33-48. In *Catch Effort Sampling Strategies. Their Application in Freshwater Fisheries Management*, Edited by I G Cowx, Humberside International Fisheries Institute, University of Hull. Fishing News Books.

Clarke, D. and Purvis, W.K. (1990) Migration of Atlantic Salmon in the Tywi System, South Wales. In N J Milner Ed, Fish Movement in Relation to Freshwater Flow and Quality. *Proceedings of Atlantic Salmon Trust/Wessex Water Workshop*, Bristol, 1989. Atlantic Salmon Trust, Pitlochry, pp 38-40.

Clarke, R.A. (1992) Influence of Stream Flows and Stock Size on Recruitment of Arctic Grayling (*Thymallus arcticus*) in the Chema River, Alaska. *Can J Fish Aquat Sci*, 49: 1027-1034.

Cowx, L.G. and Gould, R.A. (1989) Effects of Stream Regulation on Atlantic Salmon, *Salmo salar* L, and Brown Trout, *Salmo trutta* L, in the Upper Severn Catchment, UK. *Regulated Rivers: Research and Management*, Vol 3, 235-245.

Cowx, L.G, Young, W.O. and Hellawell, J.M. (1984) The Influence of Drought on the Fish and Invertebrate Populations of an Upland Stream in Wales. *Freshwater Biology*, 14: 165-177.

Cragg-Hine, D. The Assessment of the Flow Requirements for Upstream Migration of Salmonids in Some Rivers of North-West England. pp 209-215.

Craig-Hine, D. (1985) The Assessment of the Flow Requirements for Upstream Migration of Salmonids in Some Rivers of North-West England. In *Habitat Modification and Freshwater Fisheries* (Ed J.Alabaster), Butterworth, London, pp 209-15.

Craig-Hine, David. (1989) Regulation of Abstraction Rates. In *Water Schemes. The Safeguarding of Fisheries. Edited Proceedings on a Workshop held at the University of Lancaster, April 1988.* (Ed John Gregory.) Sponsored by North West Water Authority. Atlantic Salmon Trust. p 61-62.

Craig-Hine, David. (1989) Fisheries Considerations in the Setting of Prescribed Flows in River Abstraction Schemes. In *Water Schemes. The Safeguarding of Fisheries. Edited Proceedings on a Workshop held at the University of Lancaster, April 1988.* (Ed John Gregory.) Sponsored by North West Water Authority. Atlantic Salmon Trust. p 65-69.

Crisp, D.T, Mann, R.H.K. and 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.

Davidson, F.A, Vaughan, E. and Hutchinson, S.J. (1943) Factors Influencing the Upstream Migration of the Pink Salmon (*Oncorhynchus gorbuscha*). *Ecology* 24: 149-168.

Day, F. (1887) British and Irish Salmonidae. London: Williams and Norgate.

Debrowski, P. and Beall, E. (1995) Influence of Dewatering on Movements and Distribution of Salmon Parr (*Salmo Salar* L) in Relation to Habitat Characteristics in an Experimental Stream. *Bull Fr Peche Piscic*, 337/338/339: 267-275.

Dunkley, D.A. and Shearer, W.M. (1982) An Assessment of the Performance of a Resistivity Fish Counter. *Journal of Fish Biology*, 20: 717-737.

Ellis, A.E, Roberts, R.J. and Tytler, R. (1978) The Anatomy and Physiology of Teleosts. In *Fish Pathology* (Roberts, R.J. Ed), pp 13-54, London: Bailliere Tindall.

Frake, A. and Solomon, D. (1990) Fish Movement in Relation to Freshwater Flow and Quality. In *Fish Movement in Relation to Freshwater Flow and Quality* (Milner, N.J. Ed), pp 31-34, Pitlochry: Atlantic Salmon Trust.

Fraser, J.C. (1975) Determining Discharges for Fluvial Resources. Food and Agriculture Organisation Fisheries Technical Report 143, 103 pp.

Gardner, K.L.G. (1976) A Review of Factors which may Influence the Sea-Age of Maturation of Atlantic Salmon *Salmo salar* L. *J Fish Biol*, 9: 289-327.

Gandolfi, G, Pesaro, M. and Tongiorgi, P. (1984) Environmental Factors Affecting the Ascent of Elvers, *Anguilla anguilla* (L), into the Arno River. *Oebalia*, Vol X, 17-35.

Gee, Alun S. (1980) Angling Success for Atlantic Salmon (*Salmo salar*) in the River Wye in Relation to Effort and River Flows. *Fish Mgmt*, 11: 131-138.

