ATLANTIC SALMON TRUST/WESSEX WATER

# WORKSHOP PROCEEDINGS

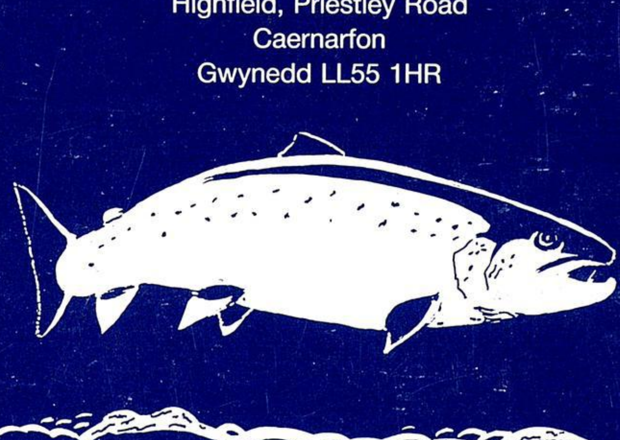
## FISH MOVEMENT IN RELATION TO FRESHWATER FLOW AND QUALITY

Held at University of Bristol

4th to 6th April 1989

Edited by N. J. MILNER

National Rivers Authority (Welsh Region)
Highfield, Priestley Road
Caernarfon
Gwynedd LL55 1HR



The Atlantic Salmon Trust
Moulin, Pitlochry
Perthshire PH16 5JQ
Telephone: Pitlochry (0796) 3439

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## FOREWORD

"After his two thousand miles, he rests,
Breathing in that lap of easy current
In his graveyard pool."

Ted Hughes

His behaviour during his two thousand miles journey is still largely cloaked in mystery, but we are beginning to know more about his behaviour once he noses his way into the estuary of his natal river.

Scientists in a whole range of rivers are seeking to learn how returning salmon react to tides, to changes in river flow and water quality; to learn how, why and when salmon are stimulated to move by characteristic fits and starts from estuary to spawning gravels. Such an understanding will be of great help in drafting operational rules for releases from reservoirs and for abstractions from rivers.

The Atlantic Salmon Trust felt that the time was ripe to provide an opportunity for these scientists to come together, in the belief that, despite the fact that each river has some unique characteristics, many elements of common patterns of behaviour could be distilled from their collective experience. This has indeed proved to be the case and the Trust believes that this report will lead not only to more people having a better understanding of the behaviour of salmon in rivers, but will also encourage an even greater research effort. Progress achieved to date, in a field of research that is in its comparatively early days, opens up the prospect of learning much more as work lending itself to statistical analysis is undertaken.

The Trust is grateful to Dr. Nigel Milner for summarising the papers given at the Workshop and, in particular, for the excellent way he has drawn together the threads of common experience which emerged from the papers and the lively discussions which followed their presentation.

Sir Ernest Woodroofe

CONTENTS

# 1. INTRODUCTION

Fish movements and the factors controlling them are of special importance for migratory salmonid fisheries management. Salmon stocks and the fisheries they support are entirely dependent upon the fishes' ability to move through estuaries and rivers and to disperse in ways that optimise catch and recruitment.

Our detailed understanding of these dispersal processes is not good. This is critical at a time of accelerating developments in water resource use that could influence fisheries by modifying the environmental cues that direct fish movements.

Several studies are in progress in Britain investigating various aspects of salmon (and sea trout) movements. This workshop provided an opportunity to review progress and collate results in order to establish common themes and to identify priorities for future work.

These proceedings will provide a summary of the presentations and conclusions for the participants. Perhaps more important is the non-specialist readership of those involved in salmon management either as anglers or managers and those responsible for managing and protecting water resources in a broader context. Hopefully, it will be valuable for such people to have a statement of present day issues and level of understanding in this rapidly evolving field.

Individual contributions are summarised in section 6. Their numbers are used as superscripts for reference elsewhere in the text. Methodology justifies a separate introductory section (2), because behavioural studies are crucially dependent on methodological technique and much debate centres on the validity and interpretation of some types of data.

Sections 3 and 4, drawing on the papers and discussion, synthesise conclusions under appropriate topics and identify priorities for future work.

2. METHODOLOGY

There are several ways to study fish movements, and these were reviewed by Potter in an introductory paper. A repeated theme was that many are complementary and which to use depends on the questions to be answered, physical features of location, time and resources. Rapid technological progress is improving the quantity and quality of data in most cases. The principal options and the type of data they generate are listed in table 1, and briefly summarised below.

2.1. Visual observation was employed by Webb [7] who not only observed fish from the bankside but followed salmon spawning behaviour in detail with remote controlled fixed underwater cameras. Passage over weirs and water falls has been employed historically and video filming is a standard technique for validating fish counters[3,8].

2.2. Sonar surveys do not appear to have been used in U.K. rivers, although they are common in marine surveys and have been used in lakes and reservoirs for assessing fish distribution and stock size.

2.3. Catch statistics are often the only data available for assessing fishery response to flow or W.Q. changes. The general view was that such data, if properly collected, can be valuable first level information for these purposes. Tracking studies have indicated that rod catches (or catch per effort, preferably) are an acceptable index of stock that has recently entered the river. Confounding factors include stock availability and changes in catchability. Rod catches provide the definitive measure of success in assessment of sport fishery performance. Fish availability may, for example be

**TABLE 1 Principal methods used to study fish movements**

| Method | Type of Movement Data | | Comments |
|---|---|---|---|
| | Past one Point | Between Two Points | |
| 1. Visual surveys | Yes | | Maily behavioural data |
| 2. Sonar surveys | Yes | | Little used in freshwater work |
| 3. Catch statistics (rods/nets) | Yes | Yes (with 5) | |
| 4. Fish counters | Yes | Yes (if 2 or more counters) | |
| 5. Conventional tagging | Yes | Yes (with method 3) | |
| 6. Trapping | Yes | Yes (with methods 5 + 3) | Also gives data on species age, and sex composition |
| 7. Tracking/acoustic | Yes | Yes | Limited life/range |
| Radio | Yes | Yes | Freshwater only |
| CART | Yes | Yes | Estuary and F.W. coverage |

assured by certain discharge or water quality conditions but they may not guarantee catchability. Clearly, catch statistics have an important role in evaluating environmental conditions for fishery protection.

2.4. Fish counters are in use by several organisations as part of routine monitoring and specific impact assessment schemes. At this workshop counter data were reported from the Frome (Dorset)[3], several spate rivers in North west England[8] and, briefly, for the North Esk[9] (Scotland).

All studies employed resistivity strip counters located on specially built crump or compound weirs. Recent design improvements render counter data more valuable than formerly and two models represented 'state of the art' - the Aquantic Logie counter and the North of Scotland Hydroelectric Board (NSHEB).

Advantages of counters for the study of fish movement were considered to be:

1) Automatic year round data collection. Low staff costs should result from this, but experience indicated that careful servicing is necessary to ensure continuing efficient operations.
2) Full river or partial river counting can be undertaken. On appropriate sites total fish numbers, passing a fixed point, can be directly measured.
3) Large quantities of data are generated over a wide range of flow and other environmental factors.

Disadvantages are

1) Installation costs are particularly high if constructed specifically for fisheries purposes. Historically, many counters have been included on gauging weirs constructed for water resources management.

2) Inability to distinguish salmon and sea trout may be a significant problem on mixed stock rivers. Size selectivity adjustment can reduce this depending on relative size of the two species; and rod catch (if accurate) or trapping data can be used to apportion numbers to species. NWWA have recalibrated size thresholds on some counters, but early results indicated that counting efficiency decreased with size. The new Logie (Aquantic) counter uses signal pattern as an index of size, and trials are underway to evaluate this with video cameras[9]. Recent evidence indicated that the size/signal relationship altered with water depth and conductivity, but corrections could be made for this.

3) Irrespective of other factors, fish availability can impair ability to distinguish relationships between movements and environmental factors[3]. This problem could be overcome (at a cost) by the use of paired counters[3].

4) Relating fish movements over a counter weir to ambient discharge gives no indication of the discharge that stimulated movement. Furthermore, because fish move variable distances and times in their passage upriver, discharges and hydrographs cannot be corrected to some predetermined point. Nevertheless empirical patterns referring to passage past the counter point have proved valuable for predicting migration flows, and have given rise to useful empirical models such as the "Stewart Formulae"[2].

Deployment of fish counters is continuing. NWW are installing a further four[8], and counters are being considered to supplement long term studies evaluating the Roadford scheme[1]. However in the context of the Hampshire Avon project, where data were required in the lower reaches of a river, high installation and associated costs (£1.3 - 1.6m) and reservations over aspects of reliability, counters were rejected in favour of tracking [2].

2.5 Conventional tagging has proved useful for establishing patterns of distribution, contributions to mixed fisheries and derivation of fisheries statistics. However, standard tags give poor data on behavioural responses to environmental factors.

