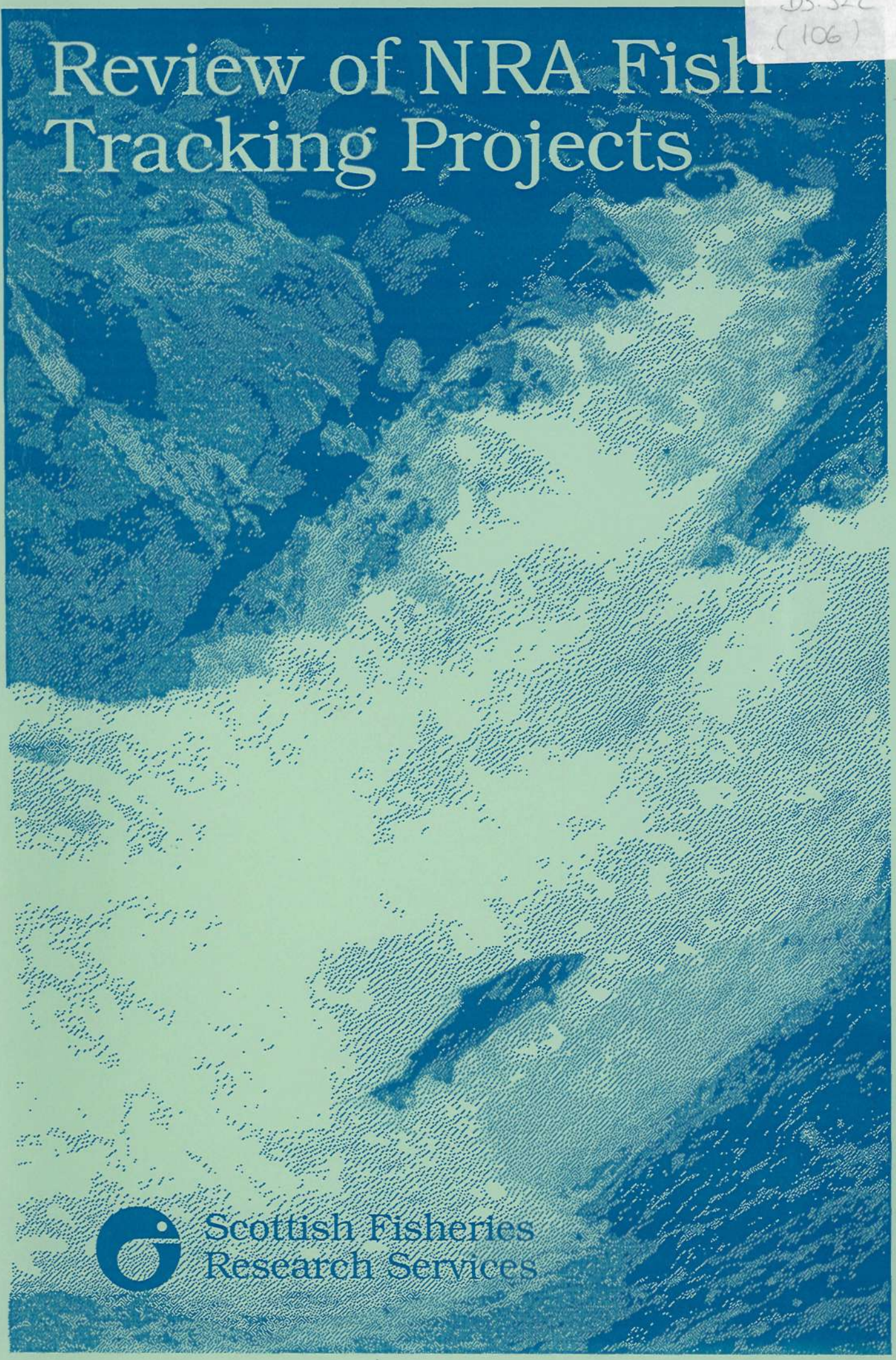
Review of NRA Fish Tracking Projects



Scottish Fisheries
Research Services

PROJECT DO2.4

Review of NRA Tracking Projects on Salmon, *Salmo salar* L., and Sea Trout, *Salmo trutta* L..

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1. GENERAL INTRODUCTION

1.1 Objectives

This study was commissioned to :-

a) Review available published and unpublished data and results of NRA salmonid tracking studies.

b) Evaluate how effectively the behavioural responses of adult salmon, *Salmo salar* L., and sea trout, *Salmo trutta* L., to changing water flow and quality conditions have been identified by utilising tracking and counters.

c) Provide advice on the outline of a research programme to meet the likely future requirements of the NRA in this field.

The study began on the 7th January 1991 and the report was completed in June 1991.

1.2 The Structure of the Report

The report briefly outlines the programme of the NRA (Section 2), placing the Fisheries programme in the context of the work of the NRA as a whole, and viewing the tracking work against the broader requirements of the NRA Fisheries research programme.

Two techniques currently exist for studying the detailed timing and extent of movements of adult salmon: tracking of individually identifiable fish, and counting the numbers of fish moving past a fixed point in the river. The development of tracking techniques and the integrated use of tracking and fish counters is briefly reviewed in Section 3. Further details of these techniques are given in Appendices I and II.

Section 4 summarises and assesses completed and current NRA tracking studies. Complete project descriptions for the studies are contained in Appendix III.

Section 5 discusses the scientific content of these studies in relation to similar work carried out elsewhere in the UK. The NRA programme of tracking studies is evaluated in Section 6. Section 7 discusses future fisheries projects and Section 8 details the future development of tracking techniques.

Finally, recommendations arising out of this review are summarised in Section 9.

Tracking work on migratory salmonids has tended to concentrate largely upon the movements of adult salmon. Much of this report will therefore be concerned with salmon tracking studies. Actual NRA studies involving sea trout are referred to where appropriate. The methodological problems of sea trout tracking studies are summarised in Appendix I.

2. THE NRA PROGRAMME

The NRA has statutory duties and powers in relation to water resources, pollution control, flood defence, fisheries, recreation, conservation and navigation in England and Wales. The Authority is also responsible for managing, planning and conserving water resources, and for controlling the discharge of waste water and pollutants into rivers, estuaries and coastal waters.

In order to fulfill its fisheries function, the NRA has responsibility for assessing the status of freshwater fish stocks and, where appropriate, coastal fisheries throughout England and Wales. These responsibilities are aided by the collection and collation of catch statistics, fish population surveys, rearing of fish for re-stocking, fish pass construction and habitat improvement.

The fisheries resources inherited by the NRA are significant. Amongst the principal current fisheries objectives are assessing the status of fish stocks and formulating policies to maintain, improve, develop, restore and rehabilitate fisheries. A related objective arising from the Water Resources functions is to develop a policy to overcome problems with fish and fisheries at low river flows often associated with water abstraction.

A specific responsibility of the Authority is the management of migratory salmonids, the salmon and sea trout. Sound management practices require a knowledge of the behaviour of fish within rivers, in terms of their general preferences for particular conditions during different phases of their life history, their response to barriers and obstructions and their specific requirements during periods of active movement. It is into this general context that fish tracking studies fit.

Much of the NRA's programme of fish tracking has arisen in response to the need for information about particular problems on individual rivers. These projects may have some relevance to the strategic framework of Fisheries, but it must be recognised that they were originally initiated in very specific contexts, and were intended to be evaluated in terms of meeting their own local objectives.

3. FISH TRACKING

3.1 Tracking Techniques

The movements of fish are difficult to observe directly in the wild. Early conventional tagging studies marked large numbers of fish with conspicuous external tags and from their release and recapture locations the gross movements of populations of fish were determined (Harden-Jones, 1968). Several different marking techniques have been developed (Laird and Stott, 1978), and these have proved useful for estimating patterns of distribution, the contributions made by different stocks to mixed fisheries and to derive fisheries statistics (Milner, 1990). These simple techniques, however, provide no information on the detailed movements of individual fish (Hawkins and Urquhart, 1983). To study the effect of environmental factors, barriers, pollution or flow modification, upon movements and behaviour it is necessary to monitor the responses of individuals in greater detail. To achieve this, fish may be fitted with external or internal transmitters emitting signals which can be detected and followed.

The first biotelemetry systems designed for tracking fish were simple acoustic transmitters. A small transmitter (Stasko and Pincock, 1977; Kanwisher, *et al*, 1973) attached to the study fish generates pulses of high frequency sound which are detected by means of a submerged hydrophone (underwater microphone). The output of the hydrophone is amplified and converted by a suitable receiver to a tone audible to the human ear. It is possible to follow the animal by using a directional hydrophone and moving in the direction of maximum signal strength (Ireland and Kanwisher, 1978; Hawkins, *et al*, 1979). The effective range of such a system depends on the initial signal strength and frequency of the transmitting tag but is typically less than 1km.

Sound waves travel particularly well through open unbounded bodies of water. In the open sea, sophisticated receivers have been developed to locate acoustic transmitters attached to fish with great precision. These can take the form of single complex receivers, capable of determining the bearing of transmitting tags or the bearing and angle of a transponding tag (Mitson, 1978). Alternatively, they can consist of fixed arrays of simple hydrophones capable of determining the position of a transmitter by comparing differences in the time of arrival of the sound signals at each of the hydrophones (MacLennan and Hawkins 1977; Hawkins, *et al*, 1979).

In shallow freshwater locations, acoustic signals are seriously affected by entrained air, complex topography, and the presence of rocks and weed. Acoustic tags are therefore often unsuitable, but radio transmitters can be used to good effect. Radio signals travel only poorly through the water, but a proportion of the radio signal is emitted from the water surface directly above the source (Priede, 1980). Attenuation of the signal in air is low and a detection range of up to about 1.5km can typically be achieved by the deployment of an antenna and receiver in air (Hawkins and Urquhart, 1983). Though such detection ranges are possible with elevated receivers (especially when deployed from an aircraft, Hawkins and Smith 1986), the range can be greatly reduced in dense woodland, or where the water body is bounded by high banks.

It is generally possible to locate the position of a radio tagged fish by placing directional antennae at two or more spatially separated sites, obtaining a bearing from each, and then determining the actual location by triangulation. To locate a fish to within a few metres when tracking in rivers, it is often necessary to walk along the river bank to locate the position of strongest signal strength.

Radio tags generally consume less power than equivalent acoustic tags and where fish are being tracked in lakes and rivers can achieve greater ranges (or longer life) for the same battery size. For example, radio and ultrasonic tags of similar size and weight designed by MAFF last for 8 months and 1 month respectively (Solomon and Potter, 1988). An additional advantage of radio tags is that they may be detected through ice (Lonsdale and Baxter, 1968).

Radio tracking has become commonplace for tracking fish in shallow freshwaters. However, radio waves are severely attenuated in sea water and acoustic systems are therefore mandatory for estuarine and marine environments. A recent development by MAFF has been the Combined Acoustic/Radio Tag (CART) which combines ultrasonic and radio transmissions, allowing the continuous monitoring of fish migrations from estuaries into rivers (Solomon and Potter, 1988; Potter, 1988). Because of the high power consumption when operating in the acoustic mode, the CART tag incorporates a timer which switches off the acoustic transmitter and maintains only the radio transmitter after a predetermined period of time has elapsed. The timer is set to operate after the fish is expected to enter freshwater.

Solomon and Potter (1988) describe a system of sonar buoys which allows radio tracking equipment to be used in conjunction with the acoustic tags required for estuarine tracking. The unit consists of an acoustic receiver, a radio transmitter and a processing and interfacing unit. Acoustic signals from a tagged fish are received and a radio pulse is re-transmitted at the water surface which is in turn detected and recorded by automatic listening stations (ALSTNs - see Appendix I for description) situated on the shore.

Another combined radio and acoustic transmitter (RAFIX) has been developed which measures the range of a fish from the difference in signal propagation times

(Armstrong, *et al*, 1988). This system has been used for tracking pike (*Esox lucius*) in a Scottish loch but its effective use may be restricted to lacustrine environments.

Tracking systems have now been in use for over forty years. Their development and refinement over this period are discussed in more detail in Appendix I. Essentially, tracking provides a great deal of detailed information about the behaviour of individual fish. It can provide a comprehensive picture of the overall scope for behaviour and allow detailed knowledge of the habitat preferences of fish during different phases of their life cycle to be determined. Because the behaviour of individuals is so variable, however, tracking does not always allow a clear analysis of the responses of a whole population of fish. It is sometimes difficult to see the wood for the trees.

3.2 The Integrated use of Fish Tracking and Counters

Fish counters essentially provide data on the numbers of fish moving past a given point on a river. They can provide accurate census data which are essential for the scientific management of salmon populations, for example, in assessing the effects of predator control, stream improvement, and stocking with hatchery reared eggs, fry or parr (Bussell, 1978). The timing of salmon passage upstream to spawning grounds and movement of kelts downstream may be investigated by the careful positioning of two or more counters. Counters also eliminate disturbance from handling individual fish and the bias which may be associated with catch data (Dunkley and Shearer, 1982). The design and limitations of current designs of fish counters are discussed in Appendix II.

Counters can indicate the numbers of fish passing a particular point of the river, and record the timing of their passage in relation to particular environmental

events. Installed in pairs, counters can indicate the proportion of fish present which respond to an environmental cue. They can therefore provide an assessment of the role of environmental parameters in controlling and modifying the behaviour of fish.

The use of a counter in conjunction with tracking can verify that the movements of relatively few tagged fish are representative of the fish population as a whole. In addition, the stock identity and destinations of populations of fish moving over a counter may be estimated by tagging and tracking individuals. Furthermore, if the counter is located in the lower reaches of a river, tracking may allow measurement of the rate of progress of salmon through the lower river. It may then be possible to relate counts recorded at the counter to times of entry to the river, state of tide, etc.

The two techniques of fish tracking and counting are complementary and there are advantages to be gained from deploying them together.

4 NRA STUDIES ON MIGRATORY FISH

4.1 The Tracking Projects

The tracking activities of the NRA are summarised below. In addition to current research projects, several important studies which were funded by Water Authorities and carried out within the last decade are also included. A total of 13 projects are summarised, full details of each being provided in Appendix III in a form approved and commented upon by the current project managers.

As mentioned in section 2, many of the NRA fish tracking studies have been established to deal with specific problems and have not formed part of an overall strategic programme. In some cases these projects were initiated by the Water Resources division of the Water Authorities, and several are now funded substantially by the plcs. The commissioning body for each project is indicated below to allow classification of the project types.

No set formal procedure for project appraisal either by the NRA regions or commissioning bodies, such as the plcs, has been identified. Project managers are generally left to drive and develop each study once the aims and objectives have been established. Feedback at regional level or from funding sources tends to occur on an informal basis and has been identified as mainly positive with general endorsement of programmes, achievements and future project development having taken place.

The importance and potential benefits of good public relations during fish tracking studies are recognised by project managers. Most salmon tracking work relies on cooperation with interested parties such as river proprietors, anglers and commercial fishing concerns. The exposure of fisheries staff to the public and the

awareness that active research is being undertaken by the NRA is probably undervalued by commissioning bodies.

Here, projects are assessed on how well their stated objectives have been achieved. Assessment of some projects is limited, however, due to their recent commencement or a lack of completed reports. Of the 13 projects considered, 7 were completed, and from these only 3 final reports or publications were available to us. In instances where reports were not available, assessment has been based upon summary sheets prepared by the project manager and in some cases discussions with the managers involved.

4.1.1 North West Region

4.1.1a. Ribble Estuary.

A six year study, involving approximately ten days active tracking work each summer, was begun in 1980, funded by North West Water and the WRC. Twenty salmon were captured in the estuary of the Ribble and tagged with external dissolved oxygen (DO) sensing transmitters. The intention was to examine the movements of the fish in relation to the discharges from a major sewage works as a contribution towards the development of water quality criteria for salmonids in estuaries. The sewage works caused an oxygen sag which could extend over 15km of the estuary, with minimum recorded values of oxygen dropping to less than 40% of the air saturation value (ASV).

Of the 20 salmon tagged, 2 died immediately after tagging and 13 left the estuary and returned to sea. Within the estuary, one fish remained relatively stationary, while the other 4 fish oscillated to and fro with the tides over a 10km amplitude, experiencing cyclical changes in DO. The results suggested that salmon will avoid

DO levels below 55% ASV if they can. This study is now complete and has resulted in two internal reports, a presentation at a workshop and two papers in primary scientific journals.

The Ribble project is the earliest Water Authority tracking study identified. The principle problem with this study was the small number of fish actually tracked. This was due to a combination of difficulties including catching healthy fish in an estuary where fish survival was poor and the logistic problems of continuous tracking in an estuary subjected to strong tidal effects. The high number of tagged fish lost, presumably returning to sea, is a problem commonly encountered during estuarine tracking studies.

The study successfully established an innovative design of DO tag as a feasible tool for use in the field. The results of the study suggested that conditions in the Ribble Estuary were not satisfactory for salmonid migration. Closer definition of the water quality requirements of upstream migrant salmon could not be acheived because of the small number of fish tracked and the low ambient DO levels encountered in this estuary. No information on fish movements under less extreme conditions could be collected. To define more fully the environmental conditions favourable for salmonid migration through estuaries a much more detailed study is required.

4.1.2 South West Region

4.1.2a. River Tamar (Roadford Reservoir Scheme).

This project was begun in 1986 and is expected to run for about ten years. It is currently funded by South West Water plc, and is under the direction of NRA Water Resources. The study was initiated following a Public Enquiry into the proposed

Roadford Reservoir Scheme. It is intended to provide information that will assist in the setting of a prescribed flow and the preparation of operating rules for the regulation of water release and abstraction.

Since 1986, a total of 440 salmon have been radio-tagged. One hundred and twenty-six (28.6%) of these were caught and released in the estuary, and the remainder caught at a weir positioned at the head of tide approximately 1.5km below the abstraction point. In 1989, 17 salmon were displaced downstream from the head of tide, and released in the estuary. So far, 53 of 143 salmon released in the estuary have been tracked into freshwater.

Only interim reports are available. It appears that the study has provided general information on the effect of flow on the migration pattern of individual fish in the river system but a full analysis of the results has yet to be carried out. It has been concluded that absolute magnitude of flow is less important in prompting movement into freshwater than the increase in freshwater flow over a previous baseline level. Once the initial phase of migration is over, fish remain in holding pools within the river until spawning time, when a further upstream migration occurs, usually in response to increased flow. A conclusion drawn by the scientists involved in the study is that determining the timing of movements of large numbers of fish into freshwater in relation to environmental factors is best addressed by the deployment of fish counters, rather than by tracking individual fish.

There are future plans to catch additional fish in the estuary using a different fishing method, tag them and track them into fresh water. A fish counter will also be deployed to aid the study. Further studies will also be carried out upstream in the Lyd sub-catchment to determine the association between movements of

spawning fish and flows at downstream confluences.

Short presentations on the study have been made at two recent workshops. Two internal reports have been prepared.

This work has provided information on the general migration patterns of salmon in the River Tamar but has not adequately answered questions concerning the effect of flow on the movement of fish from the estuary into the lower reaches of the river. An early concentration of effort on tagging fish caught at the Gunnislake trap, at the head of tide, precluded examination of the factors affecting movements below this point in the river. As with some other tracking studies, the capture of sufficient fish from the estuary, at the required times, has proved difficult and has met with limited success. Quantitative analysis of the data has also posed problems.

4.1.2b. River Torridge

In 1988 a small scale study, funded by South West Water, was undertaken to investigate the movements of salmon in relation to flow as part of a study of the effect of the Roadford Reservoir Transfer Scheme. Salmon were captured by a net and coble fishery in the estuary of the Torridge. Five salmon were radio tagged and released. Two tagged fish entered the Torridge, of these, one was caught by rod and the second was tracked through to spawning when it entered an upper tributary and was later tracked descending the Torridge. Two tagged fish entered the adjacent River Taw and one fish was not located after tagging. The study was abandoned when South West Water decided to abort the scheme of water transfer from Roadford Reservoir.

Information from this pilot study is limited by the small number of fish tagged.

4.1.3 Southern Region

4.1.3a. Rivers Test and Itchen.

This study, funded by NRA Water Resources, was begun following a Public Enquiry into proposals to increase levels of water abstraction from the Rivers Test and Itchen. The fish tracking component of the study began in 1989 and is intended to continue until 1992. It is aimed at relating the speed, timing and extent of salmon migrations to environmental factors. The effectiveness with which fish negotiate various obstructions is also being investigated, fishing mortality is being estimated and the principal spawning grounds are being located.

This investigation is making use of fish counters with closed circuit television, as well as fish tracking. Fourteen salmon have been tagged on the Test, and 34 on the Itchen. Results so far indicate that there is some interchange of fish between the two rivers. The first internal report on the study was due in April 1991, but had not been received by the time this review was completed.

Apart from the desktop feasibility study, no written material is available for this project. It is therefore difficult to assess its progress. The study has been limited so far by problems in catching and tagging fish but these should be overcome during 1991 by the temporary employment of a professional netsman. An integrated tracking and counter study of this kind has the potential to provide high quality information.

4.1.4 Thames Region

4.1.4a River Loddon

As part of an adult salmon restocking experiment, a small scale three month radio

tracking project was carried out on the River Loddon in 1988 funded by Thames Water Authority, Fisheries Division. This study aimed to investigate the effect of capture and translocation on the movements of salmon transported to a potential spawning tributary. Four fish were caught by electrofishing and two by trapping. The six fish were then radio tagged, transported to the study site by road and released. Both fish caught by trapping ascended the river and may have spawned. Of the other four fish, two immediately moved rapidly downstream, one remained in the area then rapidly descended the river, and one moved downstream then two months later was detected at the upper station.

A brief report of this work was provided in the Salmon Rehabilitation Scheme Annual Report 1988.

The small number of fish tagged during this study limits the conclusions which may be drawn from the results.

4.1.5 Welsh Region

4.1.5a. River Dee.

A three year radio tracking programme started in April 1991, funded by NRA Fisheries/Water Resources/Water Quality. It is aimed at investigating the effects of water abstraction in the lower reaches of the River Dee and examining the effects of estuarine water quality upon salmon migration patterns. There are a number of subsidiary objectives, some related to the Dee stock assessment (DEESAP) index river initiative which includes trapping, fish counter and net and angler census studies. It is intended that up to 150 fish will be tracked in each of the three years. Continuous monitoring of water quality will take place during the study. A dynamic flow and water quality model is being produced and validated for the estuarine and

freshwater reaches of the Dee. This study is an ambitious project based on one of the least compromised rivers in which NRA tracking has been undertaken. Integration of the tracking programme with the Dee stock assessment index river initiative should yield important strategic results for comparison with salmonid migratory behaviour in other rivers.

4.1.5b. Glaslyn estuary and lower river.