Harriman, P. (1961) Water Control + Artificial Freshets = Atlantic Salmon. Maine Atlantic Salmon Federation. Document No. 2, 14 pp.

Harris, Douglas D, Hubert, Wayne A. and Wesche, Thomas A. (1991) Brown Trout Population and Habitat Response to Enhanced Minimum Flow in Douglas Creek, Wyoming. *Rivers*, Vol 2, 285-294.

Harvey, Bret C. (1987) Susceptibility of Young-of-the-Year Fishes to Downstream Displacement by Flooding. *Transactions of the American Fisheries Society*, 116: 851-855.

Hawkins, A.D. and Smith, G.W. (1986) Radio-Tracking Observations on Atlantic Salmon Ascending the Aberdeenshire Dee. Scottish Fisheries Research Report No. 36, 24 pp.

Hayes, F.R. (1953) Artificial Freshets and Other Factors Controlling the Ascent and Population of Atlantic Salmon in the LaHave River, Nova Scotia. *Bulletin of the Fisheries Research Board of Canada* 99: 47 pp.

Heggenes, Jan. (1988) Effects of Short-Term Flow Fluctuations on Displacement of, and Habitat Use by, Brown Trout in a Small Stream. *Transactions of the American Fisheries Society*, 117: 336-344.

Heggenes, J. and Traaen, T. (1988) Downstream Migration and Critical Water Velocities in Stream Channels for Fry of Four Salmonid Species. *J Fish Biol*, 32: 717-727.

Hellawell, J.M, Leatham, H. and Williams, G.I. (1974) The Upstream Migratory Behaviour of Salmonids in the River Frome, Dorset. *J Fish Biol*, 6: 729-744.

Hellawell, J.M. (1973) Automatic Methods of Monitoring Salmon Populations. In *International Atlantic Salmon Symposium*, St Andrew's (Eds M.W.Smith and W.M.Carter), International Atlantic Salmon Foundation, Special Publication Series, 4(1): 117-37.

Hellawell, J.M. (1976) River Management and the Migratory Behaviour of Salmonids. *Fisheries Management*, 7(3): 57-60.

Huntsman, A.G. (1939) Salmon for Angling in the Margaree River. *Bulletin of the Fisheries Research Board of Canada*, 57: 1-75.

Huntsman, A.G. (1945a) Variable Seaward Migration of Salmon. *Journ Fish Res Bd Can*, Vol 6, pp 311-325.

Huntsman, A.G. (1948) Freshets and Fish. *Transactions of the American Fisheries Society* 75: 257-266.

Hvidsten, N.A., Jensen, A.J., Vivaas, H., Bakke, O., Heggberget, T.G. (1995) Downstream migration of Atlantic salmon smolts in relation to water flow, water temperature, moon phase and social interaction. *Nordic Journal of Freshwater Research.* **70**, 38-48.

Jackson, P.A. and Howie, D.I.D. (1967) The Movement of Salmon (*Salmo salar*) Through an Estuary and a Fish-Pass. In *Irish Fisheries Investigations, Series A*. Dublin, No. 2, pp 28

Laughton, R. (1989) The Movements of Adult Salmon within the River Spey. Scottish Fisheries Research Report No. 41, 19 pp.

Laughton, Robert. The Movements of Adult Atlantic Salmon (*Salmo salar* L) in the River Spey as Determined by Radio Telemetry during 1988 and 1989. Scottish Fish Res Rep No. 50.

Lawson, J.D, Sambrook, H.T, Solomon, D.J. and Weilding, G. (1991) The Roadford Scheme - Minimising Environmental Impact on Affected Catchments. *Water and Environmental Management*, 5: 671-681.

Linfield, R.S.J. (1985) An Alternative Concept to Home Range Theory with Respect to Populations of Cyprinids in Major River Systems. *J Fish Biol*, 27 (Supplement A): 187-196.

Lisle, T.E. and Lewis, J. (1992). Effects of sediment transport on survival of salmonid embryos in a natural stream: a simulation approach. *Canadian Journal of Fisheries and Aquatic Sciences*, 49, 2337-2344.

Lucas, Martyn C. and Batley, Emma. (1996) Seasonal Movements and Behaviour of Adult Barbel *Barbus barbus*, a Riverine Cyprinid Fish: Implications for River Management. *Journal of Applied Ecology*, 33: 1345-1358.