2.6 Tracking by telemetric tags has revolutionised the study of fish movements, permitting the direct observation of fish responses to environmental factors. Potter effectively reviewed the history and present day methodology of these investigations, which have also been reviewed by a recent workshop on the subject (Varallo, 1988). A few essential points bear repeating.

1) There are two basic techniques : acoustic transmitters which work in saltwater and radio transmitters which are best in freshwater. For studies on fish moving through estuaries and into freshwater Combined Acoustic and Radio Tags (CART) are required.

2) Tags can give precise locations of fish, and there are two broad approaches to collecting this data. Firstly, continuous remote monitoring of fish passed fixed point(s); and secondly active direct recording of continuous behaviour of individual fish as they move through a system. Depending on the questions to be answered, various combined tactics may be employed.

3) In addition to positional data some tags can transmit signals which monitor simple physiological parameters of the fish (such as tail

beat frequency, or respiration rate) and/or environmental parameters such as salinity or hydrostatic pressure.

4) The quality of tracking data is closely dependant on the condition of fish when released. Much effort and development of handling technique has gone into ensuring that tagged fish behaviour is as close as possible to that of untagged fish. Exactly what the remaining differences are is not yet fully established.

5) Interpretation of tracking data is dependent on where fish are tagged, released and what was their previous history. Such sources of variation combined with inherent variability mean that large numbers of tracks need to be established before relationships with environmental factors can be rigorously investigated.

6) Many of the difficulties noted above are being overcome by greatly improved technology and technique. Consequently, large numbers of fish can now be tracked simultaneously.

3. PATTERNS OF FISH MOVEMENT

Biological requirements and objectives change dramatically during the salmon's homeward migration, as do environmental circumstances and the nature of directional cues. A feature of the Workshop was the diversity of river types in which studies have taken place (Table 2) and the corresponding variety of conditions under which salmon movements have been observed. It is not surprising that the immediate impression gained from collating several studies on movements and flows is of confusing variability. In fact, some common patterns do emerge allowing tentative generalisations to be proposed, that will doubtless require review in the light of further studies.

**TABLE 2 Characteristics of principle rivers**

| River | Source alt (m O.D.) | Length (km) | Catchment Area ($km^2$) | ADF (cumecs) | Baseflow Index (gauging stn) |
|---|---|---|---|---|---|
| Tamar | 586 | 72 | 926 | 21.0 | 0.46 (47001) |
| Fowey | 420 | 39 | 172 | 5.3 | 0.62 (48011) |
| Usk | 886 | 129 | 1,016 | 28.3 | 0.51 (56001) |
| Tywi | 792 | 6 | 1,113 | 38.6 | 0.42 (60010) |
| Ribble | 680 | 94 | 1,140 | 31.7 | 0.32 (71001) |
| Spey | 1,309 | 165 | 2,960 | 64.1 | 0.60 (08006) |
| Dee | 1,310 | 141 | 2,100 | 45.9 | 0.53 (12001) |
| North Esk | 939 | 64 | 745 | 19.7 | 0.52 (13007) |
| Tay | 1,214 | 136 | 4,970 | 168.6 | 0.65 (15006) |
| Frome | 305 | 54 | 414 | 5.7 | 0.84 (53007) |
| Hampshire Avon | 294 | 122 | 1,704 | 20.1 | 0.85 (43021) |

3.1. Estuarine movements and entry into freshwater

There are few direct observations on salmon entering from sea. Major technical difficulties arise when tracking in this environment, and there is no guarantee that the estuary a fish has entered is that of its natal river[9]. No new data were offered on mechanisms controlling movements at this stage. There was, however, limited evidence that on the Fowey (Potter, 1988) and Avon[2] arrival in the outer estuary coincided with late ebb or early flood. This could reflect some response to cues associated with brackish discharge, and would position fish for subsequent upstream movement on the flood.

Timing and rate of passage through estuaries varied greatly between studies. On the Twyi[5] most (75%) fish passed through within seven days of tagging. On the Frome[2] most passed beyond the saline zone within 14-48 hrs; and on the Spey and Tay[9] most entered the river within 24 hours. In contrast, on the Dee[9] and Fowey (Potter, 1988), much longer delays (weeks) were observed in some cases. Such differences can be variously explained in terms of physical structure, dimensions and hydrography of the estuaries, location of capture and release and prevailing discharge conditions. There are also differences between migrant groups, with fish entering later in the season tending to delay less in some rivers[5,9].

Accepting such variations, which may be river-specific, a generalised model of estuarine movement may be as shown in Fig.1. Within the main body of an estuary salmon movements tend to be tidally directed, up on the flood and down on the ebb. This pattern may last one tide cycle, or up to several weeks and seems to be little affected by river discharge. Fish may hold up in deeper sheltered locations, particularly those committed to river entry, or drop out of the estuary altogether. The

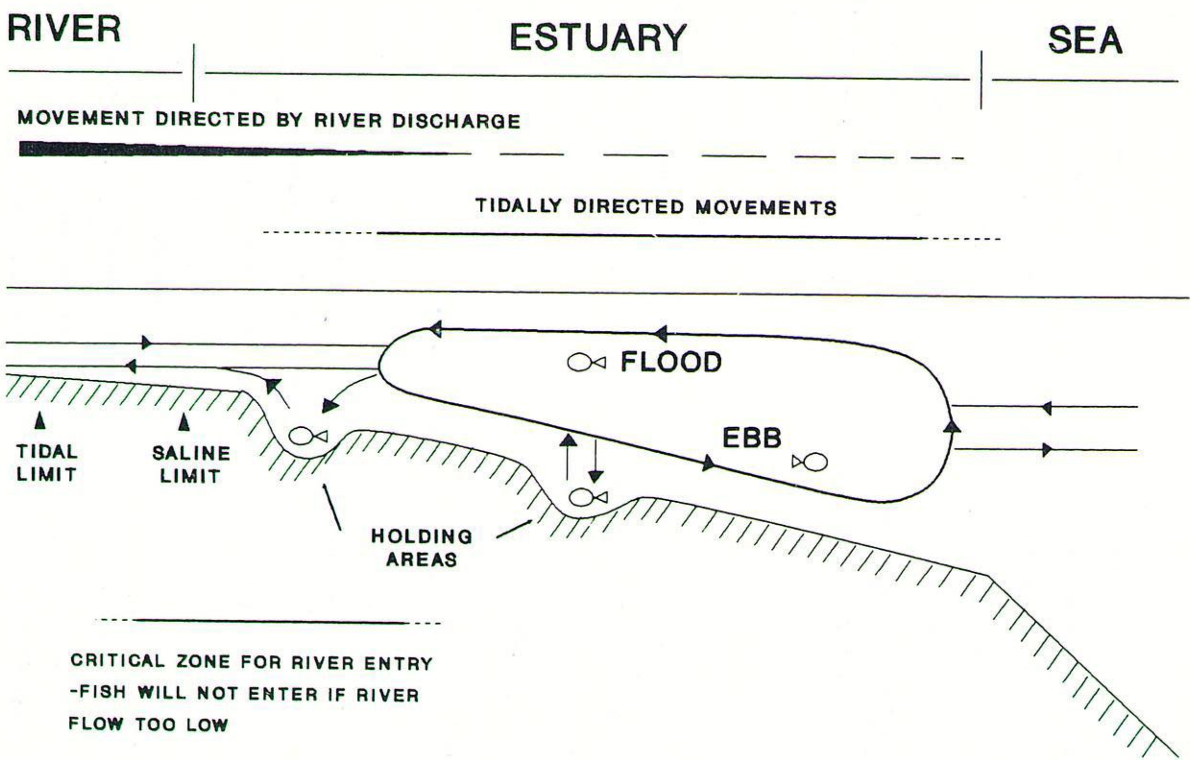



FIGURE 1 SCHEMATIC REPRESENTATION OF SALMON MIGRATION THROUGH AN ESTUARY

latter group, which includes native fish, may remain at sea for up to 130 days (Potter, 1988) before return or departure to other rivers.

Movement up into freshwater seems to be critically dependent on occurrence of adequate river discharge, a condition which has most influence on fish in the upper estuary. Whilst no common threshold was evident (and would hardly be expected given the many sources of variation), increase in discharge usually stimulates upstream movement. The Avon study[2] demonstrated that tendency to remain in the lowermost non-tidal and tidal reaches respectively was associated with discharges less than 13 and more than 10 cubic metres per second ($m^3s^{-1}$) respectively.

Fish usually entered the river at night[5,9] or dawn[2], but this pattern broke down under higher river flows when fish also entered during daylight.

At times of low discharge salmon accumulate in the estuary, possibly leading to high net catches, or they return to sea. Insofar as salmon are unlikely to move up beyond the saline limit if discharge is too low the upper part of an estuary (Fig.1) represents a critical zone where a 'decision' to move is confirmed. It is not clear to what extent duration of stay in the estuary or previous discharge regime potentiate response to freshwater discharge, but later running (= maturing?) fish seem to be less dependent on this stimulus. Although suspended migration (Brawn, 1982) occurs at low discharges and some tidal oscillations seem to be common at normal flows, a small proportion of fish was observed to move rapidly through the estuary, even on ebb tide, straight into freshwater from the sea[9].