In 1981 and 1982, a total of 21 sea trout were captured and externally tagged in the estuary of the Afon Glaslyn to investigate the effects of tidal doors, at the head of the estuary and its harbour, upon the movements of fish. The movements of fish in the sea and outer estuary, as well as in the inner estuary were examined. Fish moved into the river several hours after the tidal doors were opened, apparently in response to changes in salinity and temperature due to the release of freshwater. The behaviour of fish moving into the river itself was also examined. However, only a small number of fish were tracked and the project ceased after immediate management questions could be answered. The results are described in several internal reports to the Fisheries Technical Liaison Committee and are now being reassessed in the light of recent barrage schemes.

The study established the main features of the movements of sea trout into the River Glaslyn in relation to the opening of tidal doors.

4.1.5c. River Taff (Cardiff Bay Barrage).

This radio tracking study, funded by the Cardiff Bay Development Corporation, started in 1990 and is intended to continue for about 10 years. Its aims are to establish the impact of the Cardiff Bay Barrage upon the movements of salmon into and out of the River Taff. The Taff is a recovering river, which is already highly obstructed. Some planned and natural restocking is taking place. In the initial

phase of the study, adult fish captured in freshwater are being relocated back to the Severn Estuary, at the mouth of the Taff, and their re-entry is being monitored. This approach is necessary because of the small size of the current natural stock and the need to ensure that only Taff fish are tagged. With the completion of the barrage, the passage of fish through the impoundment will be evaluated. A supportive relocation study, using sea trout on the River Tywi in SW Wales, has also been carried out to validate this approach. The behaviour of emigrating kelts and perhaps smolts will also be examined. Outline descriptions of the planned project have been presented at two recent workshops.

Full assessment of this study is not possible as it only began in the autumn of 1990. The project is deemed to be important as it provides an opportunity to collect comparative baseline data before erection of the barrage and assess the performance of a novel fish pass. However, the conclusions which may be drawn from the project may be queried because relocated fish are being employed in the study. The difficulty with relocated fish is that they have previous experience of negotiating the lower reaches of a river, or a barrage. Therefore, their observed behaviour may not be typical of new entrants. Parallel work being carried out on sea trout on the Tywi may not produce comparative results due to the different responses of the two species. The difficulties involved in tracking only Taff fish and the limitations of relocating fish indicate that a fish counter installed at Radyr Weir may provide valuable ancillary information.

4.1.5d. River Tawe (Tawe Barrage).

A small scale pilot study, in which 6 fish have been tagged, was started in 1990, funded by NRA Fisheries. It is planned to continue the work to examine the effect of the Tawe Barrage upon fish movement into the river. The barrage is already nearing completion and will be the first of several similar proposals for Wales.

The future of this study is, however, dependent upon funding from the barrage development company.

The success of this study will be limited by the lack of control data prior to the beginning of construction. The results of the preliminary tracking study were not made available for this review.

4.1.5e. River Tywi.

A three year study was begun on the River Tywi in 1988, funded originally by Welsh Water. This project was intended to evaluate the influence of flow, including that released from the Llyn Brianne water bank, upon adult salmon migrations within the river. It was also believed that the results would assist in defining management strategies for the release and abstraction of water. There were a number of subsidiary fisheries objectives and a series of secondary analyses have already been undertaken. In addition, the study included an evaluation of the effects of the Parc Y Splott sewage treatment works upon migration success.

During the fieldwork period from 1988 to 1990, 260 salmon and 156 sea trout were captured in the outer estuary of the Tywi and tagged with radio or CART tags. Ninety four salmon were tagged in 1988 and 61 went beyond Carmarthen (at the head of tide) with 24 tracked until the spawning season. During 1988 river flow rates were relatively high and low DO concentrations were not encountered in the estuary (DO levels were always above 5 mg l^{-1}). In 1989, a drought year with low flow rates, of the 111 salmon tagged only 42 entered freshwater. A further 55 salmon were tagged in 1990 but no more details are available yet. The salmon migration behaviour observed showed the typical three riverine phases - initial progress upstream, a quiescent phase in holding pools and a final active spawning phase. So far, analysis dwells mainly on exploitation rates. In contrast to the results with

salmon, the proportion of tagged sea trout tracked through until the spawning season was much lower. In 1988, 11 sea trout were tagged, 10 entered the river but only 1 was followed through to spawning. In 1989, of 43 tagged (3 with CARTs), 22 entered the river but only 2 were tracked until the spawning season. Detailed results for 1990 are not yet available. The 1989 sea trout estuary migration results provided the tracking project with evidence that sea trout migration into fresh water may be restricted at low flow rates. This was particularly evident when night abstraction substantially reduced fresh water discharge. A review of the abstraction regime was therefore suggested by the Fisheries scientists involved.

Presentations on the project have been made at a recent workshop and a conference paper is in press. Two internal reports are available and a series of further reports and papers are in preparation.

The principle objectives of this study appear to have been only partially achieved. The limited success is due largely to the high exploitation rates reported, especially for sea trout, and the low flow rates experienced in 1989. The 1988 results serve as control data since river discharge rates were above normal but further reporting of the results achieved from the study are required for up to date evaluation.

4.1.5f. Usk Estuary.

In 1987, Welsh Water, Division of Water Quality, commissioned a study of the environmental factors affecting the passage of salmonids through the Usk estuary. The main aim was to determine a quality standard for DO and ammonia in the estuary, as an aid towards developing a sewage treatment strategy to meet that standard. Over the years 1987-1990, 251 fish were tagged and released, water quality data being collected continuously from two sites in the estuary. The migration pattern of fish was found to be predominantly driven by the tidal oscillations within the estuary. The effects of water quality and flow upon fish movements have yet to be evaluated.

A preliminary paper describing the Usk work has been published in a scientific journal, and the work has been described at a recent workshop.

The field work phase of this study has been completed. Full results from the project are not yet available, however.

A barrage scheme has now been proposed for the Usk estuary. The NRA has petitioned against the Bill proposing the barrage. Fish tracking studies have been called for as part of the feasibility study for the barrage and the earlier work will provide baseline data for that study.

Final results of this study are presently being analysed but interpretation of the results is limited by environmental monitoring from only two sites in the estuary. Monitoring of environmental parameters within a large estuary presents major logistical problems which have now been recognised by the staff carrying out this study.

4.1.6 Wessex Region

4.1.6a. Hampshire Avon and River Stour.

A 5 year study was commissioned by Wessex Water on the Avon and Stour in 1986 and is currently funded by NRA Water Resources. It was intended to examine the movements of salmon through the estuary and into the river, elucidate the influence of river flow, and investigate the effect of changes in the pattern of water abstraction, suggesting guidelines for abstraction management. A total of 437 salmon and 7 sea trout were tagged. A threshold flow at which fish passed through the estuary and continued upstream has been established. At lower flows, estuarine passage and entry to the river took progressively longer, fish sometimes remaining within the estuary for many weeks and even months until flows increased again in the autumn. Within the river, delays were noted at particular obstructions.

Five internal reports were produced and the results of the work were also presented at a recent workshop.

This study has met its main objectives in that a predictive model of the relationship between salmon movement and river flow has been produced which is intended to be used as a guideline for abstraction management.

The model is based upon the assumption that fish entering the river within 10 days of tagging are not delayed. However, it is not clear how sensitive the conclusions are to this assumption. The model also assumes that salmon movements can be related to absolute flow levels. Other workers eg. Cragg-Hine (1985), Sambrook and Broad (1989), examining fish on other rivers, have identified the importance of changes in river flow to salmon movements. Assessment of the validity of the Avon model is limited by lack of detail in the sections of the draft report available.

It is possible that the responses of salmon to river flow may vary according to the flow characteristics of the particular river, and that the results from the Avon cannot be readily generalised to other locations. Nevertheless, the Avon study must be counted among the more successful of the NRA tracking studies, and is the one which has most fully achieved its specific objectives.

The management of river flow is further discussed in section 5.1.3.

4.1.6b. River Frome.

A feasibility study on salmon movements on the Frome was conducted in 1987. The work started in 1988, originally funded by Wessex Water and now by NRA Water Resources. The aim of the study was to investigate factors affecting the entry of salmon to the river. Forty nine salmon have so far been radio tagged. This particular river has the advantage of having an electronic fish counter, data from which can be integrated with the results from tracking individual fish. However, there have been problems catching adequate numbers of fish, which together with handling difficulties and large losses/disappearances, have put the future of the study in jeopardy.

Two internal reports have been produced. A presentation on the fish counter data was also made at a recent workshop.

This study has been largely unsuccessful so far due to the low number of fish tracked. It suffers from the problem of obtaining fish from an estuary where mortality may be unacceptably high following tagging.

4.2 Project costs

Costs are shown on an individual project basis in Appendix III. The figures are based on information supplied by project managers and in most cases are estimated and probably minimised. Actual costs have been more readily identified for Wessex Region since their tracking projects have been contracted out to an independent consultant.

To allow for overheads, the manpower costs given in the project sheets have been multiplied by a factor of 1.5 (suggested by the R & D Coordinator, NRA Head Office). However, we consider this to result in an underestimate of manpower costs. A more realistic factor would include all administrative costs, superannuation, accomodation, transport and common services.

Capital expenditure has been written off over a 3 year period. Costs therefore decline after the initial 3 years of a project. Once the essential equipment has been purchased tracking projects may be run effectively without any major additional capital costs for several years.

Where available the mean annual cost of each project is shown in Table I. The costs have been adjusted to a 1991 price index for comparison. In addition, a representative annual cost per fish tagged (again adjusted to 1991 prices) is presented in Table II. Some projects have not been included in Table II since they are at an early stage and have tagged few fish or are yet to begin. It should be borne in mind that within some of the project costings there are undoubtedly hidden contributions from collaborative bodies.

Table I Mean annual project costs indicating the principal funding bodies. Costs have been adjusted to a 1991 price index. It is likely that these costs are underestimates.

River	Cost (£)	Funding body
Ribble	4,475 [a]	North West Water, WRC
Tamar	40,000	South West Water plc
Test & Itchen	34,375	NRA (Water Resources)
Dee	60,000 [b,d]	NRA (WR,WQ & Fisheries)
Taff	29,700 [c]	Cardiff Bay Dev. Corp.
Tawe	11,500 [d]	NRA (at present)
Tywi	52,000	Welsh Water / NRA
Usk	34,275	Welsh Water plc
Avon	40,962	NRA (Water Resources)
Frome	7,441	NRA (Water Resources)

[a] Project completed 1986, additional costs to WRC unknown

[b] Anticipated cost, project to commence 1991.

[c] 20% of total project cost taken to represent tracking programme costs.

[d] No capital costs incurred.

From Table I it is apparent that there is considerable variation in the costs of the tracking projects. Those projects which tag and track more fish inevitably incur higher total costs. In addition the projects involving estuary tracking, which is extremely labour intensive, are also more expensive (eg. anticipated costs for the Welsh Dee project). Contracting out tracking projects on a consultancy basis appears to give good value for money with the additional benefit of providing continuity of specialist effort during the execution of the work. Judging from the success of the Avon study, such projects can also be most effective in meeting the objectives laid down. However, the costs of NRA staff involved in establishing and monitoring progress of such projects may be underestimated.

Table II Estimated average cost per fish tagged during each project.

River	Cost (£)
Ribble	812 [a]
Tamar	477
Test & Itchen	625
Dee	- [b]
Taff	10,100 [c,d]
Tawe	2,080 [d]
Tywi	375
Usk	908
Avon	469
Frome	607

a Additional running costs paid for by WRC not included.

b Project starts April 1991.

c Tracking estimated to be 20% of total project costs.

d Relatively few fish tagged at present.

Table II shows the cost per fish tagged. Where projects are at an early stage, costs per fish tagged are of course unreasonably high, eg: Taff and Tawe. Apart from these exceptions, costs are within the same order of magnitude and vary from about £400 to £900 per fish tagged.

The greatest proportion of the expenditure once a project is established is incurred by manpower which represents around 60% of the total annual project cost (range 52.3 to 72.7%).

An estimate of costs for a river based tracking project aiming to tag 100 salmonids based on present day full economic costs would now be in the region of £70K per annum. This total allows for some capital expenditure but assumes that existing

monitoring equipment would be employed. Estuarine studies require a greater manpower input and hence a similar scale of study would require an annual budget of about £110K and fewer fish could be tracked under these confined circumstances. The purchase of specialised equipment to commence such a project (sonar receivers etc) would of course need to be tailored to the particular study site.

Difficulty was experienced in determining the costs of most of the tracking studies under review, as no standard system for estimating and monitoring costs was in place. We believe that the figures provided are likely to be underestimates.

5 THE NRA STUDIES IN A WIDER CONTEXT

Though many of the objectives outlined for the projects were site specific, some of the objectives were more general. We will draw together these more strategic objectives here, providing a framework for a general discussion of the scientific content of the projects. Those studies addressing each general objective are listed in parenthesis after each definition.

Broader common objectives were:

5.1 Examining the effects of low flow on the migration of salmonids and defining the effects of environmental factors controlling and modifying the upstream movements of salmonids. Such studies have usually but not always been associated with existing or proposed water abstraction schemes or reservoirs (Tamar, Test and Itchen, Dee, Tywi, Avon and Stour, Frome).

5.2 Investigating the effects of barrage schemes, or other obstructions, on the passage of salmonids. (Tamar, Test and Itchen, Dee, Taff, Tawe, Usk).

5.3 Studying the effects of water quality upon the passage of salmon through estuaries and rivers (Ribble, Dee, Usk).

5.4 As a subsidiary objective, estimating the population size of salmonid stocks and the exploitation rates of particular fisheries (Test and Itchen, Dee, Tywi, Avon and Stour).

5.1 The Effects of Flow

5.1.1 Estuarine Migration and Entry to Freshwater

The timing of passage of fish through estuaries can vary greatly. NRA studies in the estuary of the Tywi (Clarke, *et al*, in press) have shown that low river discharge from the river can result in delays in the movements of salmon into the estuary. Tracking has also revealed that salmon may wait weeks or even months before entering the Fowey (Potter, 1988), and Taff (Clarke, unpublished). A number of recent studies (Smith, 1990; Potter and Kell, in press; Clarke *et al*, in press) examine the implications of this flow mediated behaviour for estuarine fisheries.

There is, as yet, no generally accepted view on which features of flow are most important in inducing fish to leave the sea or saline waters of the estuary and enter freshwater. An absolute threshold value of flow for the successful entry of fish into freshwater and subsequent river migration has been established for the Hampshire Avon (Solomon, unpublished). In the Tamar, however, it is the changes in river flow above the basal level rather than an absolute threshold of flow which appears to influence entry to the river (Broad, unpublished, see Appendix 3;2a). As Webb (1989) has pointed out in the context of riverine migration, the previous regime of flow to which fish have been exposed may affect their response to changes in flow. In addition, fresh run fish may respond quite differently to fish which have been resident in the estuary for long periods.

Season may be an important factor in the relationship between fresh water flow and river entry. As the spawning period approaches fish may be more willing to enter freshwater even under low flow conditions. This is perhaps indicative that the state of sexual maturity of the fish as well as linked physiological and motivational states may be important in modifying the salmon's response to river

flow. Tidal and other environmental considerations such as light level and temperature may also be involved in river entry.

A full understanding of the significance of flow and other environmental factors in controlling salmon entry from the sea, through the estuary and into rivers requires further research. So far, the NRA studies have only made a start in addressing the problem of river entry. Nevertheless, this is an important strategic area, and the results from such studies have important implications for fisheries, water abstraction, and coastal development.

5.1.2 Riverine migration

Radio tracking studies suggest that the riverine migration of salmon may be split into 3 identifiable phases (Laughton, 1989 and 1991; Webb 1989; Milner, 1990; Clarke and Purvis, 1990; Hawkins *et al*, 1990) (Figure 1). The first phase of migration follows river entry, and may continue for 2 to 3 weeks. It may be interrupted by brief stationary periods (of a few days). During this phase, fish generally move actively at night and remain in recognised holding pools during the day. During periods of increased river flow, daylight movements may be recorded. Some individual salmon may complete most of their upstream migration during this phase. The quiescent phase which follows may last several months, the salmon remaining at a particular location for long periods and exhibiting little or no movement over a wide range of flows. Salmon may, on occasion interrupt this quiescent phase with short periods of active migration lasting a few days which take the fish further upstream. During the final phase of riverine migration, the fish resumes migratory activity, moving to its final spawning area. This resumption of active movement often coincides with autumn spates.

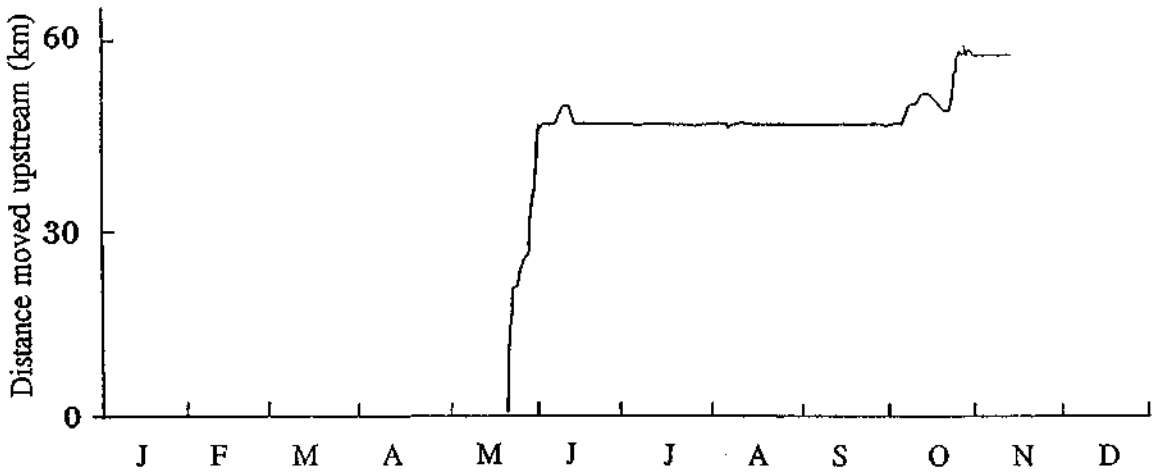

Figure 1. An example of the track of a salmon to illustrate the three phases of riverine migration.

This division of the migration into phases provides only a crude and imprecise description of the behaviour shown by the salmon. However, it does underline the observation made in several studies that the salmon's response to flow and other factors may vary depending on its phase of migration. For example, river flow may play an important part in fish entry into rivers and in initiating the final movements into spawning tributaries. Salmon may, however, fail to respond to a wide range of river flows during their quiescent phase.

During the quiescent phase the responsiveness of salmon to river flow appears to be especially complex. Salmon in smaller rivers, such as the Tywi, appear to be less likely to interrupt the quiescent phase with short periods of active migration than fish in larger river systems such as the Aberdeenshire Dee. In the Tywi a large

spawning time approached fish were more likely to respond to increased discharge. On the Avon there was little upstream progress in relation to increased discharge during the summer. A major summer spate only caused 10% of the tagged fish in the river to move in August 1986, and none moved in response to a similar elevated flow in July 1987. Similar results were reported for fish within the Tamar where it has been noted that secondary upstream migration did not usually occur until near spawning time. In the Tamar study, however, it was also found that on occasion secondary movements occurred in response to elevated flows soon after the initial rapid upstream migration.

With the approach of the spawning season response to elevated flow increases as fish make final progress to the spawning grounds. Entrance into spawning tributaries are again generally associated with elevated flows although it is not clear whether fish are responding to specific flow levels or increases in flow (Webb and Hawkins, 1989). The effect of flow on entry to tributaries is of particular importance to the Tamar study. Future work in this project is intending to concentrate effort on elucidating the flow regime needed for successful final spawning migration. NRA studies within rivers have so far been mainly descriptive, and with the exception of the Avon study there has been little attempt at analysis despite the relatively large number of fish tagged. Distinctions have yet to be drawn between the behaviour patterns shown by fish of differing sea age, or fish entering rivers at different times of the year. The habitat preferences of fish during their relatively long periods of residence within the river have yet to be investigated, despite their relevance to habitat improvement.

5.1.3 The Management of River Flow

The Hampshire Avon study has evaluated the effects of low flow on salmon movement in a chalk stream. Such a predictive modelling technique provides a basis for

hydrologists and river managers to establish an abstraction regime, which might cause a minimum of interference with salmon migration.

Such an approach was suggested by Millichamp (1976) and is illustrated in Figure 2.

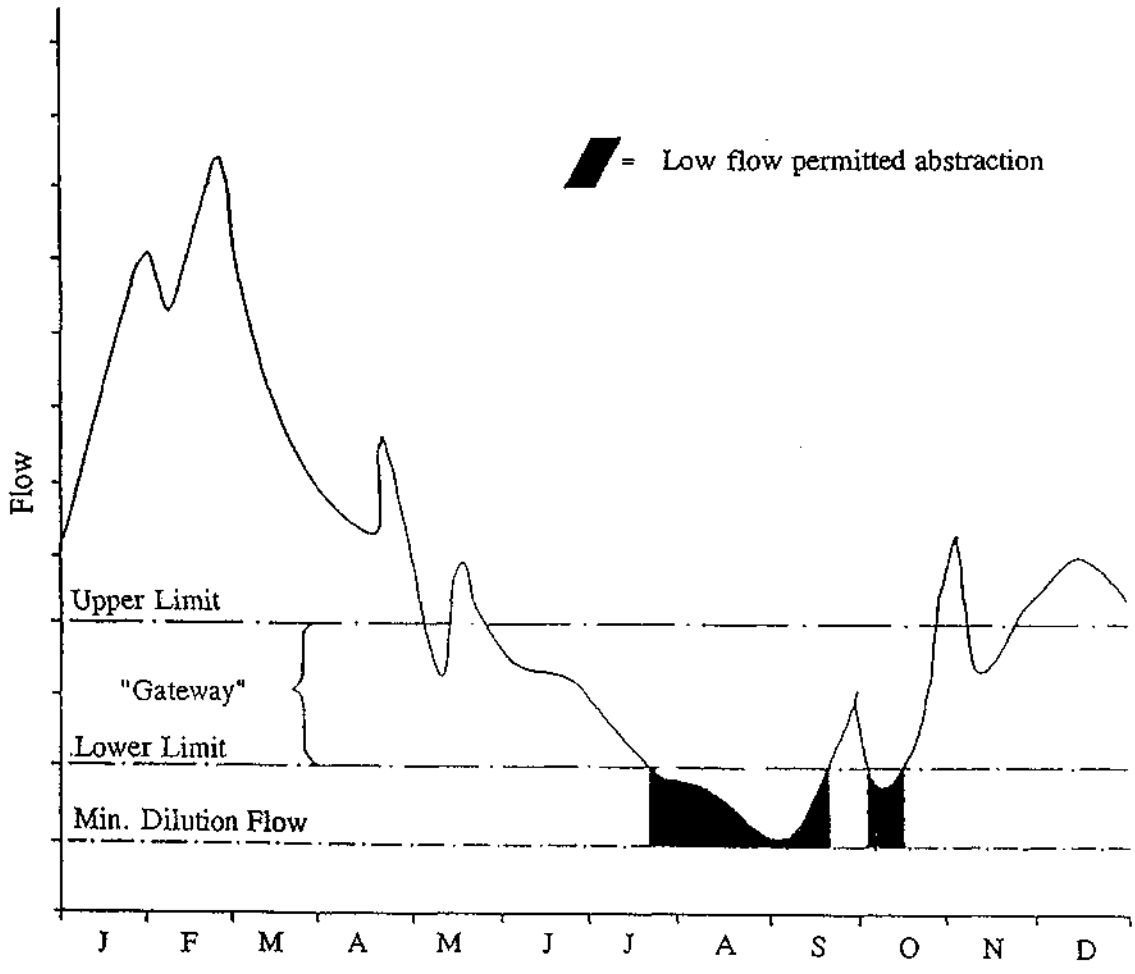

Figure 2. Reproduced from Millichamp (1976). The "gateway" for fish movement is defined between upper and lower limits of flow. A minimum dilution flow is also indicated. Fish movement is inhibited below the lower flow limit but the effect of effluents has to be allowed for, hence the inclusion of a lowest dilution flow limit.