Lucas, M.C. and Frear, P.A. (1997) Effects of a Flow-Gauging Weir on the Migratory Behaviour of Adult Barbel, a Riverine Cyprinid. *Journal of Fish Biology*, 50: 382-396.

Mann, R.H.K. and Winfield, I.J. (1992) Restoration of Riverine Fisheries Habitats. Institute of Freshwater Ecology R&D Note 105 for National Rivers Authority. 79 pp.
Martin, M.H. (1995) The Effects of Temperature, River Flow, and Tidal Cycles on the Onset of Glass Eel and Elver Migration into Fresh Water in the American Eel. *Journal of Fish Biology*, 46: 891-902.

McCleave, J.D, Power, J.H. and Rommel Jr, S.A. (1978) Use of Radio Telemetry for Studying Upriver Migration of Adult Atlantic Salmon (*Salmo salar*). *J Fish Biol*, 12: 549-558.

Menzies, W.J.M. (1916) Salmon of the East cost of Sunderland. *Fish Scot, Salmon Fish*, No. II, pp 1-27.

Millichamp, R.I. (1976) Some Thoughts on Water Abstraction on Migratory Fish Rivers. *Fisheries Management*, 7: 1-3.

Millichamp, R.I. and Lambert, A.O. (1966) On Investigations into the Relation Between Salmon Catch and Flow in the River Usk during the 1965 Season. In *Symposium on 'River Management'*, pp 119-123 (Ed P.C.G. Isaac) London: McLaren.

Millichamp, R.I. and Lambert, A.O. (1967) An Investigation into the Relationship Between Salmon Catch and Flow on the River Usk During the 1965 Season. In *River Management* (Ed P.C.G. Isaac)), MacLaren, London, pp 119-123. Proceedings of a Symposium Organised by the Department of Civil Engineering, University of Newcastle upon Tyne, 20 and 21 September 1966.

Mills D.H. (1968) Some Observations on the Upstream Movements of Adult Atlantic Salmon in the River Conon and River Meig, Ross-shire. International Council for the Exploration of the Sea, CM 1968/M:10.

Mills, C.P.R, Mahon G.A.T. and Piggins, D.J. (1986) Influence of Stock Levels, Fishing Effort and Environmental Factors on Anglers' Catches of Atlantic Salmon, *Salmo salar* L, and Sea Trout, *Salmo trutta* L. *Aquaculture and Fisheries Management*, 17: 289-297.

Milner, N.J (Ed) (1989) Fish Movement in Relation to Freshwater Flow and Quality. Workshop Proceedings, University of Bristol, 4-6 April 1989. The Atlantic Salmon Trust/ Wessex Water.

Munro, W.R. BSc. and Balmain, K.H. (1956) Observations on the Spawning Runs of Brown Trout in the South Queich, Loch Leven. *Freshwater and Salmon Fisheries Research*, 13, 17 pp.

Neville-Jones, A. (1968) The Relationship of River Flow and Salmon Angling Success in the River Towy. South West Wales River Authority Report.

North, E. (1980) The Effects of Water Temperature and Flow upon Angling Success in the River Severn. *Fish Mgmt*, 11, 1-9.

North, E. and Hickley, P. (1977) The Effects of Reservior Releases upon Angling Success in the River Severn. *Fish Mgmt*, 8, No. 3, 86-91.

Ottaway, E.M. and Forrest, D.R. (1983) The Influence of Water Velocity on the Downstream Movement of Alevins and Fry of Brown Trout, *Salmo trutta* L. *J Fish Biol*, 23: 221-227.

Peterman, Randall M. and Steer, Gregory J. (1981) Relation Between Sport-Fishing Catchability Coefficients and Salmon Abundance. *Transactions of the American Fisheries Society*, 110: 585-593.

Peters, J.C, Farmer, H.R. and Radford, P.J. (1973) A Simulation Model of the Upstream Movement of Anadromous Salmonid Fish. Water Resources Board Publication No. 21, 76 pp.

Peters, J.C, Farmer, H.R. and Radford, P.J. A Simulation Model of the Upstream Movement of Anadromous Salmonid Fish.

Potter, E.C.E. (1988) Movements of Atlantic Salmon, *Salmo salar* L, in an Estuary in South-West England. *Fish Biol*, 33 (Supplement A): 153-159.

Potter, E.C.E. (1988) Movements of Atlantic Salmon, *Salmo salar* L, in an Estuary in South-West England. *Journal of Fish Biology* 33 (Supplement A): 153-159.