There is an understandable temptation to regard freshwater as the dominant cue stimulating upstream movement from estuaries; after all it is easily measured and is central to water resource planning. However, several speakers emphasised the importance of other associated cues which may be the proximate factors to which fish respond e.g. turbidity, water chemistry (including pheromones), velocity, temperature and density. It was noted that environmental stimuli to which fish are directly exposed are difficult to measure in estuaries, especially where stratification occurs[9]. Thus causal links with movements are particularly hard to establish. The confounding influences of partial physical barriers e.g. bridges, constrictions and sills was also noted. Delay of fish at such structures has been reported.

Pollution too can impede passage in estuaries, but direct field evidence is difficult to collect. Three studies set out specifically to examine the influence of low DO[4,5,6], but due to chance climatic conditions only the Ribble study[4] had so far produced data on tracks coinciding with poor water quality.

3.2. Straying rates and "river entry"

It is clear from tracking studies that large numbers of non-native fish can be present in an estuary. These cannot normally be distinguished from natives during capture and tracking unless followed for long periods, preferably through to spawning. It is likely that the proportion of non-natives will decrease moving up an estuary, perhaps more sharply in the critical zone where directional cues may be more intensely experienced.

Straying rates reported from different studies are thus likely to be functions of capture location in the estuary[9]. Values are commonly around 10% (Table 3), but range from 0% in the Spey and Tay where tagging took place near the saline limit, to 27% in the Fowey where fish were captured throughout the estuary. The Fowey is a typical ria in which fully saline conditions extend well upstream and may thus encourage exploratory behaviour by non-native fish.

The definition of 'river entry' differs between biological and management contexts. In the biological sense, entry followed by spawning is an acceptable definition; but for management purposes entry insofar as it renders fish available to the freshwater (usually rod) fishery is an alternative. The distinction is a real one because of increasing evidence that straying between stocks is not confined to estuaries, but some fish may penetrate far (e.g. 20km plus in the Tywi[5]) into non-natal rivers before returning to sea[2,4,5,6]. Thus freshwater fisheries may be exploiting mixed stocks containing varying proportions of non-natives, according to their position in the river system and the proximity of other stocks.

It is likely that real biological straying is significantly lower than straying between fisheries. Estimates from rates of gene flow suggest it may be as little as 2% (Thorpe, 1986).

In terms of movements these observations on straying are important, for responses to flows and other factors could differ between native and non-native groups.

### 3.3. Distances and speeds in estuaries

Distances moved on tidal excursions are limited by estuary length and tidal amplitude. Fish penetrated the whole estuary length (7.5km) of the Fowey within 1.0 to 3.3 hr, and in the Tywi fish took 10.6 hrs or

TABLE 3 Numbers and fate of estuary tagged salmon

| River | No. tagged | Lost before entry | Recorded in river | Recorded in other rivers or commercial fisheries | 'Lost' in river | No. in rod catch | No. in net catch | Left river before spawning | Other |
|---|---|---|---|---|---|---|---|---|---|
| Fowey | 36 | | 17(47%) | 3+ (27%) | | 7 | (3-5%) | (23%) | 1 found by diver |
| | (CART) | | 14(56%) | | | | | | |
| Tamar | 91 | 34 | 47 | 10 | | 3 | 3 | | |
| Hampshire Avon | 262 | 10% | (50%) | (10-15%)[1] | (10%) | (10%) | (5%) | | |
| Ribble | 18 | | 4(22%) | 1(6 + %) | | | | | |
| Tywi | 94 | 18(19%) | 61(65%) | 8+(9+%) | 9(15%) | 8(%) | 2(%) | 7(%) | |
| Usk | 56 | 13[2] | 23(41%) | 5+(9+%) | 4[3] (7) | 3(5) | 4(7) | | |
| Dee | 79 | | 49(62%) | 4 | | 3 | 2 | | |
| Tay | 87 | | 54 | 0 | | 2 | 29 | | |
| Spey | 24 | | 24 | 0 | 2 | 1 | 0 | 6 | |

1 These fish found in R. Stour, which shares a common estuary
2 Some may have returned to sea undetected
3 One thought to have died post spawning

more (median 77 hrs) to travel 16km. In the Ribble and Usk estuaries, tidally directed movement often resulted in fish ending up at the outer estuary around low water when water quality conditions were at their worst.

Speed over the ground was directly measured in some continuous tracking work[9], or minimum estimates inferred from fixed listening stations (FLS). Differences were apparent between fish seemingly committed to river entry and those wandering in the estuary. In the middle Fowey directly measured average speeds of 48 $cms^{-1}$ (range 35-110) and 33 cms-1 (range 35-110)and 33 $cms^{-1}$ (range 20-40) respectively were recorded. Movement of the latter group consisted of alternative position holding and drifting. In contrast, preliminary measurements on the Usk[6] indicated that fish moving directly to freshwater moved more slowly (0.2$cm^{s-1}$) than those moving up and down on the tide (0.6 $cms^{-1}$). These values are much lower than the Fowey data, being based on FLS. Similarly FLS minimum speed estimates from the Tywi[5] were low (0.3 $cms^{-1}$).

## 3.4. Movements in freshwater

Salmon can enter rivers throughout the year, but there are pronounced seasonal differences mainly associated with arrival of migrant groups comprising fish of different sea age. Most U.K. rivers have summer and autumn runs, dominated by 2 and 1 sea winter (SW) fish respectively; but nowadays big runs of early running (February - April) spring fish (2 and 3SW) are restricted to the Scottish East coast rivers. Environmental conditions, particularly temperature and river discharge, experienced by these groups are very different, and seem to have led to different behavioural strategies to optimise energy expenditure[9]. With this proviso a recurrent pattern from tracking studies was the division of upstream migration into three major phases (Fig.2).

1. Rapid river entry
2. Quiescent phase
3. Spawning run

In terms of their total adult period in freshwater a fourth phase, kelt downstream migration is also important, but due to limits of tag duration few data are yet available.

### 3.5.1. Rapid river entry

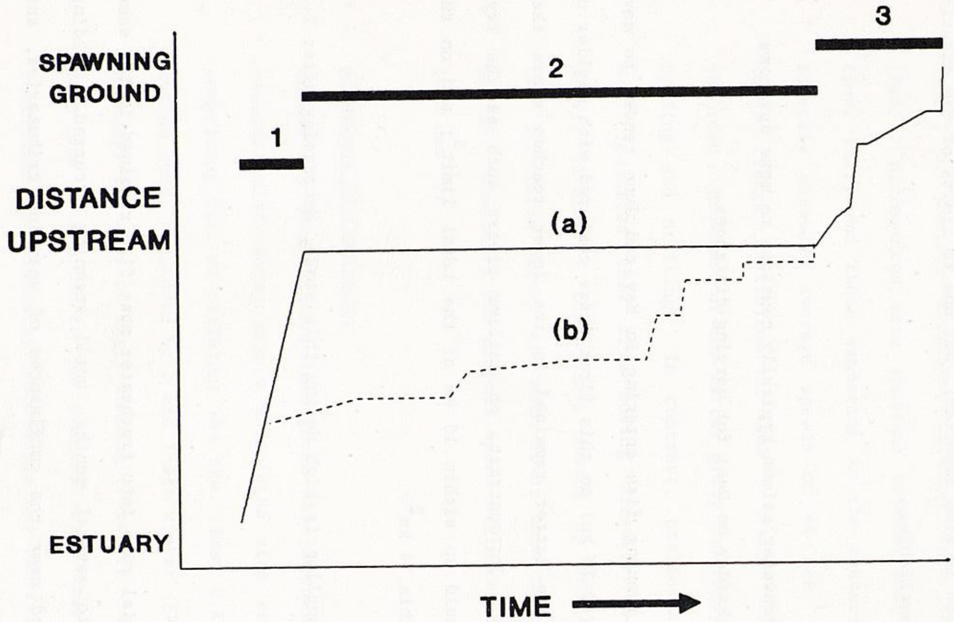
On moving into freshwater salmon typically continue to move upstream rapidly (e.g. 4-8 km/day on Dee) for varying distances.

On the Dee early running fish entering in May and June tended to move further upstream (60-70 km) on this first phase compared with earlier or later migrants. The latter remained in the lower reaches where they usually spawned[9]. In contrast, on smaller rivers such as the Twyi most fish (80%) held up within 15 km of the total limit[5]; and on the Avon most were within 34 km[2].

Vulnerability to angling is high during this stage, decreasing after 2-3 weeks[1,5].

### 3.5.2. Quiescent phase

Following the initial rush into freshwater most fish remained in the same location for up to several months, until spawning occurred. Holding frequently occurred near the confluences of spawning tributaries, and also in deep pools elsewhere. Some fish, mainly but not entirely




1. RAPID RIVER ENTRY
2. QUIESCENT PHASE (a) LONG DURATION HOLDING
(b) DISCONTINUOUS MOVEMENT
3. SPAWNING RUN

FIGURE 2 THREE PHASE UPSTREAM MIGRATION OF SALMON IN A RIVER non-natives, dropped back to sea after periods of up to 15 days having penetrated many kilometres upstream[5,6,9].