The NRA work on the Avon has established that at river flows above a threshold value, fish generally entered the river without delay. While the simple Avon model may prove effective in predicting salmon movements in that particular river, difficulties will undoubtably occur in generalising it to predict salmon movements on other rivers where flow is more dependent on surface run off and therefore may be much more variable. The model assumes that absolute flow levels rather than changes in flow are the most important factor associated with salmon movement, and further, that such flow levels are constant from one year to the next. The relatively stable flow conditions which occur in chalk streams may allow such an approach. However, studies on other rivers, such as the Tamar, have shown that it is an increase in flow rather than flow level *per se* that is the factor most closely associated with initial movement into fresh water.

Milner (1990) stressed the importance of flow management strategies in relation to safeguarding fishery interests, and has pointed out that considerable attention needs to be paid to the protection of spate events. Regulation of abstraction rates and fisheries considerations in setting prescribed flows are also discussed by Cragg-Hine (1989).

Despite the strong interest of the NRA in defining minimum acceptable levels of flow for upstream migration, there appears to have been no concerted attempt so far to use the results of tracking studies to develop a more refined model to describe the responses of salmon to flow, based on relative changes in flow rather than the absolute levels used by the Avon model. Such a model would have value both in specifying the scope of future tracking studies and in examining the consequences of particular abstraction regimes.

The NRA tracking studies conducted so far have yet to generate a better

understanding of the relationship between flow and fish movement applicable in the wider context of river management. It is fair to say, however, that no technique other than fish tracking has greater potential for generating the data necessary for a deeper understanding (for an example of a study based upon fish counters, see Cragg-Hine, 1989). There are advantages to be gained at this stage from devoting effort to the development of models, describing the response of salmon to flow - if only to improve the data collected from tracking studies, and to ensure that expensive field studies are properly designed to answer appropriate questions.

5.2 Barrage schemes and other obstructions

Obstructions to fish passage may take many forms, for example, estuarial barrages, weirs, dams, and tidal doors. Gross movements of fish past obstructions may be studied by mark-recapture or automatic fish counter studies but these do not provide detailed information on the behaviour of individual fish. Tracking can provide a clear picture of normal baseline movements of individual fish before the erection of an obstruction. The technique may also provide details of any post construction impediments to movement and may be used to assess the effectiveness of any remedial alterations. Detailed studies are required at each obstruction, as impact depends upon several local factors including the size and nature of the fish run, flow, size of the weir and design of the fish pass etc. As an example of a recent investigation outside the NRA, McLean (1990) found that Morphie Dyke (a V-shaped weir with a fish pass incorporated into the upstream apex) on the North Esk delayed the upstream migration of early running spring salmon, but the movements of late running spring fish, summer salmon and grilse were not impeded. Similarly, Webb (1990) has used tracking to study the detailed movements of adult salmon immediately downstream of a hydro-electric dam on the River Tummel at Pitlochry. The upstream migration of the fish was delayed for varying periods of time and of the 11 fish which reached the dam, only 5 successfully ascended the fish ladder and surmounted

the dam. In this case, it was apparent that the outflow from the turbine draught tubes was more attractive to migratory fish than the much lower outflow from the fish ladder.

Several barrages incorporating fish passes (eg Harris, 1989) are presently being considered for construction on Welsh rivers which support significant salmon and sea trout stocks. Such barrages may inhibit the movements of fish into the river. They may also expose migrants to greater levels of pollution. Evaluation of the success of these projects is not yet possible as most of them have only recently begun and several years of data are required to address the questions posed. However, it is clear that, in most cases, tracking is the most suitable technique to provide the detailed information which is required to identify the effects of this type of obstruction on fish. So far, too few results have been obtained from the NRA studies to evaluate the likely impact of barrages and obstructions. The Usk study has collected, and the Taff study is still collecting, baseline information on the movements of fish before the barrages are constructed. Subsequently, once the barrages are built, an assessment of the success of fish in passing through the barrages should be possible. Though some insight may be gained into faults or deficiencies in the design of the barrages and their associated passes there is perhaps a case for the NRA mounting a specific experimental study of the detailed behaviour of migratory salmonids in areas of complex water flow. The aim would be to define more precisely the routes followed by upstream migrants, with the ultimate objective of improving fish pass design. At present, designs are largely based on trial and error experience, and untested theory. Such a study might make use of a location where patterns of flow can be varied and the effects upon fish observed. Techniques such as video observation would be required to supplement data from tagged fish.

Few studies have investigated the impact of obstructions on downstream migration of smolts. Increased mortality induced at this stage may result from increased predation at sites where large numbers of smolts are delayed (Struthers, 1989) or from damage passing through turbines. This is an area which requires further investigation and this is now possible with the development of miniature transmitters (Moore, *et al*, 1990a; 1990b). Integration of tracking studies with conventional smolt tagging could perhaps provide a measure of riverine mortality. Similarly, kelt tracking could provide data on riverine mortality, habitat preference, and the timing and speed of downstream movements. There may be scope for improving survival through habitat improvement, but so far little work has been carried out on this topic.

The movements of salmonids from seawater through estuaries into freshwater have received relatively little attention but is an important area of study, particularly with regard to tidal barrage schemes and the effects of water quality. Technology is now available to overcome the logistic problems previously encountered in areas of varying salinity. However, so far only very specific studies examining effects within a particular system have been undertaken. A large scale study mounted on a pristine estuary might assist in establishing the general features of the estuarine movements of salmonids. Choice of site would need to involve hydrologists to ensure all features are incorporated into the subsequent data analysis.

5.3 Water quality

NRA studies of salmon movements in relation to water quality in the Tywi and Usk estuaries have used CART and radio tags. These investigations relied on independent environmental monitoring to measure parameters such as oxygen concentrations, suspended solids and ammonia. Alabaster and Gough (1986) investigated the effect of dissolved oxygen and temperature in the Thames Estuary by

electrofishing and sampling from fixed stations and by vessel. Results indicate that salmon migrated through areas where oxygen concentrations were down to 2mg l^{-1} at temperatures between 19 and 22^{0}C although the precise DO values experienced by the fish are unknown. This lack of precision illustrates the difficulties in relating data collected at single monitoring stations to that immediately surrounding the fish, as discussed for the Usk in Section 4.1.5f.

The Ribble estuary study overcame this problem by continuously tracking salmon fitted with DO sensing acoustic tags (Priede, *et al*, 1988a, 1988b). The maximum life of the tags was 12 days. The telemetry data derived from the study is based on a relatively small number of fish tracked for periods from 45 minutes to 64 hours. More recently, Solomon and Potter (1988), using sonar buoys on the Fowey, found that the time delay between tagging in the estuary and entry into fresh water ranged from 14 hours to 42 days, with a mean of 26.5 days. A tag with a longer life span than that used on the Ribble may therefore be required to effectively study salmon in estuaries.

The Ribble study was a promising start in investigating the water quality requirements of salmon in estuaries. However, it has not been followed up despite the importance of work in this area. Though large numbers of fish have been tagged, the Tywi and Usk studies have not yielded significant insight into the movements of fish in relation to water quality. This may partly be the result of delays in the collation and analysis of data. However, analysis is made difficult by the major problem of obtaining adequate environmental data from a range of sites to relate to the movements of fish. This is a factor which should have been taken into account at the start of these studies.

5.4 The Population Size and Exploitation Rates of Particular Fisheries.

Calculations of population size and exploitation rates are useful secondary results of tracking studies, particularly if estimates of illegal fishing can be made. Such estimates have been attempted using the results of NRA tracking studies on the Tywi, Avon, Test and Itchen. Estimation of exploitation rates is also written into the objectives of the proposed study on the Dee.

Such analyses are useful, particularly in the case of unreported catches, for example, which are difficult to estimate in other ways. It is important to emphasize the limitations in the analysis, however, including the wide confidence limits associated with the estimates and the assumptions upon which the analysis is based. Indication of when it would be inappropriate to use such data would also be a useful safeguard. These points have been adequately covered in the reports concerned.

5.5 Non-salmonid Fish

Information on the migration patterns of non-salmonid fish are required to understand aspects of this economically important fishery. Although tracking work has generally concentrated on salmonids, some coarse fish have been successfully tracked (eg. MacKay and Craig, 1983; Philippart and Barras, 1988; Armstrong, *et al*, 1989; Lucas, in press). Recent advances in tag size reduction has increased the feasibility of tracking juveniles and small species.

Investigations of the general migratory patterns of other fish was considered to be of particular interest and importance in Wessex Region where the effect of recent increases in man-made obstructions on their migratory movements is not known. So far, however, tracking work on non-salmonid fish has not been considered of high priority, and no tracking studies have been contemplated.

6 EVALUATION OF THE NRA STUDIES

The last five years has seen a great increase in fish tracking studies within the UK, largely stimulated by the development, by MAFF, of a range of versatile and reliable fish tracking equipment including tags, receivers, and automatic listening stations. It has been suggested, perhaps rather unkindly, that fish tracking is a technique looking for an application. How far is this true? Have the NRA studies already provided valuable information about the movements and behaviour of salmonid fish in relation to water flow and quality? How successful have these studies been so far?

Answering these questions is made difficult by the problems encountered in obtaining detailed information on the NRA studies. With several notable exceptions (the Ribble, the Avon and Stour and the Glaslyn studies) documentation of the projects is poor and largely consists of statements of the problems to be solved, plus general descriptions of the work presently being carried out. Very little analysis of the collected data has been presented, and it is difficult to judge whether the main objectives of the various studies have been attained or are likely to be attained.

The scope of the Ribble study was tightly defined, and despite the technical and practical difficulties encountered, and the small number of fish tagged, a clear cut result was obtained. The study was well reported. The Avon study was also well defined, achieved its objectives, and regular reports were produced. Though the results have not yet been released more widely, there is undoubtedlyy scope for publishing findings in refereed scientific journals. The Glaslyn study was an early application of tracking techniques, which has been thoroughly described, and which was terminated when immediate management questions could be answered. The results

have recently been reassessed in the light of new interest in the effects of barrages. All three of these projects attained their objectives and can be seen to have done so. They have made an important contribution towards answering local questions. Moreover, the results from the Avon study have relevance in a wider context, for example in developing operating rules for river management.

By contrast, several of the remaining studies have been more open-ended, have been poorly reported, and the results are difficult to assess. The Tamar study commenced in 1986, is continuing, but has been particularly poorly described. It is not clear how successful this project has been, or what contribution the study is able to make to our understanding of salmon migration, since even limited appraisal of the results to date is not possible. Results from the three year Tywi and the four year Usk project are both now complete, but final reports are not yet available. Again, the relevance of the results to the original objectives has yet to be fully assessed. All three of these projects are large and expensive and have involved the tracking of large numbers of fish. A regular cycle of reporting and appraisal would have benefited each of them, if only from an internal project management standpoint. In terms of providing information of value to the NRA in a wider context, only time will tell how useful these projects have been.

There have been three short projects of more limited scope, with few fish tagged, which were subsequently terminated. Five salmon were tagged on the Torridge, but work was not continued once the Roadford Reservoir transfer scheme was reviewed. This study may be resumed in the future. A three month study of a small sample of fish on the Loddon (Thames) provided interesting observations on the behaviour of transported fish, but was not followed up. The trial may be repeated. Studies carried out in the Frome have experienced capture and handling problems, and a large proportion of the fish have been lost. The project is now under review. All

three of these projects illustrate the practical and logistical difficulties which can beset a project and confirm that tracking studies should not be entered into lightly, without careful prior evaluation of their likely success.

There are four NRA projects which have just started, or are at the planning stage. The project on the Test and Itchen started in 1989, has clearly stated objectives, and though difficulties have been encountered in obtaining fish at the right place at the right time, progress has been good. The first report on the project is now due. A study on the Welsh Dee has been planned, is ambitious in scope, and is closely linked with the DEESAP index river initiative. Little documentation is available, and a more careful statement of the aims and procedures to be followed might have been expected. A study on the Taff, planned to run for 10 years, began in 1990 but further progress will depend on the Cardiff Bay barrage development going ahead, and the developers paying the full costs of the study. Documentation on this project is also meagre. A pilot study has started on the Tawe, again associated with a barrage proposal though initially funded by the NRA. A report on the pilot study due in February 1991 is not yet available. All four projects represent a major investment of NRA resources, even though part of the costs may be borne by external customers.

It is evident from inspection of these projects that project management procedures have varied widely between them. The subcontracting of work to others, as with the Avon and Stour study, with a requirement for regular reporting, has in that case been successful, serving as a model for others. With many of the in-house studies, however, it would appear that no requirement even for self appraisal has been imposed, with the result that regular reporting to management for further assessment has been patchy and almost certainly inadequate. This criticism does not reflect upon the staff engaged in the studies, all of whom show a commendable enthusiasm for

their work, and some of whom have been drafted in to continue studies started by others. It is a reflection upon the overall management of such projects from above. Sections 6.1 and 6.2 consider this problem of project management in more detail.

6.1 The Management of NRA Tracking Studies

At present, the majority of NRA tracking studies have been commissioned by external bodies or by NRA divisions other than Fisheries, usually to examine specific problems. Where local Fisheries divisions have initiated work themselves, it has also been with a view to solving particular problems.

In general, project objectives have been clearly stated and well documented. The project management problem which has arisen is a failure to adequately monitor progress, and to appraise the results. In the past, no clear central system has existed to monitor the progress of research projects and to review the effectiveness of work carried out. In some instances, an impression has been obtained that customers were not especially concerned with monitoring year to year progress. Rather, tracking was viewed as meeting a general long term requirement for information. It is suspected that in some cases, particularly in long term studies, that the research has been funded as a substitute for action. In these cases it may be in the interests of some customers commissioning the work that the studies are open ended and that the results are not widely reported.

In order that NRA Fisheries division is able to maintain a clear picture of the range of tracking studies undertaken, a system is recommended for reviewing the progress of research projects set up by the NRA.

A variety of systems for research project appraisal are now in use elsewhere. Most of them have the following elements in common:

A clear statement of project objectives, set against a specified timescale.

A summary of the resources devoted to the project, costed on an agreed basis.

A set procedure for monitoring progress against "milestones" specified in advance.

The production of regular progress reports, and a final concluding report.

In carrying out the present review it was recognised that there had been little or no monitoring or coordination of research activities on a national basis within the framework of the Water Authorities. Moreover, there has not yet been time within the NRA to develop methods for coordinating the work of the various regional groups carrying out research on fish migrations. NRA Fisheries currently funds little of the tracking work undertaken, and has not been responsible for the establishment of the current portfolio of tracking projects. Hence the need for an overall review of these activities.

However, if NRA Fisheries is to exert control over the direction of tracking work in the future, and to ensure that the strategic objectives of the NRA Fisheries are met by the individual projects, in addition to specific regional objectives, then there is a need for a central project review system to be established. Such a system is required not only to review work on fish tracking but to cover the full range of scientific activities carried out by NRA Fisheries.

It is not entirely self-evident that "fish tracking and counting" should be regarded as a main area of NRA Fisheries activity, deserving special attention. This definition of the research area concentrates on particular techniques rather than defining the research area in terms of the overall objectives of the organisation. An alternative and more satisfactory way of classifying research activities may well be arrived at in the future. Provided a comprehensive system for describing and costing projects is developed, it will always be possible to aggregate the cost of work carried out using particular techniques, like fish tracking and fish counting.

It was clear that the majority of NRA Fisheries staff engaged in tracking work were not familiar with schemes for monitoring and assessing scientific activities. The most important recommendation to come from this review, therefore, is that NRA Fisheries needs to develop a system for describing, costing and appraising its scientific projects. Such a system would allow the progress of all research activities to be monitored, and performance in meeting specific objectives to be assessed on an agreed timescale.

6.2 Communication and Staffing

Some of the NRA regions engaged in fish tracking work, and their forerunners the Water Authorities, appear to give low priority to the reporting of results. In customer driven studies, this may be due to the confidentiality of those results. However, it was unusually difficult to obtain information for many of the projects reviewed. In some cases the only details available were from brief papers presented at conferences. Results from the last two years (since the 1989 AST/ Wessex Water Workshop) were not available for most of the projects outlined. Though one would not expect all the projects to yield the production of results in refereed scientific journals, it is not unreasonable to expect expensive scientific activities to be regularly reported upon. Where appropriate (i.e. where

commercial confidentiality is not a primary consideration) such reports should be published or at least be available for scrutiny within the NRA.

Communication between regions engaged in similar activities appeared to be minimal. Discussion of problems, data analysis techniques etc would undoubtedly help in standardising methodologies, improve between river comparisons and aid the establishment and coordination of a national programme. The programme review procedure recommended earlier may serve to aid communication within the NRA. More generally, however, the lateral dissemination of information through reports, meetings and seminars, should be actively encouraged. In this way the standard of work undertaken within the various regions of the NRA may be recognised and communication with other scientists both within and outside the NRA encouraged. Time must be allowed both for reporting results and communicating with others when staff responsibilities are decided.

An important factor in determining the success of a project is the continuity of project management. "In house" studies usually show strong continuity. However, it was clear that a number of the NRA tracking studies had experienced a rapid turnover of staff, which had been detrimental to progress and which had led to poor reporting of results. The NRA policy of fixed posts with individuals having to apply for positions elsewhere to further their careers inevitably leads to a movement of staff during the course of projects with some disruption to project progress. This system may be a nationally effective strategy which ensures that staff gain experience of a range of project types but it may be detrimental to the conduct of individual studies. A system of promotion in post for NRA scientists might provide better project continuity.

On a more positive side, communication with the general public is good for some studies. For example, a very informative colour booklet detailing the work carried out on the Avon is available from Wessex Water. There is no doubt that radio tracking work is of considerable interest to the general public, to anglers, and to the media. The publicising of tracking and counting activities can readily be used to interest the general public in the scientific work of an organisation like the NRA.

7 FUTURE FISHERIES PROJECTS

Section 5 examined the broader strategic scope of the NRA tracking work already in progress.

As already stressed, most of these projects were originally established to address local problems, but nevertheless their results are potentially relevant to the broader strategic research interests of the NRA.

There would be major advantages in expanding the strategic objectives of selected existing or future tracking projects. Clearly, not all projects would be suited to taking on these broader objectives, but in the case of the larger ones, the addition of the more strategic role could be expected to greatly enhance them, with benefits for the more specific local objectives. Such an approach, with firm direction and monitoring from the NRA, might prevent a duplication of effort between projects by ensuring that each of the more important strategic questions becomes the stated responsibility of one of the project leaders.

Thus, there is scope for building into one of the existing projects the broader objective of examining all those aspects of river flow and other environmental factors that are important in inducing fish to leave the sea or the saline waters of the estuary and enter freshwater. It is important to note that an extensive system for monitoring environmental parameters such as temperature, salinity, and flow would be required for such a study. The lack of such facilities for the estuarine studies carried out hitherto has greatly limited their value. In considering a site for such a study both the Dee and the Usk would be appropriate. The current existence of an active programme on the Dee would point to this as the more favoured site.

It would be sensible to build into one of the riverine studies a requirement to develop more sophisticated models of the relationship between salmon movement and flow, with the broad objective of improving knowledge on river management and setting operating rules for the regulation of water release and abstraction. So far, this approach has only been adopted on the Avon. This may well be an atypical site, and the basing of a well focused study elsewhere, on a river with a more varied pattern of flow, would have advantages. Again, the Welsh Dee presents itself as a favourable site, though the prior existence of a considerable body of data for the Tamar would also make the latter worthy of consideration. It is important, however, that before additional fish are tracked, some simple preliminary modelling is carried out, and the actual data requirements fully specified.

The importance to the NRA of improving the passage of salmonid fish through barriers and other obstructions in estuaries and rivers is very clear, and several projects are already attempting to examine the effects of coastal barrages. It may be advisable to charge one particular group of scientists with investigating the detailed behaviour of fish in and around obstructions, and subsequently giving that group responsibility for the provision of advice on the design of barrages and their associated fish passes. Such a group should not merely examine the behaviour of fish in and around particular fixed barriers to movement. As mentioned in Section 5.2 there is scope for a detailed experimental study of the movements of salmon and sea trout with respect to variation in flow within a river channel, and around obstructions. The requirement for better fish pass design would more readily be met by such an experimental study than simply by site specific tracking studies - valuable though the latter may be.

Another area where a degree of concentration of effort might be appropriate is in the definition of water quality requirement for fish moving through estuaries. The

close degree of monitoring of environmental monitoring necessary for such a study has been revealed by both the Ribble and Usk studies. There are two approaches which can be adopted: the placement of telemetering transmitters on the fish themselves thus measuring the environmental parameter values favoured by the fish, or through intensive monitoring at a number of locations along the estuary. Either way, the degree of expense involved would make it advisable for such work to be concentrated on a particular estuary, and not spread over several independent projects. It is worth considering whether this requirement for detailed investigation of the influence of water quality could be combined with the requirement for information on the effect of river flow on fish in estuaries. Both studies require careful and extensive monitoring of environmental parameters.

A further strategic area where little work is underway, and which could be included within the mandate of a particular project, is the closer definition of the habitat preferences of salmonids within rivers. Only limited information is available on the freshwater locations preferred by returning adult salmon though such information is important in meeting the environmental needs of these fish and to general considerations of habitat improvement. Studies of the movements of fish have tended to concentrate on the routes followed and the timing of the movements. In order to understand and predict movement patterns, however, it is necessary to define the habitat preferences or requirements of fish, which will vary through the various phases of their migrations. There would be advantages in carrying out a detailed study of habitat preferences within the context of a larger riverine tracking project. Particular attention needs to be paid to defining the choices and preferences of fish during their long quiescent period within rivers, and also the more active spawning periods.