Potts, W.T.W. and Malloch, A.J.C. (1991) River Flow, Atlantic Salmon (*Salmo salar* L) Movement and Rod Catch in the Aberdeenshire Dee. *Journal of Fish Biology*, 39: 755-764.

Pyefinch, K.A. and Mills, D.H. (1963) Observations on the Movements of Atlantic Salmon (*Salmo salar* L) in the River Conon and the River Meig, Ross-shire. In *Freshwat Salm Fish Res*, Scotland, 31: 24 pp.

Radford, P.J, Peters, J.C. and Farmer, H.R. (1972) Digital Simulation of the Upstream Movement of Migratory Salmonids. In *Proceedings of the International Symposium on Modelling Techniques in Water Resources Systems* (Ed A.K. Biwas), Ottawa, May 1972, 1: 21-38.

Roberts, R.J. (1978) The Pathophysiology and Systematic Pathology of Teleosts. In *Fish Pathology* (Roberts, R.J. Ed), pp 55-91, London: Bailliere Tindall.

Rottiers, Donald V. and Redell, Lori A. (1993) Volitional Migration of Atlantic Salmon from Seasonal Holding Ponds. *North American Journal of Fisheries Management*, 13: 238-252.

Sambrook, H. and Broad, K. (1989) Roadford Water Resources Scheme: Migration of Atlantic Salmon in the River Tamar. In *Fish Movement in Relation to Freshwater Flow and Quality* (N.J. Milner, Ed). Atlantic Salmon Trust/Wessex Water Workshop Proceedings, Moulin, Pitlochry, pp 29-31.

Saunders, J.W. (1960) The Effect of Impoundment on the Population and Movement of Atlantic Salmon in the Ellerslie Brook, Prince Edward Island. *J Fish Res Bd Can*, 17: 453-473.

Saunders, Richard L. (1967) Seasonal Pattern of Return of Atlantic Salmon in the Northwest Miramichi River, New Brunswick. *J Fish Res Bd Canada*, 24(1).

Sedgewick, S.D. (1962) In Discussion of "River Utilisation and the Preservation of Migratory Fish Life". *Proc Instn Civ Engrs*, 21: 900-902.

Shepherd, C.J. (1978) Husbandry and Management in Relation to Disease. In *Fish Pathology* (Roberts, R.J. Ed), pp 276-282, London: Bailliere Tindall.

Smith, G.W, Smith, I.P. and Armstrong, S.M. (1994) The Relationship Between River Flow and Entry to the Aberdeenshire Dee by Returning Adult Atlantic Salmon. *Journal of Fish Biology*, 45: 953-960.

Smith, G.W. (1991) Salmon Movements in Relation to River Flow: Estuarine Net Catches of Adult Atlantic Salmon, *Salmo Salar* L, and Tracking Observations. *Proceedings of the Institute of Fisheries Management*, 22nd Annual Study Course, p 37-46.

Solomon, D.J. (1978a) Migration of smolts of Atlantic salmon (Salmo salar L.) and sea trout (Salmo truth L.) in a chalkstream. *Environmental Biology of Fish.* **3**(2), 223-229.

Solomon, D.J. (1978b) Some observations on salmon smolt migration in a chalkstream. *Journal of Fish Biology.* **12**(6), 571-574.

Solomon, D.J. (1988) Tuning in to Avon Salmon. *Trout and Salmon Magazine*, 50-52,

Solomon, David J. and Paterson, Donald. (1980) Influence of Natural Regulated Streamflow on Survival of Brown Trout (*Salmo Trutta* L) in a Chalkstream. *Env Biol Fish*, Vol 5, No. 4, pp 379-382.

Solomon, D.J. and Potter, E.C.E. (1988) First Results with a New Estuarine Fish Tracking System. *J Fish Biol*, 33 (Supplement A): 127-132.

Stasko, Aivars B. (1973) Progress of Migrating Atlantic Salmon (*Salmo salar*) Along an Estuary, Observed by Ultrasonic Tracking. *J Fish Biol*, 7: 329-338.

Stewart, L. (1966) River Instrumentation as Applied to Fishery Problems. *J Instn Wat Engrs*, 20: 523-530.

Stewart, L. (1968) The Water Requirements of Salmon in the River Lune; the Water Requirements of Salmon in the River Leven. Lancashire River Authority Report.
Stewart, L. (1968a) The Water Requirements of Salmon the the River Lune. Lancaster: Lancashire River Authority Fisheries Department.

Stewart, L. (1968b) The Water Requirements of Salmon in the River Leven. Lancaster: Lancashire River Authority Fisheries Department.