In all studies varying proportions of fish continued to make slower discontinuous progress upstream (Fig.2); a behaviour that seems to be less common in smaller rivers. In the longer Scottish rivers such movements were common in earlier running fish, and were often associated with increases in discharge. This sometimes resulted in fish moving into lower reaches of tributaries from where they dropped back on the receding flood. However, in most cases, fish in the quiescent phase responded inconsistently to spates. On the Twyi a large proportion failed to move on summer floods (e.g. 81% in August), although most movements that did occur happened on floods and there was an increasing likelihood of flood-induced movement as spawning approached. Similarly on the Avon large summer floods had little effect on quiescent fish (e.g. a 25 $m^3 s^{-1}$ spate in August 1986 caused 10% of fish to move and in July 1987, none moved during a flood).

Vulnerability to angling was usually low during this, the longest phase of freshwater adult residence. However, temporary increases occurred during discontinuous movements.

3.5.3. Spawning run

By Autumn most fish responded positively in all rivers to increased flow, a change in behaviour that was tentatively attributed to physiological changes accompanying maturation[5,9]. Discontinuous movements often occurred at this time, each jump being initiated by rising discharge. Late running fish typically moved upstream independently of discharge[3].

Movement to spawning areas was rapid, but tributary entry and distance moved was closely related to discharge. Usage of the smallest headwater streams, where depth, velocity and wetted area are very flow dependent, varied greatly according to annual discharge patterns[7]. Modified discharge regimes resulting from, for example, land use such as upland forestry may therefore restrict access to spawning grounds.

Webb's detailed study of spawners in the Girnock Burn[7] suggested that whilst there seems to be a threshold spate below which no fish would enter the burn, above this the threshold for individual fish may be dependent on their previous exposure and acclimation to floods. Thus, those having experienced fewer floods would require a smaller spate to stimulate entry. There were interesting behaviour differences between the sexes. Prior to spawning males moved more extensively and frequently than females, typically 3-8 km in the Dee. Moreover, males were able to detect the presence of females ready to spawn over long distances (2-3 km), and rapidly moved up to join them.

The ability to follow fish through spawning and during the downstream migration is, in most studies, constrained by tag life - the Girnock fish were tagged in the tributary late in the spawning migration. Limited data indicated that post-spawning females moved rapidly back downstream, but most males remained for long periods in the spawning area usually dying there through exhaustion[7].

## 3.5. Environmental factors influencing freshwater movements

### 3.5.1. Light

Under low to medium discharge most fish moved at night[1,2,3,9]. At higher discharge this pattern broke down and fish also moved during the day. This effect was attributed to reduced light penetration during floods due to increased colour, turbidity and suspended solids[3].

3.5.2. Temperature

In discussion reference was made to inhibitory effects of high (e.g. >21.5$^{\circ}$C) and low (e.g. <5$^{\circ}$C) temperature. The energetic costs of movement outside an optimum temperature band may account for the timing of river entry and subsequent behaviour displayed by different migrant groups. Investigations into the physiology of migration and strategies to optimise energy expenditure are the subject of continuing Scottish work[9]

3.5.3. River discharge

The advent of radiotracking has brought a greater insight into salmon responses to river flow and will improve interpretation of the extensive database available from fish counters. As most of this work is still progressing firm conclusions have yet to be reached, but some general principles are being confirmed or revised, as follows:-

(i) Generally, median flows used for migration on spate streams are higher than median available flows. The reverse can obtain on groundwater fed rivers[3].

(ii) Low flows and big floods inhibit movement. Within this migration band (Cragg-Hine, 1985) the size and timing of flow variation required to support migration is very variable between rivers, seasonally and between years on any one river.

(iii) Summer spates are essential to bring fish up from estuaries, but have a far less predictable effect on fish already in the river. During the quiescent phase there seems to be a large pool of fish that will not respond to spates. Perhaps their inclination to move is related to distance from their intended spawning area.

Paradoxically, the movements that do occur are commonly associated with spates. Thus, for the majority of fish, flow variation (fish move on rising and falling hydrographs) seems to be a necessary but not always sufficient condition for movement. Fish in big spate rivers e.g. Dee, Spey, or groundwater fed rivers e.g. Avon, appear more inclined to move independently of flows than those in smaller spate rivers e.g. Tamar. This could be a function of channel dimensions under low flow conditions.

(iv) Flow patterns supporting movement seem to be similar to those maximising angling catch (because catchability is greatest in moving fish). This is important because if it proves to be a reliable conclusion, then rod catch statistics may be valuable in preliminary assessments of in-season flow requirements (see Section 2).

(v) Whereas river discharge is the variable normally measured, the proximate factor(s) stimulating movement may be merely associated with discharge, e.g. turbidity, colour, suspended solids, chemisty, velocity. There are still no data allowing separation of the several variables changing with flow. Whilst scientifically frustrating this may not matter in practice, providing discharge bears a constant relationship with the controlling variables. However, under certain circumstances, such as reservoir release or pollution, this could break down; it will therefore be of value to understand the roles and relative importance of the various stimuli.

## 4. MANAGEMENT APPLICATIONS

Proper management of the water cycle is an integrated activity that includes at least three areas directly influenced by fish movement studies, (i) environmental protection, (ii) water resource use, (iii) fishery management.

### 4.1. Environmental Protection

In principle environmental protection is achieved by setting appropriate environmental quality standards (EQS) to protect designated uses. Unfortunately, the standards required to protect fish passage in terms of water quality and, more problematic, discharge regime are not precisely known. Legislative developments to give statutory backing to Environmental Quality objectives (EQOs) and EQSs are in hand and coincide with greater demands on rivers for a variety of industrial and domestic uses. In addition, forthcoming changes in E.C. law will require developers to identify environmental impacts and propose means of mitigation. It is therefore important that standards which are eventually adopted are correct in order to optimise water use and safeguard fish stocks. All of the studies reported at the workshop were generating data contributing to the derivation of such standards.

6Several activities potentially affecting flow and water quality were identified that in some cases were being specifically addressed by projects.

(i) Abstraction (surface or groundwater) for domestic, industrial and agricultural supply[1,2,5,8].

(ii) Intercatchment transfer.

(iii) Storage and release for water supply[1,2,8].

(iv) Storage and release for flood control[5,8].

(v) Storage and release for hydroelectric power generation[1,9].

(vi) Tidal barrage development (amenity and tidal power).

(vii) Upland land use and its influence on W.Q. and hydrological characteristics[5,7].

(viii) Sewage and water treatment works discharges[4,5,6].

(ix) Industrial discharges.

Movement studies are now becoming standard components of environmental impact assessments (EIA) for major schemes such as reservoirs or tidal barrages. As discrete pieces of work their objectives are clear, they are catchment-specific and have dedicated funding. A less satisfactory situation exists for equally important topics, perhaps more diffuse but of general application (e.g. (i), (iii), (iv), (vii), (viii) and (ix) above), in which data are gathered piecemeal and opportunistically from other work. A more unified strategic approach to such research is called for, co-ordinated and funded through a central organisation such as the National Rivers Authority which will be responsible for the setting of EQOs and EQSs for England and Wales.

All the reported studies concerned adult salmon. Attention was drawn to the limited work on juveniles, particularly smolts. This partly reflected the difficulties of safely tagging small, vulnerable fish; but was also thought to represent the lower priority afforded to this stage on account of the less direct impact of modified flows on their migration. However, an area of concern with smolts was their passage through impounded estuaries and associated exposure to poor water quality and physical damage from turbines.

4.2. Water Resources and Flow Manipulation

In addition to meeting EQSs, water resource and flood prevention developments need to maximise use and storage of water. There is scope for this if natural discharge regimes exceed requirements for migration[2] and angling.

Detailed control rules cannot yet be reliably extrapolated to all rivers from the still small number of studies undertaken, although success in developing 'local' rules has been achieved on the basis of extensive counter data in the North West Region (Cragg-Hine,1989). This situation may change in the future as data accumulate. However, it is likely that on big schemes conservation and fishery interests will always want to see convincing evidence that rules have been properly set and that they work. Effective schemes will variously include:

(i) Prescribed minimum flows (i.e. flows below which no unsupported abstraction is allowed) to protect low summer discharge.

(ii) Identification of migration bands (ranges of flows known, by investigation, to support fish passage), making due allowance for seasonal requirements.

(iii) Protection of summer spates, to ensure fish move up from estuaries and are given the opportunity to move during their quiescent phase. **N.B.** The levels and duration of such flows are not known.

(iv) Usage of the tops of spates to maximise water storage.

(v) Protection or enhancement of spawning flows, to maximise use of headwater spawning streams.