Finally, it is necessary to stress the considerable advantages to be gained from closer integration of the various NRA tracking and counting projects. There has been little evidence of any coordination between projects to date, though there has been great overlap between them, both in terms of the techniques being applied, and the objectives being followed. The value of periodically bringing the various project participants together to discuss topics of mutual interest cannot be overestimated. Moreover, there is a strong case for the NRA taking the overall lead in promoting the discussion and coordination of work on fish movements within the UK. This may be achieved through the setting up of workshops for disseminating information on existing studies, bringing together different groups to discuss the more strategic issues, and promoting the development of technical methods.

8 THE FURTHER DEVELOPMENT OF TRACKING TECHNIQUES

Tracking allows the history of individually identifiable fish to be followed through their riverine migration. It is therefore a particularly powerful tool in the direct study of the behavioural responses of fish to particular river conditions, or in the identification of the details of riverine migration for specific components of a river's stock. Some of the limitations of fish tracking and the technical advances which may overcome them are discussed here.

8.1 Fish Capture

Several projects have experienced difficulties capturing sufficient fish of good quality for tagging. This may be a particular problem if a commercial fishery does not operate in the study area or if fish are required at a time of year when they are not abundant. The behaviour of individuals in poor condition or fish displaced from another area is difficult to interpret and the use of such fish should be avoided. Better designs of fish trap are required to capture fish in good condition for tracking studies.

8.2 Number of fish tagged

Even if the problems associated with fish capture are overcome, the number of tags which may be individually identified is currently limited to approximately 100. Furthermore, many of the initial batch of tagged fish may fail to provide useful data, although the exact numbers will vary according to the circumstances of the study (Milner, 1990). Interpretation of tracking data is, therefore, often complicated by the limited quantity of data collected.

It is possible to increase the size of the initial tagged population by duplicating tags. The risk of confusing individual fish may be minimised by allowing a period

of several months, and therefore a separation between succeeding runs of fish, before using duplicate tags. This assumes, however, that the behaviour of the tagged fish can be predicted reliably.

The initial batch of tagged fish may also be increased by sacrificing individual identifiability and tagging groups of fish with tags of the same frequency and pulse repetition rate. The technical constraints to large tagging samples may be overcome by the development of coded tags which will operate on a single frequency and will be uniquely identified by a combination of pulses of varying width. These tags are presently being developed by MAFF, although there is no firm date set yet for production.

Data storage tags, that is tags which have a large memory, and are able to store environmental, physiological, or other information, rather than telemetering data directly, may provide for large sample sizes of tagged fish. Although such tags are technically feasible, considerable developments are required before they are a practical proposition. In order to retrieve the stored data either the fish has to be recaptured or it has to be relocated and the data retrieved remotely. The tag itself has to determine its own location and it is not clear how this might be achieved.

8.3 Automatic Listening Stations

In using Automatic Listening Stations (ALSTNs), a compromise must often be struck between the range necessary to detect all those fish passing the station, and the problems of imprecision of fish location. ALSTNs working at maximum sensitivity often detect tags over a range of up to 1km and the tagged fish may be anywhere within ALSTN range when registered. This imprecision contributes to the variability in calculating fish progress data from ALSTN observations. The

importance of such problems may be significantly reduced by placing stations several kilometres apart and reducing the sensitivity of each station, firstly by reducing the size of the antenna.

The deployment of ALSTNs also plays an important part in determining the quality of data produced, for example, whether fish may be detected for equal distances on either side of the station. The precision of subsequent analysis will be increased by taking into account the siting of each ALSTN and effect of siting upon the performance of the station.

8.4 Fish counters

In Section 3, the integrated use of tracking and counters is recommended. The future development and refinement of counters, summarised below, will enhance the quality of data available from fish counters.

Both of the major counter suppliers, Aquantic Ltd. and Hydro-Electric plc, are presently engaged in counter improvements. The relationship between signal size and fish length is being investigated and in the future it may be possible to separate fish counts into size categories and, consequently, sea age classes. Investigations are also underway to determine whether the new micro-processor driven counter technology can permit the use of less intrusive and expensive in-river structures.

A system to allow very rapid signal processing to permit the Logie counter to operate in a Borland lift or fish pass is being developed. Investigations are also under way to further develop the environmental monitoring capacity of the Logie counter. The system will then be able to act as a "stand alone" counter and environmental monitoring station.

Effective use of resistivity counters is restricted to narrow rivers. There is a particular need for counters which will span wide rivers without the provision of a visually intrusive, potentially obstructive Crump weir. It may be necessary to investigate sonar counters further to fulfil this requirement.

8.5 Ancillary Environmental Data

Most of the NRA tracking projects have included in their aims a study of the relationship between environmental factors and the behaviour of migrating salmonids. The choice of which factors are monitored depends upon the biological questions being addressed together with an assessment as to which are likely to be most important. In salmon tracking studies attention has been focused upon river and stream flow, water temperature, light level and time of day, dissolved oxygen (DO), tidal state, and ammonia concentration. Of these, perhaps the most important is water flow. Much of this section will therefore be devoted to consideration of this topic.

River flow has two major components - direct runoff and groundwater discharge, which tend to contribute mainly to flood events and basal flows respectively. Flow may be characterised by a number of related measures including discharge, water velocity and depth. Most tracking studies express river flow in terms of discharge which is defined as the quantity of water passing through a cross section of a channel per unit time, expressed, for instance, in $m^3 s^{-1}$. Little attention, however, has been focused on establishing which characteristics of river flow are most important to migrating salmon. Furthermore, most projects have considered fish behaviour with respect to changes in river flow. The relationship between flow and movement during periods of stable flow has received less consideration.

Flow is most commonly measured by means of either a weir, a flume or depth gauge, discharge being calculated using conversions specific to a given site. The most common measure of channel flow used in the interpretation of tracking data is mean daily flow (MDF or MDD), recorded over the standard hydrological day (0900 - 0900). Few projects have attempted to use instantaneous flows derived from original hydrographs or described discharges with respect to long term average seasonal flows.

Consideration of the best analytical methods by which the behaviour of tagged fish can be related to flow is a subject which has been little studied and deserves closer attention to allow standardisation of data treatment between regions.

Practical problems may be encountered when relating flow to fish movements. Fish are often positioned some distance from gauging sites and their behaviour must therefore be related to hydrographic events recorded some distance away. This is a particularly difficult problem in watercourses subject to rapid changes in flow.

Most studies appear to assume from the outset that their ancillary data requirements would be adequately covered by existing monitoring facilities. This may not be the case and in some cases it may be necessary to increase the number of environmental monitoring sites. A longer term approach lies in the further development of tags which will telemeter information on the environmental conditions in the immediate vicinity of the tagged animal.

In general, remote monitoring of other environmental features suffer from the same problems as discussed in relation to flow. Studies in estuaries involving fixed monitoring stations face particular problems due to the complex hydrographic structure of the environment. Such projects would benefit most from the

development of appropriate telemetering tags.

8.6 Quantitative Analysis of Data

Considerable problems are associated with the analysis of tracking studies and, in particular, with associating fish behaviour with environmental parameters. Although analytical techniques need to be developed to address the specific aims of a particular study, a general approach to data collection and handling needs to be developed which will allow some comparison between studies.

Tracking studies allow a wide range of data to be collected on migration behaviour, including for example, a relatively complete river history of individually identifiable fish. The most important features of the data need to be identified. One aspect which needs particular attention is the timing of observations in relation to the timescale of change in the various environmental parameters. Fish positions are often only checked every few days, whereas the pattern of flow changes on a scale of hours. In addition, statistical techniques need to be developed to investigate relationships between behaviour (including the river history of the fish) and environmental variables. It is recommended that as a first step towards developing an analytical approach to tracking studies that the NRA, with other interested bodies, convene a workshop to allow workers in the field to fully discuss existing and future methods of analysis especially to relate the behaviour of fish to patterns of water flow.

9 SUMMARY AND RECOMMENDATIONS

Fish tracking, whether by means of acoustic or radio tags, has now been in use for over 40 years. Essentially, tracking provides a great deal of detailed information about the behaviour of individual fish. It can provide a comprehensive picture of the overall scope for behaviour, and allow detailed information to be obtained on the habitat preferences of individual fish during the different phases of their life history. Fish counters, on the other hand provide data on the numbers of fish moving past a given point. They can provide accurate census data, and information of the movements of populations as a whole. Used in pairs, counters can indicate the propensity of fish to respond to particular environmental cues. The techniques of fish tracking and fish counting complement one another, and there are advantages to be gained from deploying them together. Both have now reached a degree of technological development which allows them to be used routinely.

Thirteen tracking projects were examined during this review, and are listed below:-

North West Region

Ribble Estuary

South West Region

River Tamar

River Torridge

Southern Region

Rivers Test and Itchen

Thames Region

River Lodden

Welsh Region

River Dee

River Glaslyn

River Taff

River Tawe

River Tywi

River Usk

Wessex Region

Rivers Avon and Stour

River Frome

Each of these studies has its own local objectives. Some have received external funding from the Water Authorities or plcs (Tamar, Torridge, Loddon), and commercial developers (Taff, possibly the Tawe in the future), while others have been commissioned by NRA Water Resources (Test and Itchen, Avon and Stour, Frome), or are jointly funded (Ribble, Dee, Tywi, Usk). Nevertheless, each study has also incorporated elements capable of contribution to the broader, more strategic of NRA Fisheries, including:

> Examining the effect of flow, and defining the environmental factors controlling the upstream movements of salmonids, especially in relation to water abstraction and water release schemes. (Tamar, Test and Itchen, Dee, Tywi, Avon and Stour, Frome)

Investigating the effects of obstructions, especially coastal barrages, on the passage of salmonids. (Tamar, Test and Itchen, Dee, Taff, Tawe, Usk)

Studying the effects of water quality upon the passage of fish through estuaries and rivers. (Ribble, Dee, Usk)

As a subsidiary aim, estimating the population size of salmonid stocks, and determining exploitation rates. (Test and Itchen, Dee, Tywi, Avon and Stour)

Three of the projects (Ribble, Avon and Stour, Glaslyn) have been completed, attained their specific objectives and full reports have been prepared for each. The results from the Avon and Stour study may have relevance in a wider context, for example in relating environmental factors including flow to the upstream movements of fish, perhaps assisting in the development of operating rules for river management.

By contrast, the Tamar, Tywi and Usk studies have been more open-ended, have not been fully reported upon, and only limited analysis of the collected data has been performed. Only time will tell whether these projects have met their specific local objectives, or are able to contribute to our wider understanding of factors affecting the movements of fish.

There have been three short projects of limited scope, with few fish tagged, which were subsequently terminated (Torridge, Loddon, Frome). All three encountered logistical difficulties. The Loddon and Frome studies may be resumed if various practical difficulties can be overcome. Work on the Torridge may be resumed if

interest in water transfer is revived.

Four NRA projects have just started, or are at the planning stage (Test and Itchen, Dee, Taff, Tawe). Two of them, the Taff and the Tawe projects are associated with barrage developments (new work on the Usk may also be considered, if plans for the Usk barrage proceed). The Dee study is ambitious in scope and closely linked with the DEESAP index river initiative. The project on the Test and Itchen has clearly stated objectives, and is making use of both fish tracking and fish counting.

Standards of management and planning have varied widely between these projects. The subcontracting of work to a consultant on the Avon and Stour, with a stated requirement for regular reporting, has been espcially successful in management terms, the project serving as a model for others - though a final report has yet to be received. This is not to say that projects like those on the Tamar, Tywi and Usk have not yielded great quantities of data, or that they are not capable of providing considerable insight into the behaviour patterns of fish, once analysis has been completed. It is simply that full evaluation of these projects is made almost impossible by a lack of written material, and especially a lack of analysis of the data collected. It would appear that no requirement for periodic appraisal of these projects has been imposed. It is possible that some of the customers commissioning the work wished these projects to be open-ended, with no strict requirement for the reporting of the results. However, it is not desirable that this deficiency should continue. A standard system for describing, costing, monitoring and reporting on all research projects is required. It is suggested that for each project there should be:

A clear statement of objectives, set against a specified timescale.

A summary of the resources devoted to the project, costed on an agreed basis.

A set procedure for monitoring progress against milestones specified in advance.

The production of regular progress reports and a final concluding report.

It is recognised that NRA Fisheries has yet to develop methods for coordinating the work of the various regional groups carrying out research on fish migrations and promoting communication between them. Hence the need for this review. It is clear however, that a system is required for reviewing progress in all scientific areas, for appraising the degree of success with which particular projects have met their objectives, and for ensuring that collectively these projects address the more strategic objectives of the NRA with minimum duplication of effort. In addition to instituting a programme review procedure, however, there is also a need for more lateral dissemination of information. Indeed, there may be a case for the NRA seeking to promote coordination of fish tracking and counting work across the UK, including other outside agencies.

Fish tracking and fish counting are merely techniques. They are essentially no different from other fisheries research techniques like electrofishing, or chemical monitoring. As the techniques become more accessible and reliable they will be used increasingly for the solution of local problems on individual rivers. Provided each individual proposal is evaluated beforehand in terms of the specific objectives each is intended to meet, these should be no unnecessary proliferation of tracking and counting techniques.

Tracking and counting have a major role to play in meeting some of the more strategic future research requirements of the NRA. There would be major advantages in meeting these objectives through the expansion of existing or planned projects. Clearly, not all projects are suited to taking on these broader objectives, but in the case of the larger ones the addition of a more strategic role would greatly enhance them, with benefits for the more specific local objectives. Such an approach, with firm direction and monitoring and proper prior evaluation, might assist in preventing a duplication of effort between projects.
Particular strategic areas of work which have been identified are:-

Identification of those environmental factors, including river flow, which control the entry of fish into freshwater from the sea or the saline waters of the estuary. Hitherto, work in this area has been handicapped by inadequate monitoring of the environmental parameters.

Within the river, there is a need to improve understanding of the relationship between water flow and upstream movement, because of the considerable relevance of this relationship to the regulation of water abstraction and water release. Though fish tracking and counting techniques have already been applied to this problem, an element which has been lacking from earlier projects has been the prior modelling of the relationship between movement and flow, and the setting up of simple hypotheses which can be tested in the field. The wider use of fish counters especially in pairs or series, would also bring benefits to this area of study.

Detailed examination of the movements of salmonid fish with respect to the patterns of water flow within river channels and close to obstructions and fish passes, and the development of better methods for easing the passage of fish through rivers is presently hampered by ignorance of the precise requirements of migratory fish.

Though such a study might employ fish tracking and fish counting, the use of other techniques - such as video observations, would almost certainly be necessary.

Closer definition of the water quality requirements of salmonid fish, especially within estuaries. It is possible that this work could be combined with a study of those factors which induce fish to leave the estuary and enter the river (described above). Both studies require the intensive and extensive monitoring of environmental parameters along an estuary. It is possible that some of these parameters can be monitored by means of telemetering tags attached to the fish.

One area of interest which has not yet been addressed by means of tracking techniques is the better definition of the habitat preferences of salmonid fish within rivers. The movements of fish through rivers have so far been described rather crudely, in terms of distances travelled upstream, or the environmental factors which control the movements themselves. It is notable, however, that as part of the process of progressing upstream salmonids spend considerable periods without moving, and that they select particular locations for this purpose. Improvement and rehabilitation of the habitat available for adult salmon within rivers, both during upstream movement, and during spawning itself, requires a more detailed examination of the habitat choices made by fish.

Subsidiary research topics which might benefit from the application of fish tracking and counter techniques include the downstream movements of smolts and kelts, and the movements of non-salmonid fish.

In terms of future development of tracking and counting techniques, the following technical requirements have been identified:

Better fish traps and fish counter techniques are required to aid the tagging of fish in good condition, at appropriate times (not just when fish are especially abundant).

Radio tags are required which will enable larger numbers of fish to be tagged and tracked simultaneously. Such tags might operate on a common frequency and be identified by difference in the coding of the sequence of pulses produced.

Existing fish counters can perform extremely well on small rivers. However, for larger rivers counters are required which will operate without the need for large, expensive, and visually intrusive civil engineering works. It may be necessary to investigate sonar counters further to fulfil this requirement.

In earlier fish tracking studies, problems have been encountered in monitoring various environmental parameters, including water flow, sufficiently often, over a long length of river or estuary. Inexpensive monitoring stations are required to collect these data. To some extent, however, these requirements can be met by the further development of tags capable of telemetering environmental data back from the fish itself.

An important feature of all tracking projects is that they arouse the interest of the general public, anglers and the media. With most of the NRA projects, communication with the public was good. The Avon and Stour project had been particularly well publicised through the production of an informative colour booklet. The publicising of tracking and counting work can readily be used to interest the public in the scientific activities of an organisation like the NRA.

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APPENDIX I. A DESCRIPTION OF FISH TRACKING TECHNIQUES

One of the earliest experiments using acoustic tags was conducted in 1956 by the U.S. Bureau of Commercial Fisheries (now the National Marine Fisheries Service). An adult coho salmon, *Oncorhynchus kisutch*, was fitted with an externally attached 132-kHz acoustic transmitter, released into Lake Union and followed from a small boat with directional receiving equipment (Monan, *et al*, 1975). Although the track lasted only one hour, the basic tag design was refined and improved and the experiment subsequently provided some insight into movements of chinook salmon, *O. tshawytscha*, coho salmon, *O. kisutch* and steelhead trout,*O. mykiss* in the Columbia River below the Bonneville dam (Johnson, 1960). In 1961, the first automatic fixed monitors were placed along the shoreline and in 1967 acoustic tracking enabled the precise identification and location of a severe temperature block to the movement of fish which could not have been pinpointed by other methods (Monan, *et al*, 1975). Acoustic tracking has subsequently been used extensively for studying salmonid movements in marine (Madison, *et al*, 1972; Stasko, *et al*, 1973; Stasko, *et al*, 1976, Hawkins, *et al*, 1979; Smith, *et al*, 1981; Potter, 1985), estuarine (Groot, *et al*, 1972; Stasko, 1975) and lacustrine environments (Malinin, *et al*, 1974; Thorpe, *et* al, *1981).*

The limitations of acoustic tracking in shallow, fast flowing waters due to severe signal attenuation, was recognised at an early stage (Stasko and Pincock, 1977). Studies of salmon on the Columbia River (Monan, *et al*, 1975), for example, were restricted by problems of severe attenuation of sound waves in turbulent areas below dams due to entrained air bubbles.

The first radio transmitter for fish tracking was designed by Lonsdale and Baxter (1968). In response to the problems encountered using ultrasonic tracking

techniques, radio tags and tracking equipment were used in 1971 to study the behaviour of adult chinook salmon as they approached Bonneville Dam (Monan, *et al*, 1975). Further radio tracking projects in 1972 and 1973 investigated the effect of river flows on salmon movements. Salmon in the Penobscot River, Maine, USA, were successfully tracked by aircraft (McCleave, *et al*, 1978). Using large tags (6.5-9.6 cm x 1.9 cm) with a short life (about 2 months) range averaged about 6 km.

The first radio tracking of fish in the UK began in 1978. Solomon and Storeton-West (1983) describe the development of a radio tracking system for studying adult salmonids in rivers. This technique has subsequently been successfully applied in studies of the migratory behaviour of salmon in several river systems (eg Solomon, 1982; Hawkins and Smith, 1986; Laughton, 1989; Webb, 1990; Milner, 1990; Clarke, *et al*, (in press)).

Sensors to study physiological and environmental parameters may be incorporated into biotelemetry transmitters (Stasko and Pincock, 1977). Factors such as temperature (Johnsen, 1980), swimming depth (Stasko and Rommel, 1974), heartbeat (Priede and Young, 1977; Armstrong, *et al*, 1989), tailbeat (Ross, *et al*, 1981), and illumination (Gayduk and Malinin, 1971) may be investigated. Sensors of environmental parameters such as dissolved oxygen (Priede, *et al*, 1988a; 1988b) have a particularly important role to play in the study of factors affecting salmonid migrations.

I.1 Tagging and tracking methodology

Capture Methods

The method of capture is very important if the behaviour of the tagged fish is to be assumed to represent movements of the undisturbed population. Commercial seine

nets, traps and bag nets are recommended as the best methods for obtaining a high proportion of undamaged fish (Varallo, 1987). Enmeshing nets like trammel nets and gill nets are generally considered less satisfactory unless the fish are removed very quickly. Most authors have stressed the importance of minimising physical damage to the fish by careful handling and rapid release of the fish.

Transmitter attachment

The first acoustic transmitters were externally clamped into the muscle behind the dorsal fin of the salmon (Stasko and Pincock, 1977). Later studies on trout developed a saddle secured by pins or wires through the dorsal muscles (Young,*et al*, 1972). The overall effect of transmitter presence on fish behaviour is difficult to determine but studies suggest that external tags can affect the swimming ability of salmon parr (Greenstreet and Morgan, 1989) and smolts (McCleave and Stred, 1975). The effect of external transmitters on adult salmonids is likely to be less significant (Stasko and Pincock, 1977; Arnold and Holford, 1978).

The simplest method of internal attachment is by gently pushing a transmitter down the oesophagus into the stomach. This technique has several advantages over external attachment. The transmitter does not snag or increase drag. Tagging causes little trauma to the fish provided the tag is of moderate size. Also, the transmitter lies near to the centre of gravity of the fish and it is usually small compared to the size of normal prey items (Stasko and Pincock, 1977). This method appears to be especially suitable for salmon during their non-feeding river migrations and does not appear to affect their behaviour adversely (Stasko, 1975).

Surgical implantation of the transmitter into the body cavity has been used widely in North American fish tracking studies (Stasko and Pincock, 1977). The procedure has only been possible in Britain since the Animals (Scientific Procedures) Act 1986

enabled licenced workers to carry out acceptable implantation procedures on wild animals (Lucas, 1989). Laboratory studies suggest that this technique is suitable for rainbow trout (Lucas, 1989) and it may overcome problems of tag attachment to sea trout. MAFF scientists have developed a miniature acoustic transmitter (17mm by 7.5mm) which is small enough to be implanted into the peritoneal cavities of salmon parr and smolts. Laboratory and field tests indicate that implantations have no effect on growth, feeding or swimming behaviour in either parr or smolts (Moore, *et al*, 1990a; 1990b). With some species, however, the tags may progressively work their way through the body wall (Lucas, 1989). Moreover, the need to make an incision in the body wall, and to close the wound with sutures or an adhesive is inevitably traumatic for the fish.

Sea trout

Specific difficulties are experienced in tracking sea trout. Early attempts to track sea trout were generally unsuccessful due to problems of tag attachment (Solomon and Storeton-West, 1983). Stomach tags tend to be regurgitated within 5 to 10 days, (Solomon, 1982) and therefore provide only very limited information. A few studies have externally attached radio transmitters to sea trout but there are several disadvantages to this method (Solomon and Storeton-West, 1983; Le Cren, 1985). External tags for sea trout must be small. They therefore have a short life span, again providing only limited information on migratory movements. Sea trout also tend to hold up under tree roots increasing the likelihood of the tag snagging and causing damage to the fish (Varallo, 1988). The Fisheries Technical Liaison Committee concluded that further development of tags for sea trout was required and recommended that alternative methods such as surgical implantation be evaluated (Varallo, 1988).