Stewart, L. (1968c) An Analysis of River Flows in Relation to the Catching of Salmon by Anglers. Lancaster: Lancashire River Authority Fisheries Department.

Stewart, L. (1968d) The Movements of Salmon in Relation to Variations in Air and Water Temperatures. Lancaster: Lancashire River Authority Fisheries Department.

Stewart, L. (1968e) The Movements of Salmon in Relation to Darkness and Daylight. Lancaster: Lancashire River Authority Fisheries Department.

Stewart, L. (1968f) Salmon Movement in Rising, Falling and Steady River Flows. Lancaster: Lancashire River Authority Fisheries Department.

Stewart, L. (1969) Criteria for Safeguarding Fisheries, Fish Migration and Angling in Rivers (Loughborough Symposium, 1969). *Proc Instn Wat Engrs*, 23: 39-62.

Stewart, L. (1969) Criteria for Safeguarding Fisheries, Fish Migration and Angling in Rivers. *Year Book of the Association of River Authorities*, pp 134-149.

Stewart, L. (1973) Environmental Engineering and Monitoring in Relation to Salmon Management. *Internatl Atlantic Salmon Foundn Special Publ*, Series 4, 1: 297-316.

Stewart, L. (1975) Some Factors Affecting Fish and Fisheries. In *Report on the Symposium on Methodology for the Survey, Monitoring and Appraisal of Fishery Resources in Lakes and Large Rivers*. Panel Reviews and Relevant Papers, Vol I and II, EIFAC Technical Paper No. 23 (Supplement 1). Rome: FAO.

Stewart, L. MSc, MIBiol. The Influence of River Flows on Salmon Migration and Angling. *Flyfishers' Journal*.

Stuart, T.A. (1962) The Leaping Behaviour of Salmon and Trout at Falls and Obstructions. *Freshwater and Salmon Fisheries Research*, 28: 46 pp.

Swain, A. and Champion, A.S. (1968) Upstream Movements of Migratory Salmonids in Relation to River Flows on the River Axe, Devon. ICES.

Thompson, K. (1972) Determining Stream Flows for Fish Life. In *Proceedings, Instream Flow Requirements Workshop*. Pacific Northwest River Basins Commission, Vancouver, Washington, pp 31-50.

Trepanier, S, Rodriguez, M.A. and Magnan, P. (1996) Spawning Migrations in Landlocked Atlantic Salmon: Time Series Modelling of River Discharge and Water Temperature Effects. *Journal of Fish Biology*, 48: 925-936.

Webb, John and Hawkins, A.D. (1989) The Movements and Spawning Behaviour of Adult Salmon in the Girnock Burn, a Tributary of the Aberdeenshire Dee, 1986. *Scottish Fisheries Res Rep* No. 40.

Webb, John. (1989) The Movements of Adult Atlantic Salmon in the River Tay. *Scottish Fish Res Rep* No. 44.

Webb, John. (1992) The Behaviour of Adult Salmon (*Salmo salar* L) in the River Tay as Determined by Radio Telemetry. *Scottish Fish Res Rep* No. 52: 19 pp.

Welton, J.S, Beaumont, W.R.C. and Clarke, R.T. (1990) Factors Affecting the Upstream Migration of Salmon in the River Frome, Dorset. In N J Milner Ed, Fish Movement in Relation to Freshwater Flow and Quality. *Proceedings of Atlantic Salmon Trust/Wessex Water Workshop*, Bristol, 1989. Atlantic Salmon Trust, Pitlochry, pp 34-36.

White, H.C. and Huntsman, A.G. (1938) Is Local Behaviour in Salmon Heritable? *Journ Fish Res Bd Can*, Vol 4, pp 1-18.

White, Ray J. (1975) Trout Population Responses to Streamflow Fluctuation and Habitat Management in Big Roche-a-Cri Creek, Wisconsin. *Verh Internat Verein Limnol*, 19, 2469-2477.

Winstone, A.J, Gee, A.S. and Varallo, P.V. (1985) The Assessment of Flow Characteristics at Certain Weirs in Relation to the Upstream Movement of Migratory Salmonids. *Journal of Fish Biology*, 27: 75-83.

Youngson, A.F, Hansen, L.P, Jonsson, B. and Naesie, T.F. (1989) Effects of Exogenous Thyroxine or Prior Exposure to Raised Water-Flow on the Downstream Movement of Hatchery-Reared Atlantic Salmon Smolts. *J Fish Biol* 34: 791-797.