(vi) Consideration of other ecological impacts associated with various discharge manipulation schemes, e.g. water quality, wetted area or velocity effects on aquatic flora and fauna.

the last inclusion in this list appears almost as a 'catch-all' item, yet is fundamental to effective environmental management. Flow control and protection must be planned and managed in the context of the total river environment. This means, for example, that setting of standards for flows and water quality should be linked; and that fisheries requirements are not considered in isolation from other components of the river corridor ecosystem.

### 4.3. Fisheries Management

Fish movement studies produce 'spin off' data of great value to fisheries management. Tracking data are effective in showing where different migrant groups spawn within a large river system[9]. This will assist in establishing spatial distribution of spawning groups, in interpreting consequences of any selective exploitation and identifying appropriate broodstock. The existence of mixed stock fisheries within rivers, shown by radiotracking, will also have implications for the way these fisheries are managed. Counter data provide a direct measure of run size; and tracking data will complement normal mark-capture methods by providing information on riverine distribution and catchability which can otherwise confound estimates of migratory populations. Radiotag data can also provide an unambiguous estimate of exploitation on in river stock. More unusually they provide a way to estimate the extent of the illegal fishery and in exceptional cases to track fish after they have been taken from the river. Enforcement strategies might, for example, include radiotagging of fish found in illegal nets.

## 5. CONCLUSIONS

It is salutory to reflect that our understanding of salmon movements, insofar as it practically modifies the way in which river flow or water quality are regulated, has scarcely altered in twenty years. The principles set out above (3.6.3) are virtually the same as those established in the 1960s and early 1970s (e.g. Baxter, 1961; Brayshaw, 1966; Banks, 1969; Alabaster, 1970; Arnold, 1974; Fraser, 1975). However, this situation is rapidly changing as recent improvements in methodology lead to increases in quantity, but above all quality, of data. This is improving basic descriptions of fish behaviour as well as allowing an increasingly analytical approach, as it becomes practical to develop and test specific hypotheses. Radiotracking in particular has revealed new information in many areas, including previously unobtainable data on intercatchment straying and migration phasing of individual fish.

Whilst it will be a major improvement when flow requirements have a more robust statistical basis, the variability already established shows that several years data are necessary to achieve this. Long term studies are costly and require secure funding. A significant part of this should continue to come from developers where appropriate; but such investigations inevitably arise in an unplanned way, and may only be of short term (e.g. 1-3 years) duration for impact statement purposes. Post-scheme monitoring also needs to be incorporated into scheme costs, and this is the present-day trend. However, there is a need for such work to be centrally co-ordinated and compatible with any national core programme. A unified strategy for salmonid movement work would at least provide for standardisation of nomenclature, basic data analysis and reporting, so that disparate studies can be more easily compared. This would ensure that priorities are addressed in a programme that gives value for money.

Priorities change, and it is always a risky business drawing up lists. However, on the basis of discussion at this workshop the following three could be regarded as dominant.

(i) Accurate setting of minimum summer flow requirements for migration and angling. This, in relation to abstraction consents and water resource schemes.

(ii) Orientation and movements in estuaries. This, in the context of estuarine barrage developments for tidal power and estuarine water quality impacts resulting from domestic and industrial discharges.

(iii) In addition to these applied aspects, fundamental research into migration strategies in the context of energetics and maturation is of great importance in understanding behaviour of migrant groups. As fisheries management leans more to conservation of phenotypic and genetic diversity this information will aid definition of environmental requirements of such groups.

Finally, to end on a topical note, global climate change and consequent shifts in environmental regimes are likely to have a profound effect on salmon movements. A task for the future will be to predict and detect such changes against a background of numerous other pressures on the species.

## 6. SUMMARIES OF PAPERS

Nine papers were presented by workers from the water authorities, (mostly now transferred to the National Rivers Authority), government laboratories - (Ministry of Agriculture, Fisheries and Food; Department of Agriculture and Fisheries for Scotland) and the Freshwater Biological Association (now the Institute of Freshwater Ecology). In this section brief details are given regarding project objectives, approach/methodology, principle conclusions and likely further developments. For further details the authors should be contacted directly.

### 6.1 Paper 1 Roadford Water Resources Scheme : Migration of Atlantic salmon in the River Tamar (H. Sambrook and K. Broad)

Mr. H. Sambrook, NRA South West Region, Southcott,
Chapple, Launceston, Cornwall, PL15 7AX.

Roadford Reservoir Scheme is a complex water resources development involving the conjunctive use of six rivers and three reservoirs in North and South West Devon. The operation of the Scheme will result in changes to natural river flows due to the implementation of new abstraction licences and prescribed flow rules. Investigations will be required to assess the impact of the Scheme on the aquatic environment and fisheries of each river catchment, in particular the migratory salmonids.

The general aim of the studies on the River Tamar was to provide data that will assist in setting prescribed flows and in the preparation of operating rules relating to regulation releases and the use of the abstraction point. In the early years attention was focused on the major abstraction point at Gunnislake in the lower Tamar. Specifically the project set out to investigate patterns of salmon movements from the upper estuary and through the river under a range of natural flows and water quality conditions. Movements past Gunnislake Weir, the tidal limit, were given special consideration.

Since 1985, the project has employed various techniques including traps, catch statistics and radio telemetry. To date, 289 salmon have been tagged with radio transmitters and released into the lower river and the upper estuary. Salmon movement data are complemented by a network of hydrometric gauging stations and continuous water quality monitoring stations. Computer modelling is in hand to allow better interpretion of the telemetry data by providing "instantaneous" flows at specific locations along the river. This approach is fundamental to the analysis of salmon movements and the understanding of their behaviour in response to "real" flow events.

The paper described the pathway of analysis used for the telemetry data based on the application of variables to "distance-time plots" and "between-scanner movements".

Detailed analysis of the Gunnislake trap data and radio telemetry information gave the following results:-

1. Salmon select the higher flows on which to move in years when there is a wide range of flows available. Under these conditons a greater proportion of the flows in the lower range are not used for migration. In contrast, in years when the range of flows is narrow salmon are apparently forced to move at the lower flows.
2. The majority of salmon movements occur on falling water, irrespective of spate magnitude.

3. In summer months salmon show a preference to migrate on relatively steady flows where the change in flow rarely exceeds a factor of 2 over the period of movement.
4. Migrating salmon show a preference for night time movement under low flow conditions.
5. Salmon moving during the day utilise a wider range of flows than those moving at night.
6. For flows <25 cumecs, net speed over the ground appears to be independent of flow. But for flows of 25-120 cumecs there is some evidence that speed is inversely related to flow.
7. Speed over the ground rarely exceeds 1 body length/second (range 0.1-1.4 bl/sec.).
8. Three major phases of movement are recorded i.e. an initial active phase of entry into the river, a dormant phase and a second active phase associated with spawning behaviour.

A more refined analysis relating movement to "instantaneous" flows is anticipated when the computer models become available later in 1989. A future development is likely to be the installation of electronic fish counters to complement the radio telemetry and trapping data.

6.2 Paper 2 <u>Fish movement in relation to freshwater flow and quality (A. Frake and D. Solomon)</u>

Mr. A. Frake, Wessex Rivers, Avon and Dorset Area Office,
2, Nuffield Road, Poole, Dorset, BH17 7RL.

Abstraction from The Hampshire Avon forms a very important part of the long term resource strategy for South East Dorset and West Hampshire region of Wessex Water authority. It is estimated that about 35% more water will be required over the next 25 years. The Avon will contribute to this with future strategies restricting ground water developments and placing increasing reliance on bankside storage and direct abstractions from the lower reaches. This five year project was begun in 1986 to evaluate the impact of various resource options. The main objectives were: 1) to describe the current patterns of salmonid movements in the estuary and up river, and how this is influenced by river flows and other environmental variables, 2) to predict the effect of any proposed changes on the pattern of movement. 3) to suggest guidelines for abstraction that secure water resources developments and protect fish movement.

Three different methodologies were considered : fish counters, fish traps and fish tracking. Counter data would only have been valuable in this context if available near the head of tide, and then would need complementary tracking observations to give information on fish availablity. Installation costs of counters and traps were prohibitively expensive, and radio tracking was the chosen method - a technique that

would give "spin off" information on distribution, behaviour and angler exploitation. Fish were captured by commercial nets at Mudeford, released in Christchurch harbour and tracked by combination of fixed listening stations (FLS) and active tracking. Flow and certain other environmental variables were monitored at a number of points. Observations were made in two main rivers, the Avon and Stour, which share a common estuary.

In the first three years 261 salmon were tagged (between April and end July) but sea trout tagging has been discontinued for practical reasons. The fate of tagged fish was described. Typically, of those marked at the harbour mouth, 10% disappear without trace (through e.g. tag failure, return to sea/other rivers), 5% are recaptured by nets, 10-15% are recorded in other nearby rivers, 10% are reported caught by ànglers, and

10% are "lost" during the freshwater phase) (e.g. tag failure, unreported capture). Thus by autumn about half the tags are still in useful service. Most fish (90%) entered the Avon.