Solomon (1989) notes that early tests involving implantation of tags into the body cavities of a small number of fish yielded promising results. As a result of the 1986 act, implantation may become an established procedure in the future. Recent studies also suggest that stomach tagging may be suitable for larger sea trout (>60cm) which may retain transmitters for periods of up to several months (Purvis and Clarke, 1990; Clarke *et al*, 1990).

Methods of Radio Tracking

The simplest method of tracking a radio tagged fish is by detecting signals from the river bank using a portable radio receiver and antenna. In general, either H-adcock or YAGI antennae are used; the latter being more directional but more difficult to deploy. The movements of fish past a particular point on a river may be monitored continuously using Automatic Listening Stations (ALSTNs). A series of very successful ALSTNs have recently been developed by the MAFF Fisheries Laboratory at Lowestoft and are now available commercially. Similar devices are now also being marketed by a Swedish company.

An early ALSTN comprised a receiver with short range aerial, a tape recorder, a timer/control box and a power supply, all enclosed in a weatherproof box. This system was later substantially modified to include a Yaesu receiver able to scan rapidly through 10 channels, tuned to pre-set frequencies, at pre-set intervals and to print out the time and channel number on detection of a radio signal. Thus a large number of tagged fish may be detected (Solomon and Storeton-West, 1983; Hawkins and Smith, 1986), with a minimum of power consumption. In deploying automatic listening stations there often has to be a compromise between using a sufficiently large antenna to detect all the fish passing the station, while at the same time ensuring that the antenna does not detect fish over a very wide range. Information on the time of passage is best obtained, for example, with a small

antenna, detecting transmitters only in the immediate vicinity.

Detection from an aircraft, usually by means of a simple dipole, is effective at long ranges, but because of the speed of travel is incapable of providing a precise location. It has advantages in detecting "lost" fish, or in surveying large rivers.

APPENDIX II. AUTOMATIC FISH COUNTERS

To automatically record the passage of a fish, a physical difference between the fish and its surrounding water may be used to activate a recording system. Beach and Walker (1974) examine the basic physical properties of a fish and the ways in which these can be utilised in fish counters. Currently sonar and resistivity counters are in general use and will be discussed below. Mechanical (Jackson and Howie, 1967) and biolectrical (Hellawell, 1972) counters have also been developed, but the problems associated with them far outweigh their effectiveness.

Sonar counters were developed for use in Alaska rivers which are wide, deep, relatively free of debris and which have populations of many thousands of Pacific salmon which move steadily upstream in well defined periods (Bussell, 1978). Tests of the Bendix sonar counter in British rivers were unsuccessful, however, and a later development, the Birmingham Sonar counter, also proved unsatisfactory (Braithwaite, 1971; 1974). The possibility of further research into this technique has been discussed, since there may be scope for developing the technique for counting in wide river systems.

The main type of fish counter now used in Britain is the electrical resistivity counter. This is based upon the principle that a fish has a greater conductivity than an equivalent volume of freshwater, therefore, the passage of a fish between a pair of electrodes changes the effective resistance which is used to trigger the counter (Hellawell, 1972). Most counters consist of three electrodes effectively making two pairs, the middle electrode being common. From the sequence of changes in resistance between the two pairs of electrodes, the direction of movement of the fish can be determined. Logic circuitry has been developed which detects and records the direction of movement. Delays may also be included to prevent

multiple counting if the fish hesitates or vacillates while crossing (Beach and Walker, 1974; Holden, 1988).

Resistivity counters may be considered to consist of two parts: an underwater detection unit and a counter unit situated on the bank, which contains the logic circuitry and registers. There are three types of underwater detection unit: tube, channel and strip, each of which is most suitable for different river locations.

Lethlean (1953), working for the North of Scotland Hydro Electric Board (NSHEB), first described the resistivity method of automatically counting fish. The original Lethlean counter consisted of three metal rings mounted a fish length apart on the inside surface of an insulated tube. The small radius of the tube ensured that fish passed close to the electrodes. This original tubular design which is still in use today, is limited to incorporation into a fish pass such as a fish ladder where fish have to swim through the tube to move to the next pool in the ladder. It may also be incorporated into a Borland lift (Holden, 1988) or Denil fish pass (Beach, 1984). The simple tube counter design is therefore limited to sites where a fish pass is present (Bussell, 1978). Other disadvantages of this detection unit are that debris, for example, plastic bags or logs may block the tube. Water flow through the tube should be maintained at 1 to 2 ms^{-1} to discourage fish from lingering over the counter (Bussell, 1978). Maintenance of the flow at a level where the tube is always full prevents entrainment of air which could cause false counts. A well sited tube counter is expected to count with an efficiency of greater than 95% (Simpson, 1978), and for this reason such counters have been widely used where the conformation of the river or fish pass is appropriate.

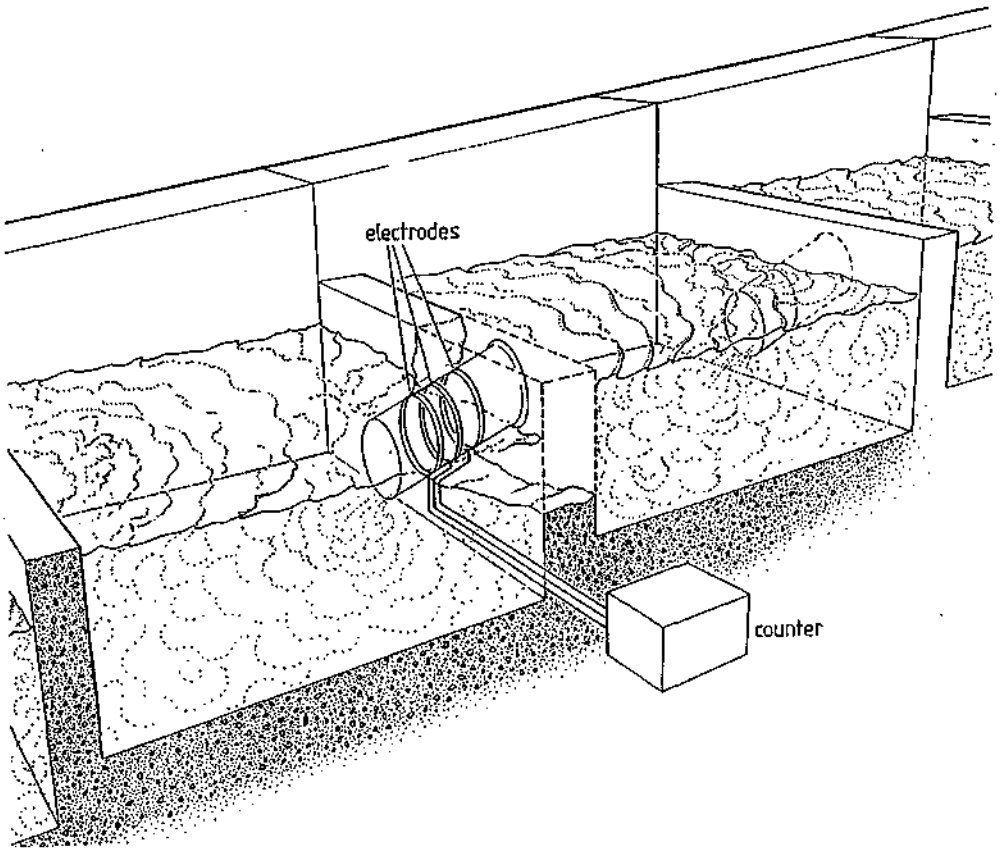


Figure 3 The NSHEB tube resistivity counter.

The original tube counter was subsequently modified into an open channel sensor (Lawson, 1974; Bussell, 1978). This is rectangular or U-shaped in cross section. If the channel is narrow and deep, the electrodes are placed across the base and up the sides; if it is wide and shallow, the electrodes are restricted to the base to prevent their exposure to air (Holden, 1988). The open channel counter can be much larger than the tube counter and can be adapted to small streams or fish passes (Lawson, 1974). The major advantages of the open channel compared to the tube are that the risk of blockages is reduced and fish are not constrained to pass through a small passage. Fish may be held up by a tube counter but are much less likely to be held up by an open channel or strip counter. The strip counter consists of 3 strip electrodes, usually fastened to the downside of a Crump Weir, extending across

the entire width of the river. This design eliminates the risk of blockage by debris but is more exposed to damage from objects such as boulders, when the river is in spate. Several problems are encountered with the strip counter. Sensitivity is dependent upon the distance of the fish from the electrodes. Fish moving upstream are likely to be close to the bottom, but fish descending may be further away from the electrodes (Beach, *et al*, 1981; Dunkley and Shearer, 1989). There is therefore a bias towards ascending counts.

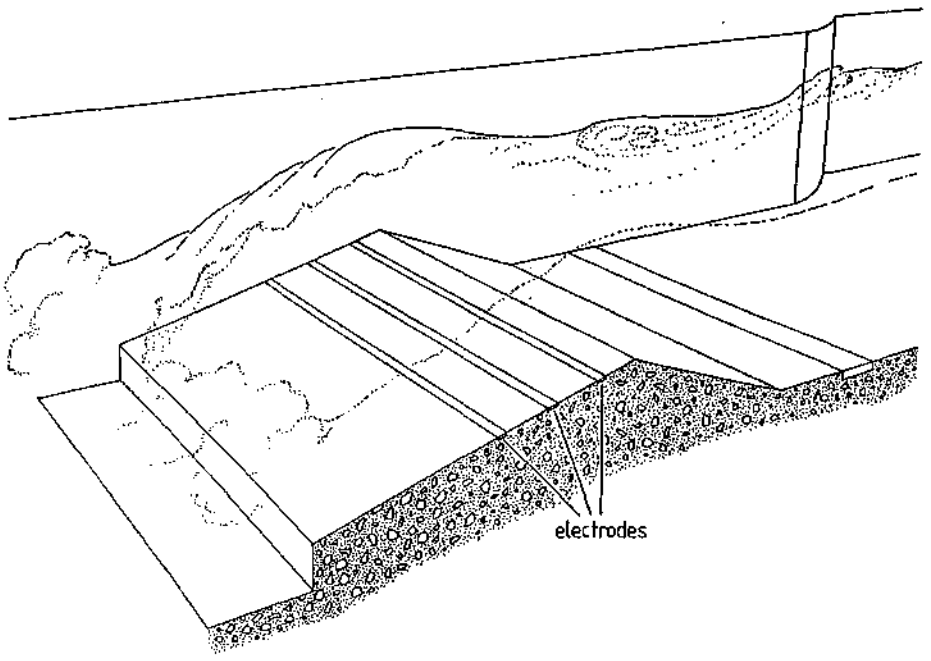


Figure 4. The NSHEB strip resistivity counter. The electrodes are fixed to the downstream face of a Crump Weir.

Significant advances in counter circuitry were made in the 1980s and the latest two resistivity counters, the NSHEB (now Hydro-Electric plc) Mark X and the Logie counter developed by the Department of Agriculture and Fisheries for Scotland (now Scottish Office, Agriculture and Fisheries Dept.) in conjunction with a commercial electronics company, Aquantic Ltd, now contain computers (Holden, 1988). These

allow self calibration as well as signal processing to be conducted on line.

The Mark X and Logie counters both automatically monitor and compensate for environmental changes in up to 4 channels simultaneously. Independently, an algorithm compares the form of a received signal with that of a stored fish signal only counting those signals where the comparison is good. Fish smaller than a pre-set threshold are also rejected and the counters are capable of sorting fish into approximate size groups (Holden, 1988).

The Mark X has principally been developed for installation at the exit from Borland lifts where large numbers of fish pass across the underwater detection unit in a short time. For this purpose it is essential that no time delay is involved in signal processing and the Mark X is well designed to cope with this particular requirement. In contrast, the algorithm within the Logie counter takes about one second to process signals limiting its ability to count fish ascending the river in quick succession. However, this time delay is incurred through a more detailed comparison of the signal, therefore the accuracy of the Logie is expected to be higher.

The Logie counter has a self test capability which uses an inbuilt "dummy fish", this can be inserted into any channel in either direction every 30min. There are two models of the Logie counter, the 1700A which is a single-channel counter and the 2100A which may contain up to 4 counting channels for use with compound weirs. The counters may be interrogated and controlled remotely using a microcomputer and modem. The Logie also has an optional conductivity meter module which can be retro-fitted. This allows modification of the processing algorithm to compensate not only for changes in bulk resistance but also specifically for changes in water conductivity. The Logie counter on the Crump Weir on the North Esk has an accuracy

of 99%, validated by a video camera, whereas the Mark X counter situated in the Borland lift at Aigas power station on the River Beauly, has an accuracy of 95.5% validated by visual counts. Although comparison is not entirely valid as the counters are being utilised with different types of detection unit, these figures illustrate the very high level of accuracy which is now possible with automatic fish counters.

II.1 The Advantages and Limitations of fish counters

Fish counters have the great advantage of making it possible to estimate the total numbers of migratory fish moving past a given point in the river. This in turn may enable spawning stock size to be estimated (provided subsequent mortalities can be determined). Where different components of the stock move upstream at different times of the year, the relative contributions made by these components can be investigated. In particular, it is possible to examine the contribution made by fish which enter the river outside the fishing season, and which are not normally sampled. Counters, therefore, avoid the sampling problems associated with tracking studies, and questions concerning the fish at the population level may be approached with some confidence.

It is more difficult to employ counters to examine the responses of fish to environmental variables. A simple counter, on its own, simply measures the numbers of fish passing over it in a given period of time. It cannot give an indication of the environmental cues that stimulated the movement. To determine the effects of a particular variable - like river flow - it is necessary to know the proportion of those fish present which are moving. Careful study of the responses of fish therefore requires two or more counters in series.

Fish counters are usually extremely expensive to install. Though the electronics are relatively inexpensive, most monitoring sites require extensive engineering work to be undertaken to position the electrodes. Indeed, where a strip counter is to be used on a river of any size, a Crump weir is usually necessary, often at more than one level to cope with varying flows. Only at sites where gauging weirs or fish passes are already present can a fish counter be installed at moderate cost.

Counting techniques for use on narrow, shallow rivers, or where water is constrained to run through channels or tubes are now well developed. Future developments at such locations may well take the form of the addition of various sensors to monitor flow and water quality. However, problems still have to be overcome in installing electronic counters on larger rivers, where the costs of installing a Crump weir are extremely high, or where aesthetic consideration may rule out the construction of such a weir. Future research will need to be carried out to facilitate the application of counting techniques in these circumstances. It is by no means clear whether conductivity counters will provide the solution to these problems, or whether new acoustical techniques will need to be developed.

APPENDIX III NRA Tracking Project Summaries

1) North West Region
   1a. Ribble Estuary

2) South West Region
   2a. River Tamar
   2b. River Torridge

3) Southern Region
   3a. Rivers Test and Itchen

4) Thames Region
   4a. River Loddon

5) Welsh Region
   5a. River Dee
   5b. River Glaslyn
   5c. River Taff
   5d. River Tawe
   5e. River Tywi
   5f. River Usk

6) Wessex Region
   6a. Rivers Avon and Stour
   6b. River Frome

1a) NRA FISH TRACKING PROJECT

REGION:	North West (North West Water)
STUDY LOCATION:	Estuary of the River Ribble
COMMISSIONING BODY:	North West Water; Water Research Council
PROJECT STAFF:	J.B. Leeming; D. Cragg-Hine; K.M. Wilson; J. Nott; I.G. Priede
SPECIES:	Salmon and sea trout
START DATE:	1980
DURATION:	6 years, approx. 10 days/summer

AIMS and OBJECTIVES:

1) Investigation of the factors and stimuli influencing the migration of salmonid fish in estuaries;

2) Improvement of knowledge towards the development of water quality criteria for migratory salmonids in estuaries;

3) Development of telemetry systems (mobile/fixed) for location of fish and measurement of water quality;

4) Provision of local information regarding the water quality of the Ribble Estuary at times of upstream fish migration;

5) Provision of local information about salmonid migration and movement in the Ribble Estuary in relation to the protection and regulation of the fishery.

STUDY DESCRIPTION:

Discharge from a major sewage works 9km below the tidal limit of the Ribble creates a biological oxygen demand (BOD) causing an oxygen sag that can extend over 15km with minimum recorded values <40% air saturation value. First trials with acoustic tags were carried out in 1980 and oxygen telemetry work began in 1982. A total of thirty three salmonids were tagged with dissolved oxygen (DO) sensing acoustic transmitters. Tags were mounted externally. No details are available of the sea trout tracked. Of the 20 salmon tagged, 2 died immediately after tagging and 13 returned to sea. Within the estuary, fish oscillated to and fro with the tides over a 10km amplitude through cyclical changes in DO. Results indicate that fish will avoid DO concentrations below 55% ASV if possible.

PROBLEMS/LIMITATIONS:

Highly labour intensive; complex logistics due to difficult access, shallow water, fast tides.

REPORTS PRODUCED:

Leeming, J.B., Wilson, K.W., Cragg-Hine, D. and Nott, J.(1982) Report on sonic tracking of salmon, Ribble Estuary, 1980-82. North West Water. Priede, I.G. (1985) Investigations of movements of salmon in an estuary using acoustic oxygen sensing transmitters. Interim report to WRC Environment.

Priede, I.G., Solbe, J.F.de L.G., Nott, J.E., O'Grady, K.T., and Cragg-Hine, D. (1988). Behaviour of adult Atlantic salmon, Salmo salar L., in the estuary of the River Ribble in relation to variations in dissolved oxygen and tidal flow. Journal of Fish Biology, 33A, 133-139. Priede,

I.G., Solbe, J.F. de L.G., and Nott, J.E. (1988) An acoustic oxygen telemetry transmitter for the study of exposure of fish to variations in environmental dissolved oxygen. Journal of Experimental Biology, 140, 563-567.

Priede, I.G., Cragg-Hine, D., Solbe J.F.de L.G. and O'Grady K.T. (1990). Tracking salmon in the estuary of the River Ribble. In: Milner, N.J. Fish Movement in Relation to Freshwater Flow and Quality. Proceedings of the Atlantic Salmon Trust/Wessex Water Workshop, Bristol, 1989, AST, Moulin, Pitlochry.

PROJECT COSTS

MANPOWER (salaries x 1.5): total cost £26.8k

CONSULTANCY: N/A

CAPITAL COSTS (ALSTNs, receivers, etc): £0.35k

RUNNING COSTS (fish, tags): Paid for by WRC, costs not known

ESTIMATED FULL ANNUAL COST:

1980 = £ 0.85k
1981 = £ 5.5k
1982 = £ 4.9k
1983 = £ 4.9k
1984 = £ 0
1985 = £ 4.2k
1986 = £ 6.65

NB All costings adjusted to 1991 prices.

Approximate total cost to North West Water = £26.8k

FUTURE PLANS:

Project complete

2a) NRA FISH TRACKING PROJECTS

REGION: South West
STUDY LOCATION: Tamar (Roadford Reservoir Scheme)
COMMISSIONING BODY: NRA Water Resources
(funded by SW Water plc)
PROJECT STAFF: Kelvin Broad (Fisheries scientist)
SPECIES: Salmon
START DATE: 1986
DURATION: continuing

AIMS and OBJECTIVES:

To provide information that will assist in the setting of a prescribed flow, and in the preparation of operating rules relating to regulation releases and abstractions just above head-of-tide.

To investigate patterns of salmon movements from the estuary, into freshwater, past the abstraction point and through the river system under a range of flows. Particular attention to be paid to the importance of freshwater flow into the estuary and regulated flows in the Lyd sub-catchment.

STUDY DESCRIPTION:

Following a Public Inquiry a programme of fisheries investigations was instigated to assess the implications of the proposed Roadford Reservoir Scheme. The radio tracking project formed part of this programme, together with fish trapping, electrofishing surveys and the analysis of rod and net catch data.

Since 1988, every effort has been made to tag and release as many fish as possible in the estuary. It is the movement of salmon from the estuary into freshwater, in response to flow below the abstraction point that is of particular concern in the determination of an acceptable prescribed flow. Over the period 1986 to 1990, a total of 440 salmon have been radio tagged (143 released in the estuary). A small number of fish (17) were displaced from the Gunnislake trap (at the head of tide) and released in the estuary in 1989.

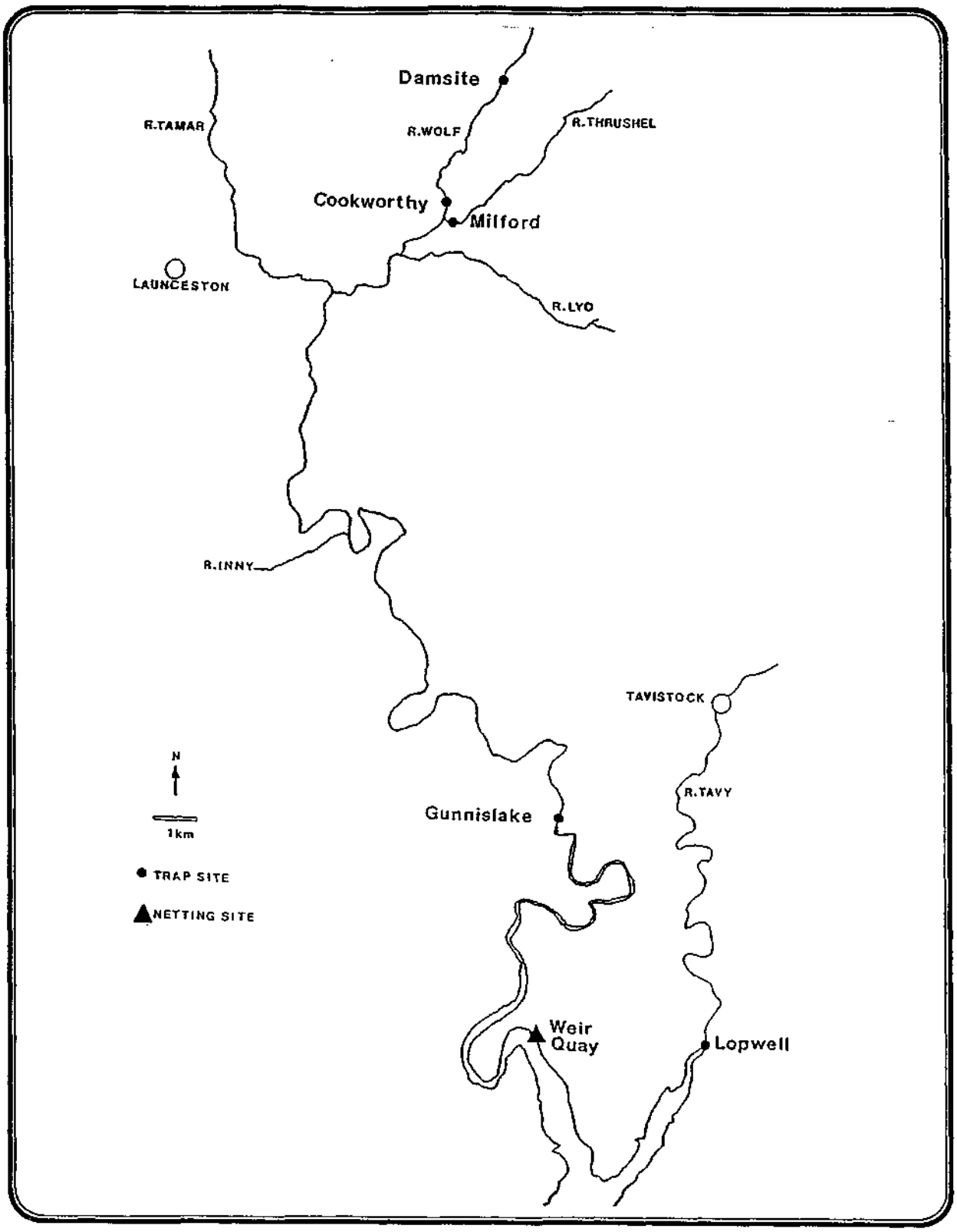
RESULTS

The general pattern of salmon movements have been described as follows:

a) Salmon enter the river in response to an increase in freshwater flow and continue moving upstream for up to 3 weeks before settling in a suitable holding pool (some fish settle in the estuary).

b) Secondary movement does not usually take place until spawning time approaches, when upstream migration is resumed, again usually in response to an increase in flow.

c) Occasionally, secondary movements occur before spawning time, but this would normally occur soon after a fish has initially settled, and in response to elevated flow.