**Results and conclusions so far**

1. Fish generally leave saline influence 12-48 hours after tagging. Most then pass the tidal limit within a few hours and pass up river varying distances. However, as the season progresses (June - July), increasing numbers of fish delay between the saline limit and the tidal limit, some remaining there for several weeks. More fish also tend to remain in the lower non-tidal reaches.
2. The tendency to remain in the lower reaches appears to be influenced by the prevailing freshwater discharge. An increasing tendency to remain in the lowermost non-tidal reaches and tidal reaches appears to be associated with the hydrographs falling below about 13 $m^3$/sec (1120 Ml/d) and 10 $m^3$/sec (864 Ml/d) respectively. Elevated discharge following heavy rain in July 1987 (flows increasing from about 10 to 19 $m^3$/sec) was associated with a great reduction in tendency to remain in lowermost reaches.
3. At all flow levels observed so far during the tagging season (lowest about 9 $m^3$/sec) some fish penetrated several tens of kilometres before laying-up.
4. After entering fresh water fish continue to move, on a discontinuous basis, for up to about three weeks, though many cease upriver migration within days. While this first phase of riverine movement takes a few fish as far as Salisbury (60 km above the tidal limit) or even beyond, most fish remain downstream of Fordingbridge (35km). After this migration there is little movement until the Autumn.
5. Large summer spates may have a minor effect upon laid-up fish. Flows peaking around 25 $m^3$/sec in late August 1986 moved about 10% of fish laid-up in the lower river, but a similar event in July 1987 failed to stimulate movement of any laid-up fish.

6. Increasing flows following heavy rain in October in each of the three years of study have been associated with large scale movements of most fish within the river. Movement then occurs on a discontinuous basis, stimulated by further increases in discharge, until spawning time from mid-December onwards. Most spawning takes place in the region of Salisbury or in tributaries upstream.
7. The observations on the relationship between migration and distribution within the river and flow, and on the diurnal patterns of movements around the tidal limit, would allow a preliminary assessment of the likely impact of any proposal to abstract water and would suggest appropriate control rules.

6.3 Paper 3 <u>Factors affecting the upstream migration of salmon in the River Frome, Dorset. (J.S. Welton, W.R.C. Beaumont and R.T. Clarke)</u>.

Dr. J.S. Welton, IFE, The River Laboratory, East Stoke, Wareham, Dorset, BH20 6BB.

This paper described the results of long term fish counter studies on the River Frome, carried out since 1973 to examine some of the factors affecting salmon movements.

The resitivity counter (North of Scotland Hydroelectric Board (NSHEB) models have been used) site is at East Stoke, 12km upstream of the tidal limit. Electrodes are located on a 3.5 m wide central gauging weir, with flood spill weirs on either side. Velocity over the strips varies seasonally between 0.5 and 3.0 $ms^{-1}$.

Annual upstream counts have ranged between 952 (1976) and 4,907 (1987). A bimodal pattern of summer and late autumn runs was evident from monthly counter data alone, but when daily records were compared with age data 4 migrant groups were identified. The numerically smallest group, being 3/4 sea winter (SW) fish, occurred in March/April, then 2 SW fish in May/June followed by 1 SW fish in June/July and a late autumn (October/November) run of mixed age group, mainly stale fish that had remained in the river for some time.

The data were split into daily and four-hourly counts and mean flows in order to examine the effects of changing discharge and diurnal movements/patterns.

Effects of discharge change

When annual data were combined (1973-87) there was no significant difference between numbers moving on rising or falling discharge. But when July and November data were considered separately some tendency for earlier fish to move on falling discharge was suggested. Interpretation of counter data for this purpose was complicated by not knowing where fish were when stimulated to move, and by seasonal differences in the availability of rising/falling conditions. The response to spates varied seasonally. In the early season (January to August), there was little correlation between movements and flow peaks, although low base flows were thought to have been the cause of low grilse run in 1976. In contrast, later running fish movement (September to December) was more strongly associated with peaks. Breakdowns in this pattern may have reflected availability of fish, and late runners moved independently of flow, presumably due to spawning urge.

Closer examination of seasonal flows showed that fish tended to use > median flows in January/ March and September/November, whereas in April/July more than 50% used flows < monthly median.

Effect of light

A strong diel pattern was evident in summer months but not in early or late season. After removing the effect of between-year variance it was shown most fish moved at dawn (0400 - 0800) in June and July. In all months, the percentage of fish moving at > median flows during daylight hours was greater than during darkness. Diel movements in summer months broke down during floods when fish moved during the day. This was thought to result from increased turbidity.

The discussion emphasised the interpretive difficulties with counter data, caused by unknown availability of fish and uncertainty over the length of time fish move in response to a stimulus. A two counter system and use of radio tracking would be very beneficial in this respect. A more general problem was the interdependence of causal factors, for example suspended solids, light penetration, velocity and various other water quality parameters which change simultaneously in a flood. On the Frome a site existed where it might be possible to vary suspended solids (and light penetration) independently of discharge. This would be looked at in the future.

## 6.4 Paper 4 Tracking salmon in the estuary of the River Ribble (I.G. Priede, D. Cragg-Hine, J.F. de L.G. Solbe and K.T. O'Grady.

Dr. D. Cragg-Hine, NRA North West Region, P.O. Box 12,
Newtown House, Buttermarket Street, Warrington, WA1 2QG.

The objective of this study (1982 - 86) was to investigate the effects of low dissolved oxygen (DO) concentration on the movements of adult salmon in the Ribble estuary. In this estuary an oxygen sag can extend over a distance of 15km with minimum recorded values < 40% air saturation value (ASV., the DO concentration that prevails under ambient temperature and pressure when saturated by air derived oxygen). This is due to biological oxygen demand (BOD) generated by a major sewage works discharge located 9km downstream of the tidal limit. The stimulus for the project was the recent development of a DO sensing acoustic tag (Priede et al, 1988a) which required field testing, and basic results have already been published (Priede et al, 1988b).

The experimental design was influenced by the tag type and the physical nature of the estuary. The tag produced a signal frequency that varied with DO, and thus continuous tracking was necessary to gain information in relation to ambient D.O., measured during the tracks. Tracking was from paired small boats, with a large personnel and complex logistics associated with the difficult access, shallow water, and fast tides (up to 2.5ms$^{-1}$) prevailing in the 20km long estuary.

Fish were captured by drift netting in the lower estuary, and the tags attached externally under anaesthesia. The work programme was organised in 10 day blocks during summer months when the D.O. sag developed in the estuary.

Results and discussion

In general there was no evidence that salmon avoided areas of low D.O. or that movement patterns were affected down to 40% ASV. The Ribble estuary is very well mixed and fish were not exposed to vertically stratified water quality. On one occasion a fish moved to a shallow (15cm) area of 100% ASV when the main channel was at 60% ASV. It was significant (see below) that at DO < 50% ASV it was impossible to capture and process fish and still keep them alive.

18 successful tracks were made during which 4 fish moved into fresh water, indicating that a significant proportion of fish entering the estuary may not have been of Ribble origin. A stereotyped estuarine behaviour pattern

was postulated in which fish having entered the estuary in the flood may spend one or two (rarely more) tidal cycles oscillating with the tide over, typically, an 8km length i.e. 16km tidal amplitude. Thereafter fish move upriver (home fish) or back out to sea (non-Ribble fish); subsequent return of the latter group could not be ruled out. Tidal movements were not passive, and speed over the ground was typically less than water velocity, indicating periods of position holding or swimming against the flow. Movement was typically in hops of 100 to 200m.

Tidally directed movements resulted in fish reaching the head of tide when DO was highest, at high water and then if no upriver movement occurred, dropping back to experience worst D.O. conditions further down the estuary at low tide.

The apparent lack of impact on salmon passage of DO down to 40% agrees with other studies on Pacific salmon (Hallock etal, 1970; Alabaster, 1988) and on Atlantic salmon in the Thames (Alabaster and Gough, 1986). It is, however, in contrast with the EC Directive limit of median ASV = 90% (9mg $O_2 l^{-1}$ at $15^{o}C$) recommended for salmonids in freshwater. The authors drew attention to the phenomenon of 'chokers', moribund fish taken by commercial nets when ASV < 50%; and suggested that although passage could still be maintained under these conditions the scope for resistance to additional stressors of any form was severely reduced.

6.5 Paper 5 Migration of Atlantic salmon in the River Tywi system, South Wales (D. Clarke and W.K. Purvis)

Dr. D.Clarke, NRA Welsh Region, Regional Laboratory,

Penyfai House, Furnace, Llanelli, Dyfed.

The river Tywi supports a major Welsh fishery, having annual average rod catches of 900 salmon and 6,000 sea trout since 1983. However, salmon stocks are thought to have declined in recent years and among the factors which have been suggested as possible causes are the impact of regulation flows from Brianne reservoir and low D.O. in the estuary. The latter can be severe with sags down to $1mgl^{-1}$, and has variously been attributed to tidal resuspension of estuarial muds, discharge from a major STW in the upper estuary and breakdown of marine algae. This paper presented initial results from a three year study, begun in 1988, intended to examine effects of these impacts on estuarine and inriver movement of salmon.