Map 1. Trap sites and netting sites on the Rivers Tamar and Tavy.

d) The absolute magnitude of the flow necessary to induce initial movement into freshwater is less important than the size of the spate relative to the previous baseflow level.

Tracks of entry into freshwater (taken as movement past Gunnislake Weir) have so far been obtained for only 53 fish.

Tracking in the Lyd sub-catchment is providing information on the flows necessary at downstream confluences to attract spawning fish towards the new reservoir.

PROBLEMS/LIMITATIONS:

a) The amount of data which can be obtained is limited by the technology to a maximum of 100 fish tracks per year.

b) Obtaining sufficient fish from the right place (ie the estuary) at the right times (eg summer low flow periods) has proved difficult.

c) It is not clear whether the behaviour pattern of a fish is interrupted/ modified by capture and tagging.

d) It is difficult to determine the precise timing of fish passage and the start of fish movement.

These points make quantitative analysis difficult. Fish counter or trap data may be more appropriate in most situations. Timing of fish passage in relation to flow at certain points in the river system is perhaps better addressed with a fish counter.

To obtain further evidence of fish movements in response to flow rates in the lower river, the movements of fish between successive ALSTNs have been analysed. Computer analysis was used to identify the precise timing of movements and to determine a mean flow over the period. The results of this analysis were in close agreement with those obtained from trapping at Gunnislake (based on a much larger sample).

The radio tracking study has provided valuable information on the general pattern of fish movements throughout the river system but the limitations of the technique must be appreciated. It is not the best approach when a large volume of data is required on the precise flow requirements for fish passage at a given point in a river system (eg for the setting of a prescribed flow at an abstraction point).

REPORTS PRODUCED:

Hambly, T.C. (1987). Roadford Fisheries Investigation Team Telemetry Report for 1987. Internal Report.

Roadford Operational and Environmental Study - Fisheries. Internal Report.

Sambrook, H. and K. Broad (1990). Roadford Water Resources Scheme: Migration of Atlantic salmon in the River Tamar. In: Milner, N.J. Fish movements in relation to water flow and quality. Proceedings of the Atlantic Salmon Trust/Wessex Water Workshop, Bristol 1989. AST, Moulin, Pitlochry.

Varallo, P.V. (1988). Report on MAFF/WAA Fisheries Technical Liaison Committee Workshop on Acoustic and Radio Tracking of Adult Migratory Salmonids. Report No. FTLC 88/8.

1991 PROJECT COSTS

MANPOWER (salary x 1.5):		£20k per annum
CONSULTANCY:		N/A
CAPITAL COSTS (equipment, etc): (discounted over 3 years)		£60k
RUNNING COSTS (fish, tags, etc):		£10k
ESTIMATED TOTAL 1991		£ 30k
PREVIOUS AND FUTURE ESTIMATED COSTS:	1986 =	£ 50k*
	1987 =	£ 50k
	1988 =	£ 50k
	1989 =	£ 30k
	1990 =	£ 30k

* All costs at 1991 prices.

TOTAL COST TO PRESENT = £210k

FUTURE PLANS:

1991 - Tag 100 fish in estuary using own trammel net. Track into freshwater.
- Tag as many fish as possible in Lyd sub-catchment.
- Install fish counter at Gunnislake Weir and validate.

1992 - Operate fish counter.
- Restrict radio tagging to Lyd sub-catchment.

2b) NRA FISH TRACKING PROJECT

REGION: South West
STUDY LOCATION: River Torridge
COMMISSIONING BODY: South West Water
PROJECT STAFF: K. Broad, H. Sambrook
SPECIES: Salmon
START DATE: 1988
DURATION: < 1 year

AIMS and OBJECTIVES:

To investigate the relationship of salmon movement and distribution with respect to flow movement as part of a study of the effect of the Roadford Reservoir transfer scheme.

STUDY DESCRIPTION:

Salmon were captured by a net and cobble fishery with the help of a commercial netsman in the estuary of the Torridge during June 1988. Five salmon were radio tagged and released. Two tagged fish entered the Torridge. One was caught by rod and the second was tracked through to spawning when it entered an upper tributary and was later tracked descending the Torridge. Two tagged fish entered the adjacent River Taw and one fish was not located after tagging. The study was abandoned when the decision was made to abort water transfer from the Roadford Reservoir Scheme.

PROBLEMS/LIMITATIONS:

40% of the tagged fish entered another river system.

REPORTS PRODUCED: none

Work refered to in:

Hambly, T.C. (1988). Roadford Fisheries Investigation Team Telemetry Report for 1987. Internal Report.

PROJECT COSTS NO DETAILS AVAILABLE

TOTAL ESTIMATED COSTS 1988 = £10k

FUTURE PLANS:

Project may be revised in 1991 by NRA Water Resources as part of a baseline study prior to further developments on the Torridge.

3a) NRA FISH TRACKING PROJECT

REGION: Southern
STUDY LOCATION: Rivers Test and Itchen
COMMISSIONING BODY: NRA Water Resources
PROJECT STAFF: Adrian Fewings; 1 x Technician;
Dr. D. Solomon (Project Consultant)
SPECIES: Salmon
START DATE: October 1989
DURATION: Tracking continuing until 1992

AIMS and OBJECTIVES:

1) To relate environmental factors with speed, timing and extent of salmon runs. Environmental factors include flow, level, light, temperature and turbidity.

2) To investigate effectiveness of fish passes, including weirs and sluices, at key sites on both rivers.

3) To estimate the fishing mortality in the fisheries.

4) Determine the locations of principal spawning grounds.

STUDY DESCRIPTION:

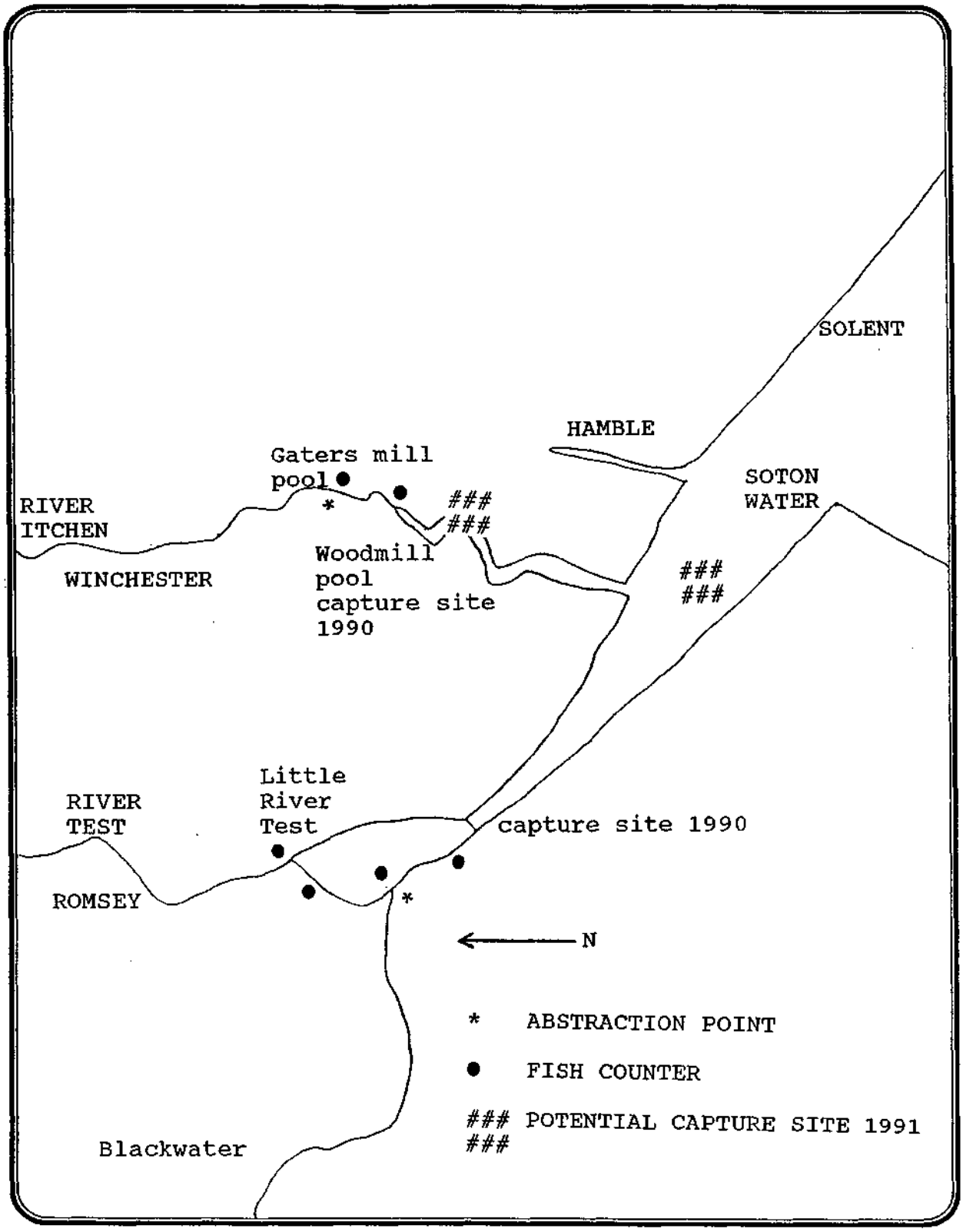
With a need for increasing water abstraction from the rivers Test and Itchen and prior to a public enquiry during 1988, it was decided to investigate the movements of salmon in the Test and Itchen. At that stage Dr Solomon was engaged as a consultant to advise on practical matters and also assist in the preparation of reports. Initial annual support from him of 24 days in 1989 is expected to decrease to 18 days.

The braided nature of parts of the river systems make radio-tracking and counter installation difficult. However, there are currently 4 counters in the rivers (most have CCTV installed) :-

On the Itchen at Woodmill Pool a Hydro Electric Mk 10 counter is installed on top of a Denil fish pass. About 2 km upstream another Denil pass with a fish counter straddles the river at Gaters Mill (electrical screens were used here in the past but mechanical screens are in use at present).

On the Test there are currently 2 Hydro Electric Mk 10 counters, one where the main river diverges into the Little River Test and the second on the main river further downstream. Radio-tracking studies began in 1989/90 and constitute about 30% of the total project effort. Initially fish for radio-tracking in the Itchen were obtained from the commercial net and coble fishery operating in Woodmill Pool. However, this capture location does not allow the investigation of residence time since fish may have been present in the pool for an undetermined time prior to capture. A new capture site closer to the estuary is proposed for 1991 in addition to the above.

Salmon for radio-tracking in the Test have been captured in the estuary at the head of tide with trammel nets. In future it is proposed to augment this with the



Map 2. Fish counter and abstraction points on the Rivers Test and Itchen.

capture of fish even further downstream.

So far 14 salmon have been tagged on the Test and 34 on the Itchen. A total of 9 ALSTNs are employed for both rivers. Individual fish location is carried out routinely. It has been found that there is a degree of fish interchange between the river systems with up to 15% of fish tagged moving up and down both rivers. The exploitation rate of fish by anglers has also been examined by combining data from the fish counters with returns of tagged fish by anglers.

PROBLEMS/LIMITATIONS:

It has been difficult to obtain fish from the right area at appropriate times (the commercial nets only operate from April).

REPORTS PRODUCED:

Initial deadline for summary of data collected during 1990 was March 1991.

1991 PROJECT COSTS:

MANPOWER (salary x 1.5):	£20.25k per annum
CONSULTANCY: 18 days	£ 4.5k per annum
CAPITAL COSTS :(equipment, etc): 9 ALSTNs (discounted over 3 years)	£ 8k per annum
RUNNING COSTS (fish, tags, etc): 80 tags	£ 6k per annum
TOTAL 1991:	£38,750
PREVIOUS AND FUTURE COST ESTIMATES:	1990: £30k 1992: £33k

TOTAL PROJECT COSTS TO PRESENT: £ 30,000

FUTURE PLANS:

It is anticipated that this project will continue on existing objectives and with existing resources until 1992, when it will be reviewed. NRA Fisheries will continue to perform the work with funding from NRA Water Resources.

4a) NRA FISH TRACKING PROJECT

REGION: Thames
STUDY LOCATION: River Loddon, Berkshire
COMMISSIONING BODY: NRA Thames
PROJECT STAFF: Peter Gough
SPECIES: Salmo salar
START DATE: October 1988
DURATION: 3 months

AIMS and OBJECTIVES:

To investigate the effect of capture and transport on adult salmon relocated to a potential spawning stream.

STUDY DESCRIPTION:

As part of a larger study six fish were stomach tagged with radio transmitters and their subsequent movements followed. Four of the fish were caught by electrofishing in the lower Thames and two were caught in the trap at Molesey.

The patterns of movement shown by these fish are interesting, however, the small number of fish tagged obviously restricts the conclusions which can be drawn. The immediate and rapid downstream movement of two of the fish is considered to be an adverse reaction to the stress of handling procedures. This could also be due to the fact that the fish in question were not destined for the River Loddon.

The two fish which apparently adapted best to the situation, fish 5 and 6, both ascended a weir and moved upriver to occupy a suitable holding pool. It was assumed that they then left the area, presumably downstream, however their detection again much later did suggest that they ascended the river further and perhaps even spawned. Certainly some large redds, too large it was felt for the trout present, were observed about 0.5km upstream of the upper station.

The remaining two fish, 3 and 4, showed an intermediate pattern of behaviour. Fish 3 was released at the same time and place as fish 1 and 2. It remained at the point of release for six days than moved downstream. Fish 4, a female grilse, moved rapidly downstream but two months later was detected at the upper station. It remained in range for two hours and was not detected again. The contrast between this and the behaviour of fish 5 and 6 which also remained in the area might be due to the method of capture; fish 1, 2, 3 and 4 were caught by electrofishing, whereas 5 and 6 were captured in the trap.

PROBLEMS/LIMITATIONS:

Conclusions which can be drawn from this study are limited by the very small sample size and differences in the treatment and history of the fish. Although interesting observations were possible, a larger study is required to provide data to base a

translocating programme on.

REPORTS PRODUCED:

Salmon Rehabilitation Scheme, Annual Report 1988.

PROJECT COSTS NO DETAILS AVAILABLE

FUTURE PLANS:

Repeat trial sometime in the future.
Use of MAFF gear to study successful use of new fish passes in the Thames in 1991 or 1992.

5a) NRA FISH TRACKING PROJECT

REGION: Welsh
STUDY LOCATION: River Dee
COMMISSIONING BODY: Welsh NRA (Fisheries/Water Resources /Water Quality).
PROJECT STAFF: David Clarke (Manager); Temporary staff
SPECIES: Salmon and sea trout
START DATE: April 1991
DURATION: 3 years

AIMS and OBJECTIVES:

i) Evaluation of the influence of flow on adult salmonid migration in the River Dee, with particular reference to the effect of alternative abstraction strategies in the lower main river.

ii) Evaluation of the effect of estuarine water quality on salmonid migration success; in particular the effect of Chester sewage treatment works

iii) Examination of migration patterns in the upper/canalised section of the River Dee, with particular reference to migration success past the tidally influenced weir at Chester.

iv) Evaluation of Chester weir trap, in particular:

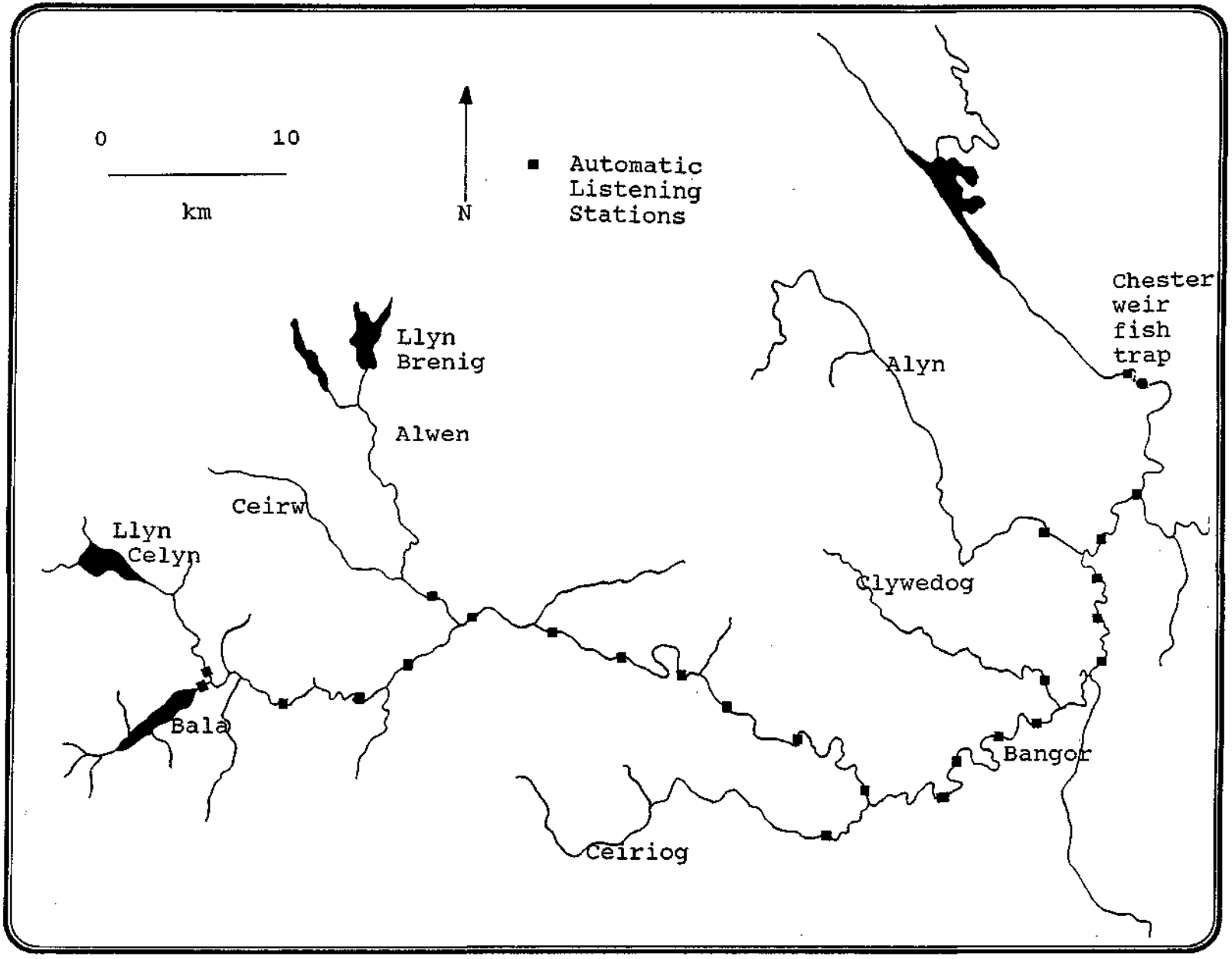
a) Proportion of fish moving through the trap/over the weir (trap efficency).
b) Detailed behavioural study of the trap area.
c) Stock identity of salmon captured within the trap.
d) In conjunction with DEESAP (Dee Stock Assessment) evaluation of exploitation rates in legal and rod fisheries.

v) Evaluation of in-river illegal take.

vi) Pilot study to evaluate the feasibility of assessing the impact of canoeing at Chester Weir on salmon migration.

STUDY DESCRIPTION:

A three year radio tracking programme will be implemented, involving the tagging of up to 150 fish per annum from estuarial nets and Chester Weir Trap. Progress of these fish will be monitored using the 36 ALSTNs and 10 acoustic buoys transferred from the River Tywi Programme. The tracking data will be linked to automatic water quality monitoring data from continuous monitoring in both the estuary and freshwater stretches; continuous flow gauging data will also be available. The project will also be able to take advantage of major water quality resource input during 1989/1990, which is supporting the production of a fully validated dynamic flow and water quality model of both the estuarine and freshwater reaches of the Dee.



Map 3. ALSTN sites on the River Dee.

The project is also closely linked and integrated with the regions Dee stock assessment (DEESAP) index river initiative, which includes trapping, fish counter and net and angler census studies. Both DEESAP and the tracking programme will benefit from this joint approach.

PROBLEMS/LIMITATIONS:

None identified.

REPORTS PRODUCED:

N/A Project recently commenced

1991 PROJECT COSTS

MANPOWER (salaries x 1.5): £35k per annum

CONSULTANCY: N/A

CAPITAL COSTS (equipment, etc): 0
Equipment discounted in Tywi project

RUNNING COSTS (fish, tags, etc): £25k per annum

1991 TOTAL = £60k
(Water Resources £30k; Water Quality £12k; Fisheries £18k.)

FUTURE ESTIMATED COSTS: 1992 = £60k
1993 = £60k

Costings at 1991 prices

TOTAL COST TO PRESENT: £ 0

FUTURE PLANS:

Implement identified programme

5b) NRA FISH TRACKING PROJECT

REGION: Welsh
STUDY LOCATION: Glaslyn estuary and lower river
COMMISSIONING BODY:
PROJECT STAFF: Nigel Milner
SPECIES: sea trout
START DATE: 1981
DURATION: 2 years

AIMS and OBJECTIVES:

To investigate the influence of tidal doors on fish movements between the Glaslyn estuary and river.

STUDY DESCRIPTION:

The Afon Glaslyn estuary is unusual in having an outer shallow estuary, an inner deeper harbour and, upstream, tidal doors. Sea trout were externally tagged with acoustic tags alongside the dorsal fin using steel pins and Peterson discs. Seven fish were tracked in 1981 and 14 in 1982. Movements of tagged fish could be split into three phases. Firstly, some time was spent in the sea or outer estuary where the fish tended to move up and down with tidal currents. Secondly, the fish moved into the deeper saline layers of the inner estuary where they tended to hold their position or swim very slowly (0.3 - 0.5 body lengths per second). Thirdly, the fish moved into the river apparently in response to changes in salinity or temperature caused by the increase in freshwater flow 1.5-3.5 hrs after the opening of the tidal doors. After some vacillation below a road bridge or at the tidal doors, fish did not stop in the lower 4km of the river. Within 1 - 10 days the tagged sea trout moved 4 - 8km upstream. Fish then held up for long periods (3 - 79 days, mean 47 days) in the vicinity of spawning tributaries.

The project was completed in 1982, but the results have recently been reassessed in the context of estuary barrages and the impact of artificial tidal cycles.

PROBLEMS/LIMITATIONS:

No details available

REPORTS PRODUCED:

Milner, N.J. (1981). Hydrographic studies in Porthmadog Harbour, April 1981. Welsh Water, FTU(N) 81/5.

Milner, N.J. (1982). Acoustic Tracking of sea trout in the Lower Glaslyn 1981. Welsh Water, FTU(N) 82/1.

Milner, N.J. (1982). Operation of Porthmadog Tidal Doors in relation to fish passage. Welsh Water, FTU(N) 82/4.

Milner, N.J. (1988). Sea trout movements in Glaslyn estuary and lower river, with special reference to passage through tidal doors 1981 and 1982 in Varallo, P.V. Report No. FTLC 88/8.

Milner, N.J. (in prep.). Sea trout behaviour in an estuary and lower river, with reference to the influence of tidal sluices.

PROJECT COSTS:

NO DETAILS AVAILABLE

FUTURE PLANS:

Competing priorities led to cessation of project when immediate management questions could be answered.

5c) NRA FISH TRACKING PROJECTS

REGION:	Welsh
STUDY LOCATION:	River Taff (Cardiff)
COMMISSIONING BODY:	Cardiff Bay Development Corporation
PROJECT STAFF:	M.J.Mills (Project Manager)
	G.O.Jones (Project Officer)
SPECIES:	Salmon and sea trout
START DATE:	Autumn 1990
DURATION:	Three years preconstruction and up to seven years post construction.

AIMS and OBJECTIVES:

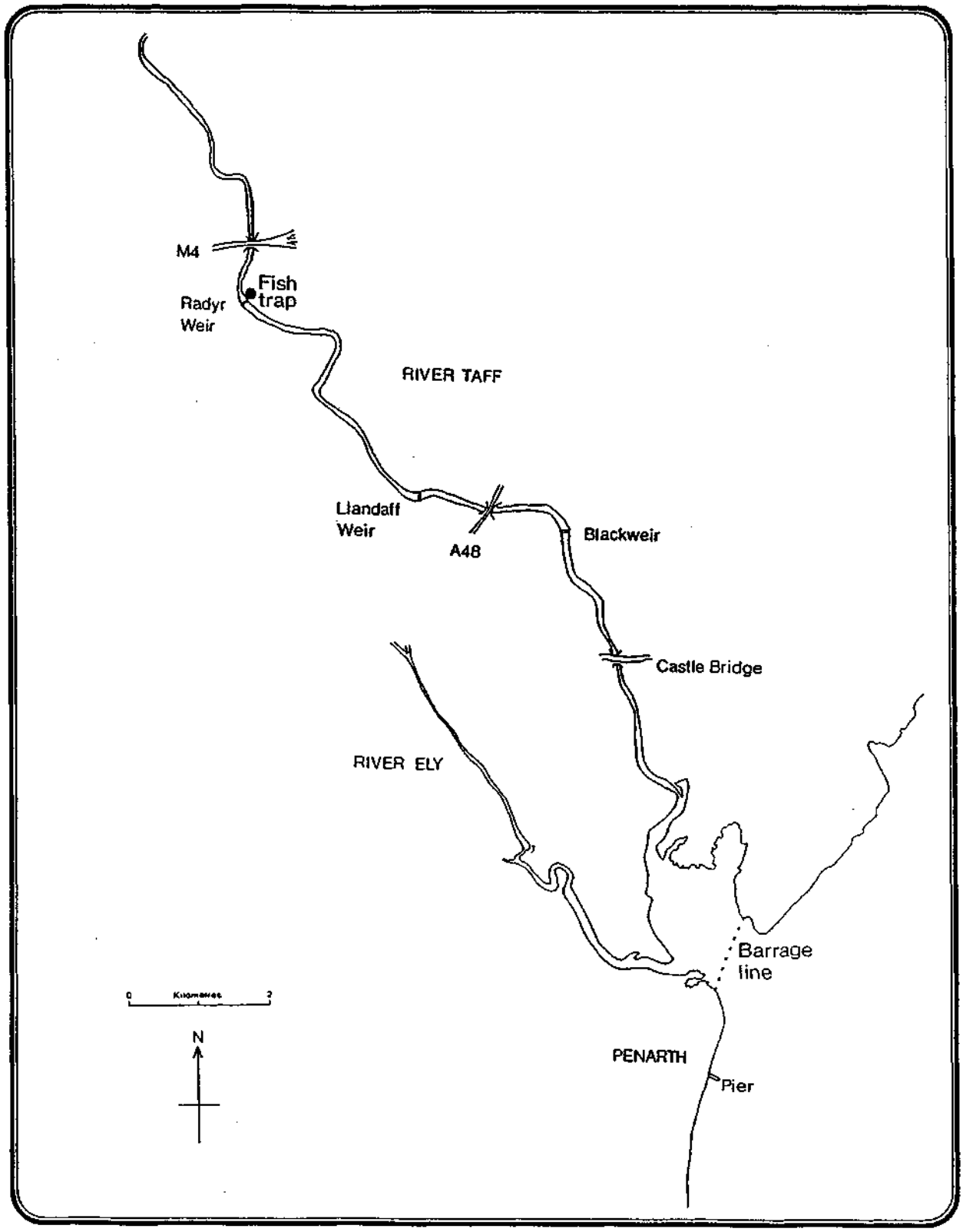
To assess any impact, and the mechanisms causing it, of the Cardiff Bay Barrage on the salmon and sea trout fishery of the River Taff by studying:-

a) Migration of adult salmon into the river
b) Time of entry and survival of returning adults
c) Emigration of smolts and kelts

STUDY DESCRIPTION:

Prior to the proposed construction of a non-tidal barrage across the lower reaches of the River Taff (which is awaiting the consent of the Secretary of State for Wales), a radio-tracking study has started as part of the programme to assess the impact of the barrage on the migratory salmonids of the Taff. The Taff is a recovering salmonid fishery which migratory fish had previously been eliminated from. It is an obstructed river, with many weirs, not all of which yet have fish passes. The current rod catch in the lower reaches is about 80 fish annually and rising. Prior to 1989 a limited amount of restocking by the water authority took place and some natural stock replenishment has been taking place (history described by Harris, 1988). In 1989, and for subsequent years over the duration of this study, about 10,000 microtagged salmon smolts have been stocked into the Taff and the return rates of adult fish are being assessed using anglers catch statistics, electrofishing and trapping at Radyr Weir fish pass.

At present, the part of the study involving radio tracking comprises a baseline study to investigate migratory behaviour of returning adult salmon especially in relation to their passage over existing weirs. Entry of salmon into the river in the absence of a barrage is being investigated by trapping fish in freshwater at the Radyr Weir fish pass, radio tagging and relocating them back to the Severn Estuary at the mouth of the Taff. This approach is necessary because of the small size of the current natural stock and the need to ensure only Taff fish are tagged. A 100% re-entry rate has so far been acheived with seven tagged fish, which were trapped and returned towards the end of the 1990 run. A further supportive relocation study, using sea trout on the River Tywi in SW Wales, has also been carried out to validate this approach.



Map 4. The lower River Taff location of the proposed barrage line and fish trapping site.

PROBLEMS/LIMITATIONS:

Further tracking work may depend on the outcome of the Cardiff Bay Barrage proposal which is awaiting consent of the Bill. Combined acoustic and radio tracking of migrating adults through the estuary in the region of the barrage is currently inhibited by the unsuitability of the area for deployment of acoustic buoys.

REPORTS PRODUCED:

The Barrage proposal is outlined briefly in the proceedings of a workshop "Water Schemes - The Safeguarding of Fisheries" sponsored by the AST and North West Water, 1988.

The project was described at the AST salmon rehabilitation meeting in 1990.

1991/92 PROJECT COSTS: These are total project costs: the radio tracking costs are only a part of the total.

MANPOWER (salaries x 1.5):		£ 32.9 k per annum
CAPITAL COSTS (equipment, etc):	Llandaff trap	£ 80 k
RUNNING COSTS (fish, tags, etc):		£ 49.7 k
	1991/92 TOTAL =	£162.6 k
PREVIOUS AND FUTURE ESTIMATED COSTS:	1989/90 =	£ 45.5 k
	1990/91 =	£148.5 k
	1991-98 =	£ 82.6 k
	1998-99 =	£ 66.6 k
	1999-2000 =	£ 53.1 k

NB. All these costs are fully recharged to the Developers - Cardiff Bay Development Corporation - Nil costs acrue to the NRA.

FUTURE PLANS:

If the Secretary of State gives his assent to the barrage plan and construction goes ahead, then the performance of a barrage fish pass and the passage of fish through the impoundment would be evaluated using CART tagged fish. The behaviour of emigrating kelts and maybe smolts, trapped in the downstream trap at Llandaff, would be assessed through the impoundment and the barrage

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5d) NRA FISH TRACKING PROJECT

REGION:	Welsh
STUDY LOCATION:	River Tawe
COMMISSIONING BODY:	Welsh NRA; some funding may be obtained from the Tawe Barrage Promoter
PROJECT STAFF:	R. Wightman
SPECIES:	Salmon and sea trout
START DATE:	1990
DURATION:	continuing until 1994/95

AIMS and OBJECTIVES:

To conduct an impact assessment of the effects of an existing river barrage on the migration of salmonids.

STUDY DESCRIPTION:

The Tawe Barrage was the first of several barrier proposals in Wales intended for amenity and recreational purposes. At present the barrier is about halfway through construction. It is a partial exclusion barrage overtopped by high tides creating a brackish water environment upstream.

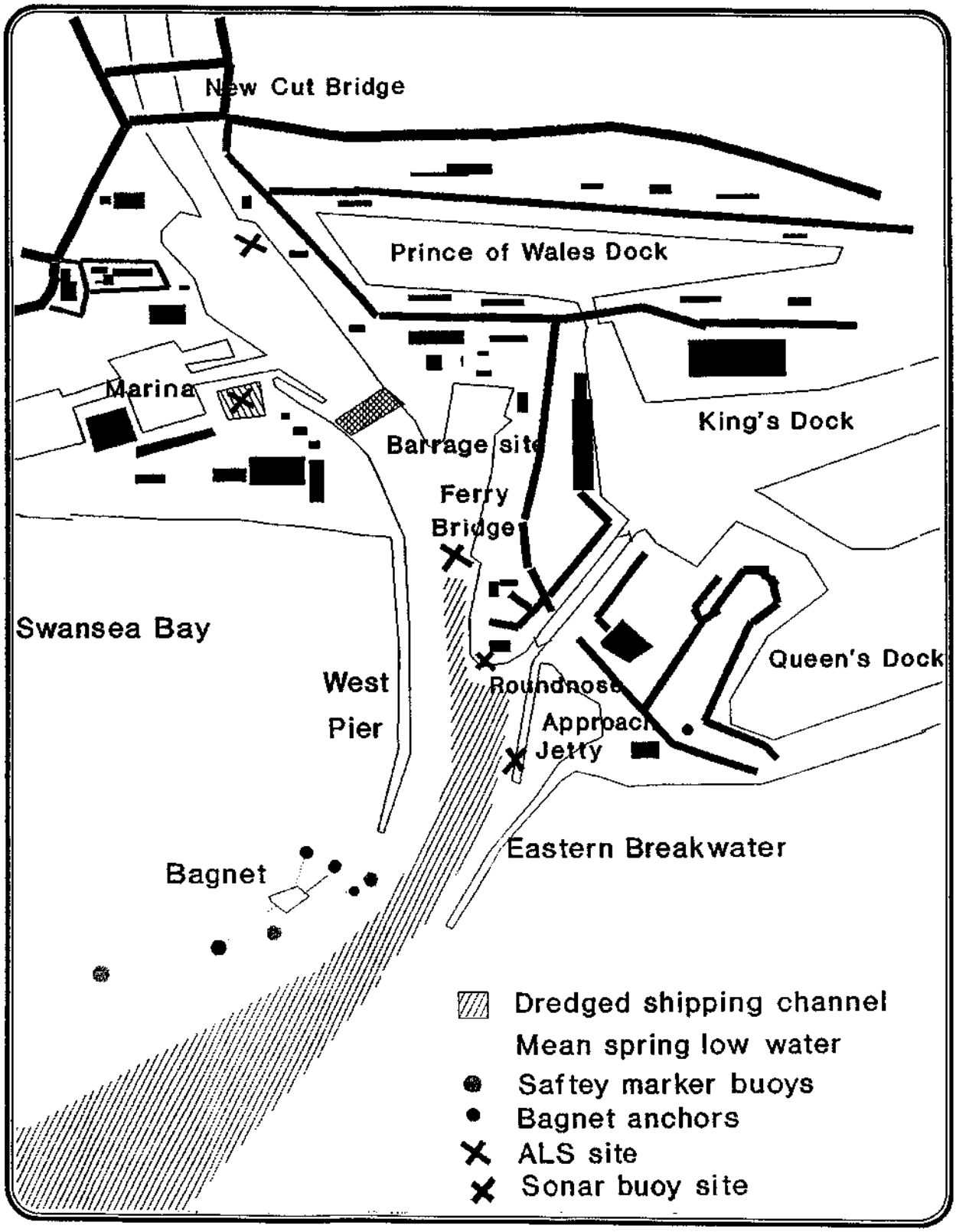
A small scale tracking study has started, restricted due to limited funding. Trial fishing has so far resulted in 6 fish being radio-tagged as a preliminary step.

PROBLEMS/LIMITATIONS:

Funding for the proposed post-construction study is not yet secured, therefore the pilot study was funded by the NRA, although it is intended to try to recover the costs from the scheme promoters.

REPORTS PRODUCED:

Draft report on 1990 part of the pilot scheme has been produced.



Map 5. Swansea Docks and the Tawe Estuary showing the site of the Tawe Barrage.

1991 PROJECT COSTS

MANPOWER (salaries x 1.5):	£10,500 per annum
CONSULTANCY:	N/A
CAPITAL COSTS (equipment, etc): (discounted over 3 years)	0
RUNNING COSTS (fish, tags, etc):	0

1991 TOTAL : £10,500

PREVIOUS AND FUTURE ESTIMATED COSTS:

1990 = £12,500
1992 = £ Not known*

* Dependent upon securing funding and progress with the barrage

TOTAL COSTS TO PRESENT: £ 12,500.

FUTURE PLANS:

Further tracking work may depend on funding by the promoter.

5e) NRA FISH TRACKING PROJECTS

REGION: Welsh
STUDY LOCATION: River Tywi
COMMISSIONING BODY: Welsh Water/NRA
PROJECT STAFF: David Clarke (Manager), D.M. Mee, S.A. Crudgington.
SPECIES: Salmon (sea trout included during project)
START DATE: 1988
DURATION: 3 years

AIMS and OBJECTIVES: (As originally identified)

a) Evaluation of the influence of flow on adult salmon migration in the River Tywi, with particular reference to management strategies for the water bank in Llyn Brianne

b) Evaluation of stock identity of within-river stocks. Evaluation of stock identity of catches within estuarial net fisheries.

c) Evaluation of in-river survival of salmon to spawn.

d) Evaluation of legal and illegal exploitation rates within freshwater.

e) Assessment of the effect of legal seine and coracle fisheries on recreational fisheries

f) Evaluation of the impact of Parc-Y-Splott sewage treatment works/low dissolved oxygen levels on migration success.

STUDY DESCRIPTION:

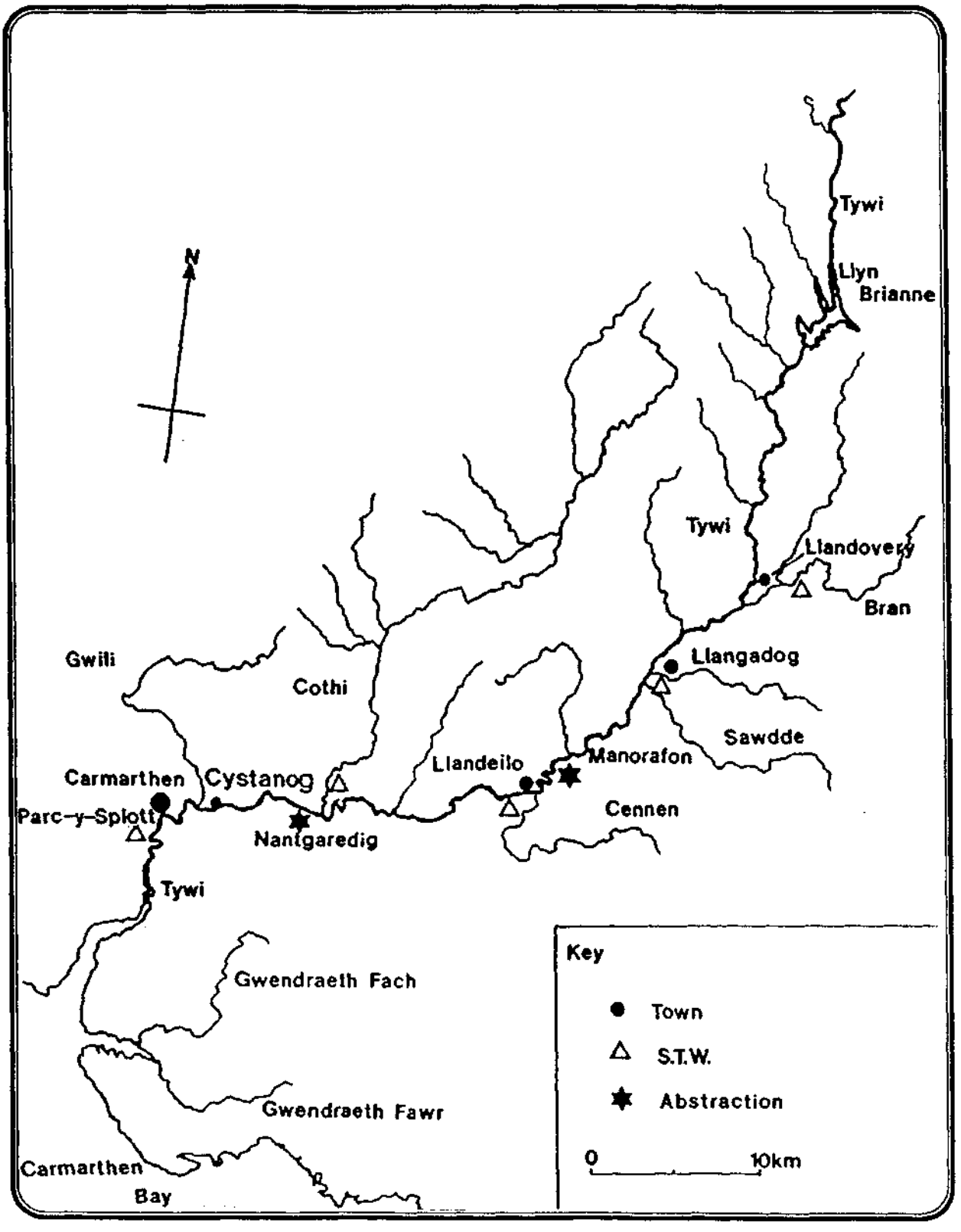
Two hundred and sixty salmon and 156 sea trout, captured in the outer estuary of the River Tywi have been tagged with radio or CART tags during the period 1988-1990. Tracking has been subsequently carried out using up to 36 ALSTNs and 10 acoustic buoys. These data are supported by continuous water quality monitoring in both the estuary and fresh water, and by continuous flow gauging in fresh water.

Additional study elements include:

i) Maintenance of control tags for failure rate assessment, both in the lab and in-river.

ii) Study of effect of relocating fish from fresh water to salt water.

The study has also allowed the collection of a substantial amount of catch per unit effort (CPUE) data/biological sampling. These data comprise information covering direct observations of more than 1556 seine net hauls and 312 jumper net tides by NRA staff, with biological information from some 400 salmon and 1500 sea trout. This is supported by further detailed information from angler census/biological sampling.



Map 6. The Tywi catchment.

RESULTS:

The programme has run well and has addressed a range of questions additional to the aims and objectives identified above. In particular, substantial progress has been made in the study of sea trout behaviour, both in fresh water and estuaries; valuable biological information describing both salmon and sea trout stock has been collected, and valuable information has been collected which has been used in negotiations of barrage proposals.

PROBLEMS/LIMITATIONS:

None identified

REPORTS PRODUCED:

Clarke, D. and Purvis, W. K. (1989). Migration of Atlantic salmon in the River Tywi system, South Wales. In: Milner, N.J.(Ed). Fish movement in relation to Freshwater Flow and Quality. Proceedings of the Atlantic Salmon Trust/ Wessex Water Workshop, Bristol 1989, AST, Moulin, Pitlochry.

Purvis, W.K. & Clarke, D. (1990). Freshwater migration of sea trout in the River Tywi, 1988-1989. NRA Report PL/REAU/90/3, 26pp.

Clarke, D., Purvis, W.K. & Mee, D. (1990). Migration of sea trout in the Tywi estuary during 1989. NRA Report PL/REAU/90/4, 30pp.

Clarke, D., Purvis, W.K. & Mee, D. (in press). 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. Proceedings of Catch / Effort Conference, Hull, 1990.

IN DRAFT:

Biological Characteristics and Exploitation of Atlantic Salmon (Salmo salar L.) in the River Tywi.

Biological Characteristics and Exploitation of Sea Trout (Salmo trutta L.) in the River Tywi.

Estuarial migration of Atlantic Salmon (Salmo salar L.) in the River Tywi.

Estuarial migration of Sea Trout (Salmo trutta L.) in the River Tywi.

REPORTS TO BE PREPARED BY JULY 1991:

Freshwater migration of Atlantic Salmon (Salmo salar L.) in the River Tywi.

Freshwater migration of Sea Trout (Salmo trutta L.) in the River Tywi.

A study of Sea Trout relocated from freshwater to the River Tywi Estuary; comparison with control releases in the estuary.

Telemetric Tag Reliability/Control Study.

Flow requirements for salmonids in the River Tywi, with Particular reference to management strategies for artificial releases and abstraction.

Management of exploitation within the River Tywi catchment - Seine, Coracle and Rod fisheries.

Effect of estuarial water quality on salmonid migration success in the River Tywi.