Ninety four Atlantic Salmon, captured in the lower Tywi estuary, were tagged with radio transmitters and their movements followed during July-December 1988. Seventy fish were detected in the freshwater reaches of the Tywi and six were subsequently relocated outwith the catchment. The significance of these results in terms of stock identity within the estuarial net fishery and lower river rod fishery areas was discussed. Up to 40% of estuary-caught fish could have been of non-Tywi origin. Moreover, non-native fish penetrated far into the system and remained available to the rod fishery for up to four weeks. Up to 11% of in-river stock could have been non-native fish.

Flows were abnormally high for the time of year and most of the fish entering freshwater did so within four days of tagging. Evidence of both flow-dependent entry and tidal oscillation within the estuary was restricted to fish tagged during the lower range of flows examined. Upstream migration through the upper estuary included active swimming during the latter part of the ebb and slack period, as well as migration with the tide. In lower flows (<25 $m^3s^{-1}$) fish showed preference for entry at night; no such preference was observed at higher flows.

Following entry, fish typically remained active for 10-20 days, migrating a variable distance upriver, during which time they were vulnerable to rod recapture, six of eight rod recaptures being taken within 15 days of entry. This was followed by a quiescent period, sometimes interspersed with further upstream movements and short range 'exploratory' behaviour in the vicinity of confluences. Despite high base flows and frequent flood events, the bulk of tagged fish remained stationary in deep pools in the lower 20 km of freshwater until late autumn. Following the quiescent period(s) nearly all significant upstream movements (>2 km) were initiated during flood events (39/40). As the spawning period approached, the proportion of available fish moving on such events increased, presumably as a result of internal physiological changes and changes in external factors such as water temperature or daylength.

6.6 Paper 6 <u>Movement of adult Atlantic salmon (Salmo salar) in the Usk estuary (M.W. Aprahamian, C.D. Strange and C. Dimond)</u>

Dr. M. Aprahamian, NRA Welsh Region, St. Mellons Business Park, St. Mellons, Cardiff.

The River Usk, South wales, supports an important salmon fishery. However, D.O. sags in the estuary may be impairing fish passage. At low freshwater discharge D.O. < 3mg $l^{-1}$ can exist for 8km of the estuary during the ebb and for about 2.5km on the flood tide. This is thought to be caused by oxygen demand of resuspended sediments and of polluting discharges which occur along 13km of estuary. The objectives of this study were to 1) determine whether water quality was affecting salmon movement through the estuary and into fresh water; 2) to determine the limiting W.Q. conditions; and 3) to use this information to advise on the sewage disposal strategy for South Gwent.

Passive tracking was selected on the grounds of cost effectiveness over the limited time available for study, because the method allows several fish to be monitored at once. Fixed listening stations in freshwater and sonar bouys in the estuary complemented the use of CART tags. Estuarine water quality (D.O., suspended solids, salinity) was recorded for half tidal cycles at two points. Salmon were caught by trammel net in the lower 2.5km of estuary, and released from a fixed site about 1.3hr after low water.

During 1988 56 salmon were tagged of which 23 (41%) were known to have migrated into freshwater, 20 (35%) were last recorded migrating out of the estuary, 11 (20%) were last recorded in the inner estuary and 2 (4%) were never seen after release. 2 of the 11 fish last seen in the estuary were subsequently recaptured in other rivers. Most fish entering freshwater did so rapidly taking between 1 and 4.5 days, including temporary movements out of the estuary. Those fish showing estuarine movements oscillated with the tide over approximately 10km, moving up on the flood and down on the ebb. This patttern broke down in the tidal freshwater zone. Fish which moved directly into freshwater moved more slowly (over the ground) than those which remained in the estuary.

Unfortunately for the study, freshwater flows in 1988 were unusually high and no low DO conditions prevailed, minimum value being 4.5 $mgl^{-1}$. The work will continue in 1989 with more sonar buoys and improved water quality monitoring.

## 6.7. Paper 7 The entry and movements of spawning fish in relation to water flow in the Girnock Burn, a tributary of the Aberdeenshire Dee (J. Webb)

Dr. J. Webb, DAFS, Marine Laboratory, P.O. Box 101,
Victoria Road, Torry, Aberdeen, AB9 8DB.

This paper describes studies on the Girnock Burn a tributary of the Aberdeenshire Dee. This work is part of a three year (1986-88) project sponsored by DAFS and AST on salmon migratory behaviour in Scottish East coast rivers. The objectives of this study were to investigate the movements and behaviour of spawners before, during and after the spawning season in relation to flow. Observations were specifically made on 1) movements in the mainstream Dee prior to tributary entry; 2) movements in the lower Girnock downstream of an adult trap; 3) movements in the upper tributary, including sex differences in behaviour and distribution in response to flows.

A variety of methods were applied included radiotracking (active and passive), direct observation and remote observation using underwater video cameras. The latter, although not described in this paper, provided the subject of a very effective video presentation during the workshop.

Forty six salmon were tagged during the three years, captured in the Girnock adult trap, located 900m above the confluence. Details of the methods and a fuller account of the 1986 results are given in Hawkins and Smith (1986) and Webb and Hawkins (1988).

Summary of results

1. Behaviour of tributary entrants, radio-tagged and displaced back to the mainstream Dee.

   Observations proceeded about 6-8 hrs after each tagged fish had descended from the trap area back into the Dee. Fish released from the trap early in the season took up temporary residence in the main river, at distances ranging from a few metres from the confluence point, to the junction pool at the confluence of the river Gairn and the Dee, 2.7km further downstream. Under conditions of basal seasonal flow within both the Dee and the tributary, activity was limited to crepuscular and nocturnal periods only. Fish repeatedly approached the immediate confluence area but made no attempt to enter the lower reaches of the burn. Different levels of activity by different fish was evident. Tagged males showed the greater overall level of activity. Disruption of the regular pattern of activity coincided with increases in flow in the main holding areas, and consisted of a general increase in activity by both sexes. Fish often approached the immediate confluence area within 0.25-2 hours of any increase in flow. There were few movements above the confluence of the Dee and Girnock. Most activity took place further downstream.

2. Burn entry, and ascent to the trap area.

Entrance to the burn and ascent to the trap-site invariably coincided with an increase in flow above the seasonal norm within the burn. No single threshold of flow provoked this activity, and fish ascended the tributary over a range of elevated flows. This observation explains the sporadic seasonal timing of the entrance of pre-spawning adults to the trap. Migrants entering the tributary but not ascending as far as the trap site over the duration of a single flood, returned to the main Dee within 24hrs. Residence within this area of the burn, by both males and females, only occurred after the initiation of spawning activity. In the latter half of the 1987 and 1988 spawning seasons, a number of fish entered the lower reaches, and spawned on areas of gravel distributed between the confluence area and the trap-site. This activity was recorded over a range of discharges, fish often entering the tributary at flows significantly less than associated with the entry of former migrants before spawning activities began. In the absence of spates, few of these short range entrants continued their ascent to the trap area. This failure on the part of late running fish to ascend through the lower reaches of the burn to the trap area, even by tagged fish which had previously entered the burn and ascended to the trap earlier in the season, suggests that the stimulatory role of increases in flow in the initiation of both burn entry and ascent may reduce towards the end of the spawning season.

There was a strong tendency for fish of both sexes which had entered the burn earlier in the season, and were then released downstream to the main-stem, to re-enter and successfully spawn in the burn. Those fish that did not successfully ascend and spawn in the burn spawned in areas of the main river only a few km downstream of the confluence area.

C. Timing and distribution of spawning activity in relation to flow.

Bankside observations over three consecutive spawning seasons have suggested that females may spawn at quite different levels of flow within different areas of the stream. Some areas of the burn are utilised over a comparatively wide range of seasonal flows, whereas others are only utilised at specific levels of discharge. The detailed relationships recorded between spawning and flow are inevitably specific to the Girnock burn. However, a prelimiary analysis of the data does indicate that discharge regime may serve to control the timing and distribution of spawning activity. It is important for the success of spawning throughout the burn as a whole that a wide range of flow conditions occur during the spawning season.

Discharge regimes within the tributary may influence a wide range of activities associated with the entry, ascent and final distribution of spawning activity of ascending salmon populations. Full assessment of the potential consequences of various changes in the hydrological characteristics of upland tributaries awaits an extension of these studies.

6.8. Paper 8 <u>North West Water projects(C.M. Newton and D. Cragg-Hine)</u>

Mr. Chris Newton, P.O. Box 12, Newtown House, Buttermarket Street, Warrington, WA1 2QG.

This paper summarised work within NWWA on the use of counters to investigate fish movement - river discharge relationships. Most of this activity has been aimed at resolving conflicts between resource use and fish migration and angling. In addition, the findings have been used to interpret water quality impacts (principally acidification) and to assist in designing fish pass schemes.