1991 PROJECT COSTS

MANPOWER (salaries x 1.5):		0
CONSULTANCY:		N/A
CAPITAL COSTS (equipment, etc):		36 ALSTNs, 10 acoustic buoys
(discounted over 3 years)		4 radios purchased in 1987
RUNNING COSTS (fish, tags, etc):		0
PREVIOUS ESTIMATED COSTS:	1988	= £ 52k
	1989	= £ 52k
	1990	= £ 52k

TOTAL COST TO PRESENT: £ 156,000.

FUTURE PLANS:

Complete reports. Identify nationally/regionally relevant information and disseminate. Implement recommendations of reports in management of the Tywi catchment.

5f) NRA FISH TRACKING PROJECTS

REGION: Welsh
STUDY LOCATION: River Usk
COMMISSIONING BODY: Welsh Water plc
PROJECT STAFF: M.J. Mills (Project Manager)
SPECIES: Salmon and sea trout
START DATE: 1987
DURATION: Fieldwork completed December 1991

AIMS and OBJECTIVES:

The original aim of this study was to investigate water quality effects on the migration of salmonids through the Usk estuary, particularly with respect to dissolved oxygen concentration. The study was commissioned by Welsh Water plc in order to determine the quality standard for DO in the estuary necessary to protect migratory fish and thus to develop a sewage treatment strategy to meet this standard.

Following the Usk Barrage Proposal, the aims and objectives have been varied to include analysis of the data to provide relevant supportive information for operational Fisheries staff responding to the Barrage proposals.

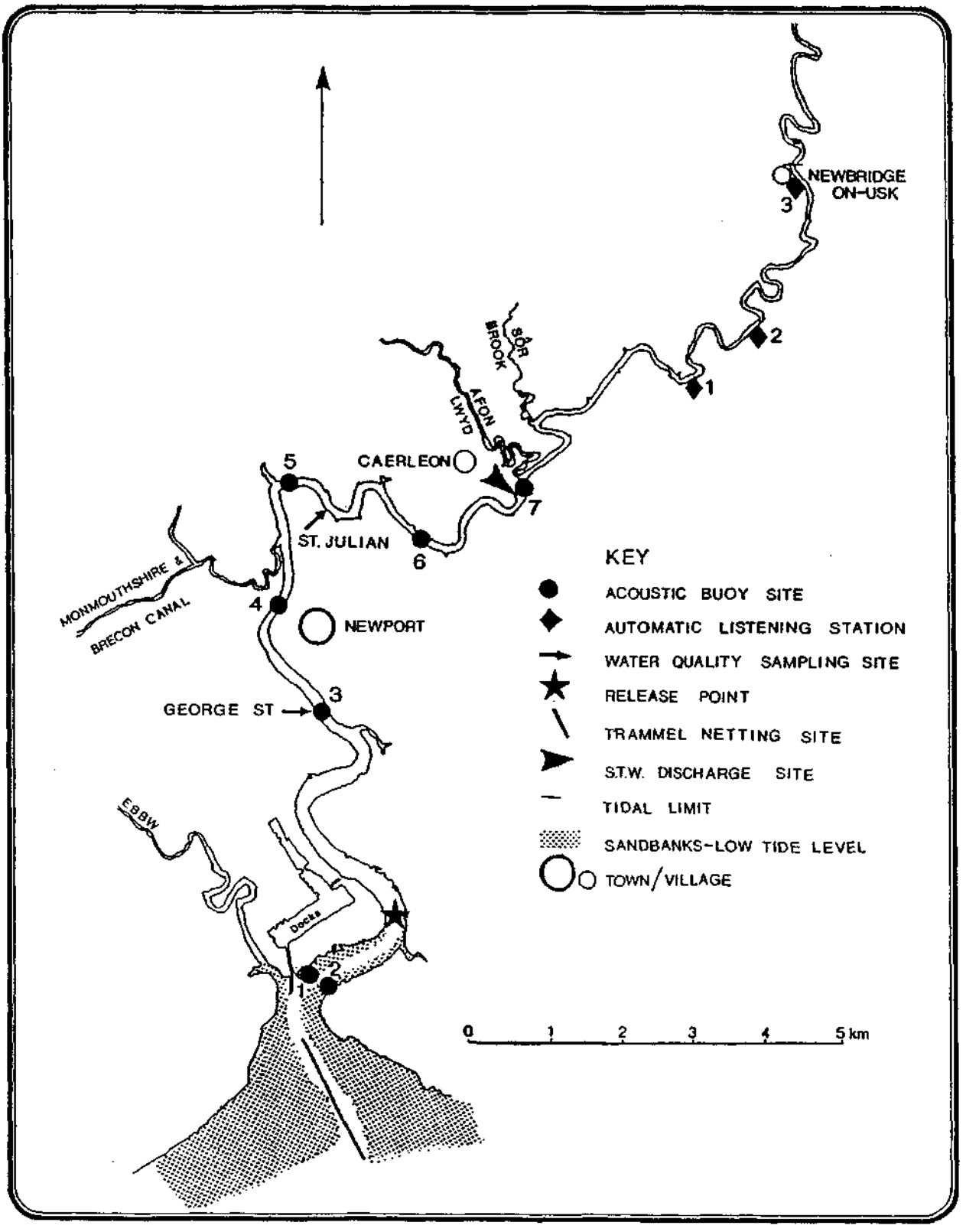
STUDY DESCRIPTION:

Thirty two salmon were radio-tagged during 1987 as a preliminary investigation. In 1988/89 the study was expanded to include tracking in the estuary itself using CART tags and acoustic buoys. One hundred and nineteen fish were tagged and tracked during 1988/90. During the study continuous water quality data has been collected from two fixed sites in the estuary using Aquasensor monitors for DO, temperature, salinity, current speed, depth and suspended solids. The migration patterns of tagged fish have been found to be predominantly tidally driven oscillations until they eventually migrate upstream, or leave the estuary. The effects of water quality and flow have not yet been fully analysed.

In addition to the original study there is now a proposal to construct a barrage across the Usk Estuary. The NRA has petitioned against the Bill proposing this barrage on the basis of its potential interference with fish movements through the estuary plus potential water quality and sedimentation problems in the upstream impoundment.

PROBLEMS/LIMITATIONS:

Further tracking work may depend on the outcome of the Usk Bill.



Map 7. Fish tracking monitoring sites and water quality sampling sites in the Usk Estuary in 1989

REPORTS PRODUCED:

Aprahamian, M.W., Strange, C.D. and Dimond, C. (1988). Movement of Atlantic salmon, Salmo salar L., into the River Usk, South Wales, in relation to water quality. Journal of fish biology, 33A, 245-247.

Aprahamian, M.W., Strange, C.D. and Dimond, C. (1990). Movement of adult Atlantic salmon (Salmo salar) in the Usk estuary. In: Milner, N.J. (Ed) Fish Movement in Relation to Freshwater Flow and Quality. Proceedings of the Atlantic Salmon Trust/Wessex Water Workshop. Bristol, 1989, AST,Moulin, Pitlochry.

1991 PROJECT COSTS

MANPOWER (salaries x 1.5):		0
CONSULTANCY:		N/A
CAPITAL COSTS (equipment, etc): (discounted over 3 years)		0
RUNNING COSTS (fish, tags, etc):		0
PREVIOUS ESTIMATED COSTS:	1987/88 =	£ 44.6k*
	1988/89 =	£ 43.4k*
	1989/90 =	£ 46.6k**
	1990 =	£ 2.5k++

* Capital and revenue costs all charged to Welsh Water Authority.

** Includes £28.6k recharged to Welsh Water plc and £18k manpower costs to NRA Welsh Region.

++ NRA manpower costs on data analysis and reporting.

TOTAL COSTS TO PRESENT: £ 137,100

FUTURE PLANS:

The initial study has now been completed. Future work will depend upon objection to the Usk Barrage.

6a) NRA FISH TRACKING PROJECT

REGION: Wessex
STUDY LOCATION: Hampshire Avon and River Stour
COMMISSIONING BODY: NRA Water Resources
PROJECT STAFF: Allan Frake
David Solomon (consultant)
SPECIES: Salmon
START DATE: 1986
DURATION: 5 years

AIMS and OBJECTIVES:

1) To determine the current pattern of movements, in space and time, of salmon into and through the estuary, into freshwater and up the river and how this is influenced by river flows and other environmental variables.

2) To investigate the effect of any proposed changes in the pattern of abstraction.

3) To suggest guidelines for the management of abstraction which are acceptable to the water supply undertakings and protect the pattern of movements detailed by 1) above.

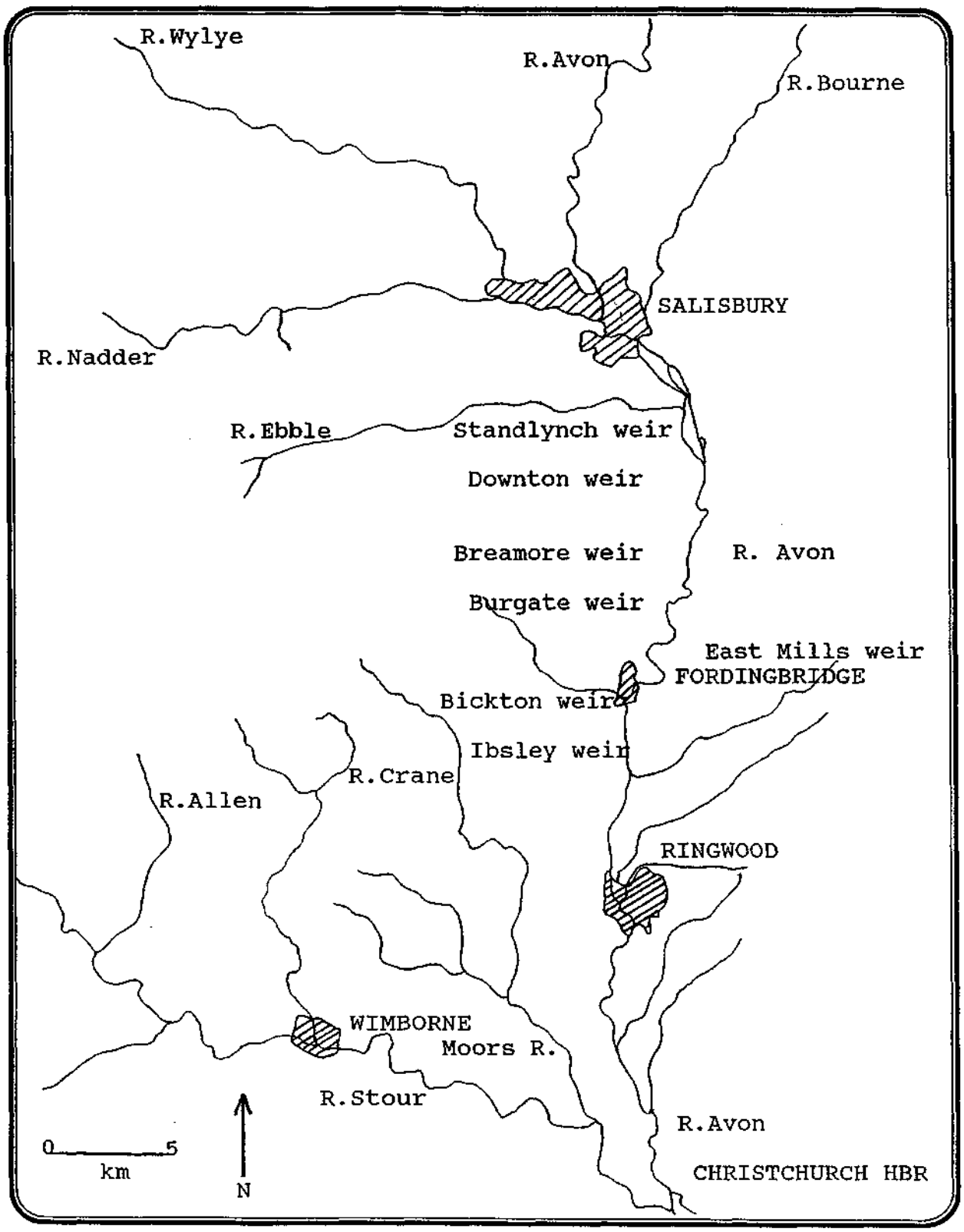
STUDY DESCRIPTION:

A total of 437 fish were tagged in the years 1986 to 1990, of these 34 were fitted with CART tags. Seven sea trout were tagged in 1986 but several problems were encountered and results were disappointing, sea trout tagging was therefore discontinued.

Hampshire Avon

Effect of flow.
It was found that at river flows in excess of 13 m^3s^{-1}, fish generally passed through the estuary within about 12 hours, and entered the river without delay. Most fish continued upstream, on a discontinuous basis for many days and the population became well dispersed throughout the river. When flows fell below 13 m^3s^{-1}, there was a marked tendency for estuary passage to take longer; at 12m^3s^{-1} many fish took up to 2 days to enter the river and at 10m^3s^{-1}, entry took many days. At even lower flows there was an increasing tendency for fish to remain within the estuary or tidal reaches for many weeks or even months, until flows increased again in the autumn. Falling flows also influenced the distance upstream that fish migrated in the initial phase (ie before the autumn). Below 13m^3s^{-1}, fish tended to remain in the lowermost few kilometres of non-tidal river. As flows fell further, fish tended to remain in the uppermost tidal reaches. Temporary increases in flow following heavy rain in the summer were effective at stimulating the movement of some fish which entered the river within the previous 3 weeks.

Obstructions. Four mills or weirs were alleged to cause delays to upstream movement of salmon. Fish passes were installed at two of these structures in 1987/88. Low flows in 1989 were associated with increased delays at Bickton Mill and Breamore



Map 8. The Rivers Avon and Stour

Mill. At Standlynch Mill delays were reduced after the construction of the fish pass.

Population Estimates. Estimates of population were calculated proportionally from the number of radio-tagged salmon entering the Avon, the number reported captured by anglers, and the total angling catch. These annual estimates for the period 1986-89 are 5187, 3256, 4018, 3457. Due to the low number of recaptures, confidence limits are wide.

Exploitation rates. It is possible to derive exploitation rates from population estimates and declared catches:-

commercial nets: 1986-89 15.0%, 10.6%, 12.6% and 10.0%

angling: 1986-89 19.3%, 16.0%, 17.6%14.3%

Confidence limits are so wide that no significance can be read into the variations between years. The relative constancy of the estimates, however, provides a useful overall picture of population levels and exploitation rates.

River Stour Numbers of tagged fish entering the Stour in 1986-89 were 8,8,12,17, respectively, of these a total of 12 retraced their paths and ascended the Avon. An estimate of the size of the Stour salmon run from 1986 data was 724 (95% confidence limits 319-1130). Observations of spawning tagged fish suggested a minimum spawning stock of 272. However, runs in later years were smaller.

Data from 1987 from 5 tagged salmon ascending the Stour suggest that movements were generally associated with elevated discharge. The lowest discharge at which passage past the tidal limit was achieved was $4.2 m^3 s^{-1}$.

In 1988 and 1989 half of the fish recorded reaching Iford Bridge on the Stour subsequently entered the Avon. It was planned to make a particular study of the River Stour with regard to water quality in 1989 but lack of fish ascending the river prevented a detailed investigation.

PROBLEMS/LIMITATIONS: None identified

REPORTS PRODUCED:

Solomon, D. (1987). Hampshire Avon Salmon Radio Tracking Report for 1986. Wessex Water Report.

Solomon, D. (1988). Hampshire Avon Salmon Radio Tracking Report for 1987. Wessex Water Report.

Solomon, D. (1989). Hampshire Avon Salmon Radio Tracking Report for 1988. Wessex Water Report.

Solomon, D. (1990). River Avon Salmon Radio Tracking Report for 1989. Report to the National River Authority (Wessex Region).

Frake, A. and Solomon, D. (1990). Fish movement in relation to freshwater flow and quality. In: Milner, N.J. Fish movement in relation to freshwater flow and quality. Proceedings of the Atlantic Salmon Trust/Wessex Water Workshop, Bristol, 1989. AST, Moulin, Pitlochry.

1990 PROJECT COSTS (indicate full annual cost)

MANPOWER (salaries x 1.5): £ 1,282 per annum

CONSULTANCY: £ 24,380 per annum

CAPITAL COSTS (ALSTNs, receivers, etc): £ 28,556 total
(discounted over 3 years)

RUNNING COSTS (fish, tags, etc): fish - £ 18,965 total
tags - £ 28,978 total

PREVIOUS AND FUTURE ESTIMATED COSTS 1986 = £ 44,770
1987 = £ 44,770
1988 = £ 44,770
1989 = £ 35,251
1990 = £ 35,251

TOTAL PROJECT COSTS TO PRESENT: approximately £204,811

FUTURE PLANS: Project complete.

6b) NRA FISH TRACKING PROJECT

REGION: Wessex
STUDY LOCATION: River Frome
COMMISSIONING BODY: Wessex Water/NRA Water Resources
PROJECT STAFF: Allan Frake; David Solomon (Consultant)
SPECIES: Salmon
START DATE: 1987
DURATION: ongoing

AIMS and OBJECTIVES:

1) To investigate factors affecting salmon entry from Poole Harbour and subsequent passage upriver.

2) To integrate results from radio tracking fish with data obtained by the FBA (IFE) electronic counter at East Stoke.

STUDY DESCRIPTION:

A field feasibility study of tracking salmon on the River Frome undertaken in July and August 1987 yielded some promising results. The full investigation began in 1988. Fifteen salmon were tagged in 1988, 25 in 1989 and 9 in 1990. Tracking data from 1989 indicates that flows down to $1.7m^3s^{-1}$ did not significantly deter fish movement upstream as far as Wareham Bridge. Low freshwater discharge has a major influence on fish movements at and above the tidal limit. Water temperature in excess of 20^0C appeared to deter movement of salmon from the estuary into the river.

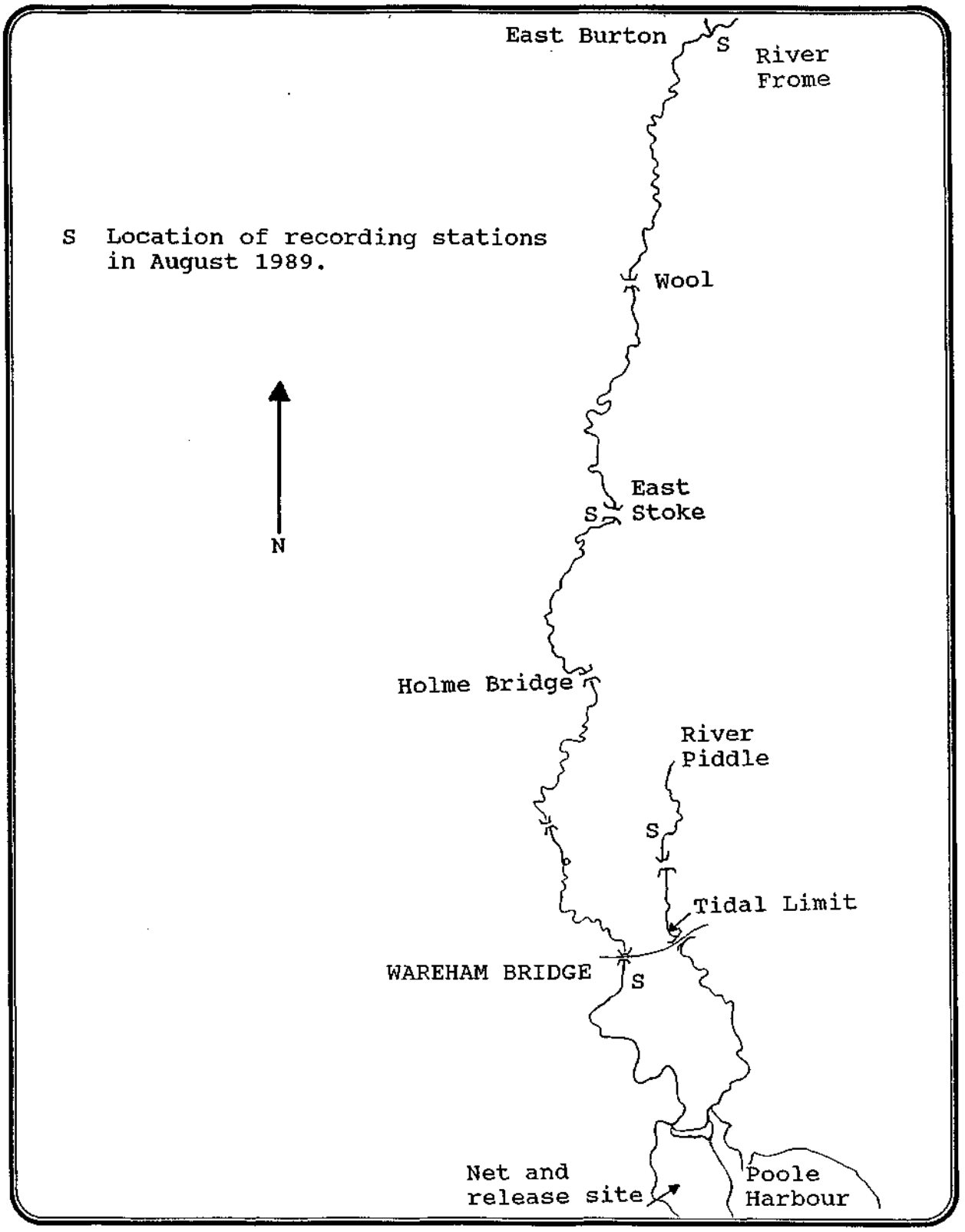
PROBLEMS/LIMITATIONS:

In 1989 over half the tagged fish were lost or disappeared. The most likely sources of loss are considered to be 1) illegal netting in the Frome and Piddle estuaries and 2) high water temperature caused severe handling problems; some fish are known to have died after tagging. Low numbers tagged in 1990, despite input of considerable effort, means that the future of the project is under review.

REPORTS PRODUCED:

D.J. Solomon (1989). Report to Wessex Water River Frome Salmon Radio Tracking, Report for 1988.

D.J. Solomon (1990). Report to Wessex Water River Frome Salmon Radio Tracking, Report for 1989.



Map 9. Location of ALSTNs on the Rivers Frome and Piddle in 1989.

1991 PROJECT COSTS

MANPOWER (salaries x 1.5):	£ 201 per annum
CONSULTANCY:	£3,819 per annum
CAPITAL COSTS (ALSTNs, receivers, etc): (discounted over 3 years)	£8,400 total
RUNNING COSTS (fish, tags, etc):	£5,284 total
PREVIOUS ESTIMATED COSTS:	1987 = £8,142 1988 = £8,142 1989 = £8,142 1990 = £5,341

TOTAL COST TO PRESENT: £ 29,764.

FUTURE PLANS:

As a range of problems has prevented the full-scale implementation of the tracking project it is intended to review the project. Results so far will be integrated with the counter results obtained by IFE and an analysis of estate angling records before further fieldwork is undertaken.