Eleven counters are presently in use in the Region. Although these are expensive to install the large quantity of data generated was felt to justify their use. The paper outlined validation exercises, completed and in hand, that employed continuous VDR with infra red illumination at night. Three types of counter had been evaluated; the original NWW counter, the K.M. Lawson counter and the Logie (Aquantic) counter. The latter was found to perform best and recent work with this unit on the River Kent was described. The great benefit of the Logie in providing size information based on signal pattern, was offset by changes in size/signal relationship as conductivity and water level altered during spates. The North Esk (Scotland) where the system was developed, was thought to provide more stable conditions than the N.W.W. rivers.

Modifications have now been made by the manufacturer to compensate for this.

Reference was made to the hydraulic design of weirs need to ensure rapid fish passage and to avoid extraneous noise. Generally, counters performed satisfactorily and installation of a further three or four was planned.

Some examples of results were given. Movement of salmon on the River Lune at Forge Weir was associated with both rising and falling hydrographs, but ceased at the peak of big spates. Attention was drawn to the observation, often reported, that the flows when the greatest total of fish actually move are rather less than those fish seem to prefer when expressed as movements-per-flow-occurrence. This is due to the lower frequency of the preferred flows.

Data from recently installed counters, e.g. on the Derwent, have confirmed the flow predictions (for survival flow, fish migration and angling) based on the Stewart formulae expressed as flow-per-unit-river width (Stewart, 1969).

For the future, NWW is committed to using counters and intends to adopt a mixed strategy in which techniques such as tracking are used to test hypotheses and assumptions based on counter data. Examples of future problems for study included the influence of afforested tributary flows on angling success in the river Eden, changing movement patterns associated with maturation, and movement patterns into a large subcatchment of the Eden made recently accessible by fish passes.

6.9. Paper 9 <u>Salmon movements in Scottish rivers (A.D. Hawkins, G. Smith, J.Webb, A.D.F. Johnstone and R. Laughton.)</u>

Dr. A.D. Hawkins, Director, DAFS, Marine Laboratory,
P.O. Box 101, Victoria Road, Torry, Aberdeen, AB9 8DB.

This paper reviewed results from several related projects in an extensive Scottish programme investigating factors controlling river entry, upstream movement and spawning in east coast rivers. The work, variously carried out on major Scottish rivers, The Tay, Spey, Dee and North Esk, is jointly undertaken or supported by DAFS, the AST, the District Salmon Fishery Boards, the North of Scotland Hydro Electric Board, local councils and others.

Numerous sources of data have been examined including net and rod catch statistics, conventional smolt tagging and adult recaptures and radio tracking. Most of the results referred to radiotracking between 1985 and 1988 on the Dee (88 fish, 73 radio tags + 15 CARTS), Tay (87 fish) and Spey (24 fish).

<u>Coastal Movements</u>

Acoustic tracking studies in the sea have shown salmon movements, relative to the ground, to be strongly related to tidal currents. However, individual fish consistantly swim in a particular direction and show relatively constant swimming movements relative to the water. Fish may orientate by vertically stratified hydrographic features such as temperature. Extensive wandering along coasts may occur during which salmon can negotiate their way past the leaders of fixed nets.

<u>Timing of Return</u>

Fish enter the larger Scottish east coast rivers in almost every month of the year. Data from the former netting fisheries on the estuary of the

Aberdeenshire Dee show a spread of catches from the opening day, in February, to the end of the season, in August. However, there are two main peaks in catches, in spring and early summer, the first consisting entirely of multi-sea winter fish, and the second of mainly one sea winter fish, or grilse.

Estuarine Movements

The comparatively few studies available indicated that salmon may behave differently in different estuaries. In the Dee, fish may either move rapidly into the river, return to the sea, some entering the river up to several weeks later, or remain for some considerable time in the estuary. In the Tay, passage through the estuary is more rapid, within 24hr. Those differences may reflect the natural diversity of estuary types each with unique combinations of physical and hydrographical features that require specific behaviours. Equally, observed variations could reflect the different locations of capture and tagging. Tay fish for example are tagged in the upper estuary and may represent individuals strongly committed to river entry. In contrast the Dee fishery may take a high proportion of non-active fish or natives not yet ready to move into freshwater.

Movements within the River

Our studies suggest that a number of phases can be identified during river migration.

a. Initial movement

Fish initially move rapidly from the head of tide, often for 24-36 hours non-stop, to positions up to 30km upstream. Speed was rapid, up to 30 km/day. This activity was recorded over a range of seasonal flows and times of day.

b. A Period of Discontinuous Movement Upstream

Fish generally move at night often remaining in recognised holding pools during the day, although, during periods of spate, daylight movements were observed. Fish complete most of their upstream progress during this phase.

c. The Quiescent Phase

Fish may spend up to 3 months in a single pool exhibiting little or no movement over a wide range of flows.

d. Resumption of Migratory Activity

Fish movements often coincide with changes in river flow associated with autumn spates. Fish move to final spawning positions.

This general description of river migration may be modified by the time of year when fish enter the river. Migrants entering from August onwards, for example, tend to spawn in the lower reaches and consequently may reach their spawning position on completion of only their initial phase of movement.

## Future work

The programme will examine behaviour at specific locations where flow/movements relationships are likely to be critical. This includes tributary confluences, natural barriers such as falls and shallow bars, and artificial obstructions including fish passes, H.E.P. dams and fish counting weirs. Work will also continue on the very early running mutli-sea winter fish that occur in good numbers in Scottish rivers and will extend the observations on factors controlling passage through estuaries.

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## PARTICIPANTS

## WESSEX WATER/AST WORKSHOP

"Fish Movement in Relation to Freshwater Flow and Quality"

### Chairmen

| | | |
|---|---|---|
| 4 April | p.m. | Mr. Gordon Bielby (South West Water) |
| 5 April | a.m. | Sir Ernest Woodroofe (AST) |
| | p.m. | Dr. D. Solomon |
| 6 April | a.m. | Rear Admiral D.J. Mackenzie (AST) |
| | | Sir Ernest Woodroofe |

### Speakers

Dr. A. Aprahamian (NRA Welsh Region)
Dr. D. Clarke (NRA Welsh Region)
Dr. D. Cragg-Hine (North West Water)
Mr. A. Frake (Wessex Water)
Dr. A.D. Hawkins (DAFS, Marine Laboratory, Aberdeen)
Mr. C. Newton (North West Water)
Mr. E. Potter (MAFF, Lowestoft)
Mr.H. Sambrook (South West Water)
Mr. J. Webb (AST/DAFS, Marine Laboratory, Aberdeen)
Dr. S. Welton (Freshwater Biological Associtiion)

### Others

Dr. J. Alabaster
Mr. S. Bailey (Yorkshire Water)
Mr. A.J.R. Barber (Wessex Water)
Mr. W. Beaumont (Freshwater Biological Association)
Mr. K. Broad (South West Water)
Dr. J. Chandler (Southern Water)
Dr. R. Cresswell (NRA Welsh Region)
Miss. S. Crudgington (Welsh Water)
The Hon. E.D.G. Davies (AST)
Colonel J. Ferguson (Salmon and Trout Association)
Mr. D. Gifford (Wessex Water)
Dr. P. Gouch (Thames Water)
Mr. G. Hadoke (AST)
Mr. A. Hatcher (Marine Resources Research Unit, Portsmouth Polytechnic)
Dr. G. Kennedy (Dept. of Agriculture, NI)
Mr. R. Laughton (DAFS, Marine Laboratory, Aberdeen)
Mr. M. Martin (AST)
Dr. G. Mawle (NRA Welsh Region)
Dr. R. Merry (South West Water)
Dr. D.H. Mills (Dept. of Forestry and Natural Resources, Edinburgh University)
Dr. N. Milner (NRA Welsh Region)
Mr. D. Mitchell
Mr. I. Mitchell (Tay Salmon Fisheries)
Dr. A. Moore (MAFF, Lowestoft)

Dr. K. O'Grady (NRA)
Dr. D. Piggins (Salmon Research Trust of Ireland)
Mr. W. Purvis (NRA Welsh Region)
Capt. J.B.D. Read (AST)
Mr. N. Reader (South West Water)
Mr. I. Russell (MAFF, Lowestoft)
Mr. G. Smith (DAFS, Marine Laboratory, Aberdeen)
Miss. E. Twomey (Dept. of the Marine, Dublin)
Major S. Vines ("Salmon, Trout and Sea Trout")
Mr. Walker (Northumbrian Water)
Dr. D.R. Wilkinson (Wessex Water)
Mr. R. Williamson (DAFS)
Dr. M. Windsor (NASCO)

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| Atlantic Salmon: Planning for the Future (Proceedings of the 3rd Internatinal Atlantic Salmon Symposium, Biarritz, 1986) | edited by D. Mills and D. Piggins - | 45.00 |
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| "Will There Be a Salmon Tomorrow" | - | 16 mm film |
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| "The Salmon People" | - | Video (VHS) |
| "Irish Salmon Harvest" | - | Video (VHS) |
| "Managing Ireland's Salmon" | - | Video (VHS) |
| "Salmon Tracking in the River Dee" | - | Video (VHS) |

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