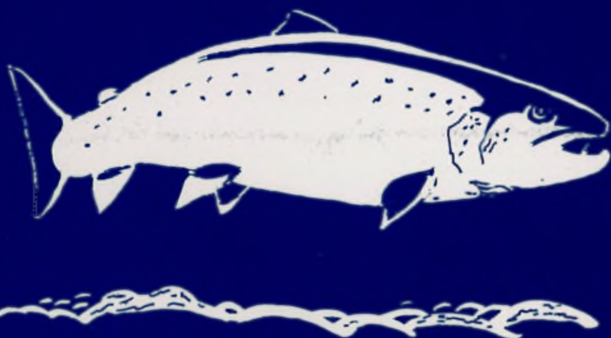
ATLANTIC SALMON TRUST

SURVEYING AND TRACKING SALMON IN THE SEA

E. C. E. POTTER and A. MOORE
Ministry of Agriculture, Fisheries and Food



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SURVEYING AND TRACKING

SALMON IN THE SEA

by

E C E Potter and **A Moore**
Ministry of Agriculture, Fisheries and Food

Based on a workshop organised
by
The Atlantic Salmon Trust and the Atlantic Salmon Federation
in
Edinburgh, December 9-10, 1992.

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FOREWORD

The problem of allocation of the salmon resource is confounded by marine environmental and biological factors such as sea temperature, salinity, productivity, food availability and predation. Such factors might have a much greater effect on the size of returning salmon stocks than closure of the open seas fisheries. However, due to the difficulties of studying anadromous fish in a marine environment, there had been no work in this field until the open seas fisheries provided the platform for data collection. Even so, there had been little co-operation between hydrographers, planktologists, marine biologists and salmon scientists. The realisation of this omission triggered the need for all specialists to pool their information. An opportunity for this was achieved at the Fourth International Salmon Symposium held in June, 1992, at St. Andrews in Canada. At that meeting it was agreed that a multi-national workshop, organised jointly by the Atlantic Salmon Trust and the Atlantic Salmon Federation, should be held to discuss ways to increase further our knowledge of salmon in the sea. Such a workshop was held in Edinburgh on 9th/10th December, 1992, and these proceedings record the deliberations of the 24 participants from Canada, Norway, Sweden and the UK at that meeting.

As will be evident from reading this report, it was concluded that there could be considerable value in research projects at various stages of the marine life cycle, including observation of the departure of smolts from the estuaries and of post-smolts and adult salmon while feeding in the sea and on their return migration. The Workshop has identified a number of relevant techniques, including the use of research vessel cruises to undertake research fishing, tagging, and the operation of sector scanning sonar to detect and track fish fitted with transponder/sensor tags. The significance of interpreting and exploiting knowledge of environmental conditions in real-time, on a spatial scale not obtainable from shipboard observation, was seen to argue the requirement for information from earth observation satellites. The need for international co-operation in this field was strongly stressed by all participants.

It is hoped that this publication will result in multi-national and multi-disciplinary support for the various proposals and recommendations formulated at this Workshop.

Derek Mills
Chairman, Honorary Scientific Advisory Panel,
Atlantic Salmon Trust.

No human being knows for certain how far the salmon go out into the sea when they descend from the river. Mr Miller tells me he has evidence that they go a long way out into the Bay of Galway.

Francis T Buckland, 1905

1. SETTING THE SCENE

Concern has been growing in recent years over the declining levels of salmon catches in many parts of the North Atlantic. Various groups have examined this problem, and it is widely believed that the factors responsible for the decline have been operating during the marine phase of the life history (e.g. Anon, 1992a; Anon, 1992b). However, very little is known about this phase of the life cycle and thus the factors that may be responsible for the decline.

Salmon in the sea was one of the central themes of the Fourth Atlantic Salmon Symposium, held in St Andrews, New Brunswick, in June 1992. At that meeting it was agreed that a multi-national workshop, organised jointly by the Atlantic Salmon Trust and the Atlantic Salmon Federation, should be held to discuss ways to increase knowledge of the marine phase of the Atlantic salmon life cycle. The participants in the subsequent Workshop held in Edinburgh on 9-10 December, 1992 are listed in Section 9. The terms of reference defined for the Workshop were:

- **to review and evaluate techniques for counting salmon at sea and tracking their movements;**

- **to review proposals for research that will provide information on the movements, behaviour, distribution and abundance of salmon in the sea; and**

- **to consider the scope for international co-operation in the organisation and running of these research programmes.**

The Workshop also recognised the need to consider the problems of collecting physical data, particularly on environmental conditions, in relation to the distribution, movements and behaviour of salmon in the sea. This was therefore accepted as a fourth term of reference.

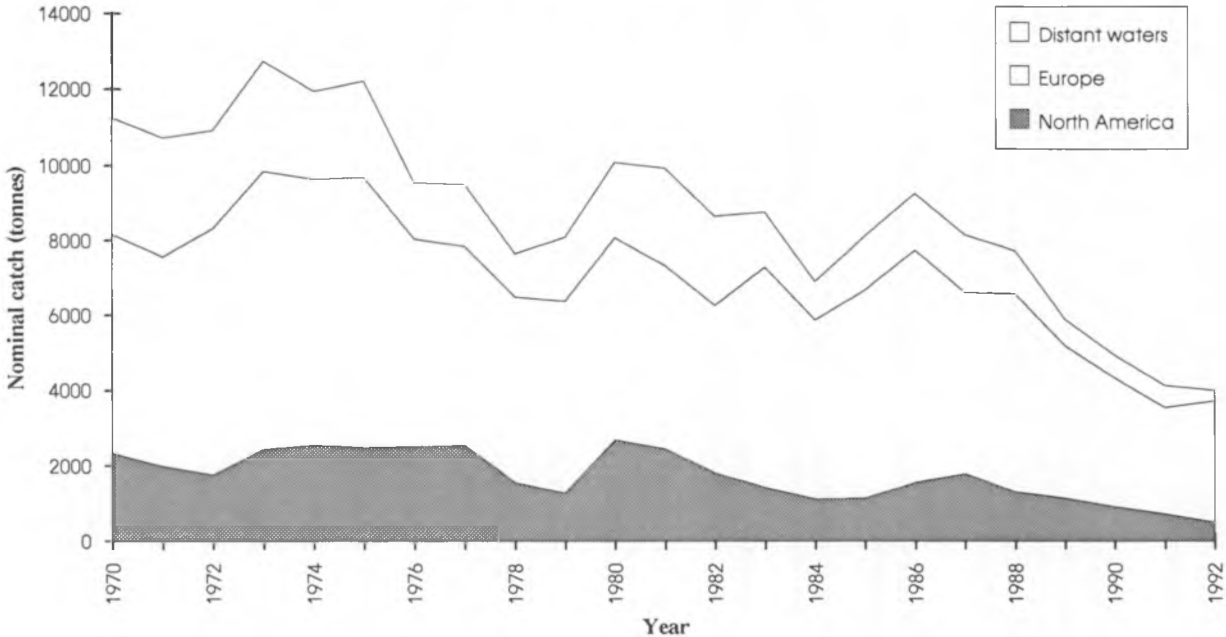
The Workshop specifically restricted its discussions to salmon in the marine environment, thus covering the period from smolt emigration from the estuary mouth to adult return to the same point. It also considered emigrating kelts both as an important part of the population in their own right and because the behaviour of kelts may provide an insight into the behaviour and distribution of all adult salmon in the marine environment. The terms used in this report to describe different stages in the life cycle are as defined by Allan and Ritter (1977).

The report begins by outlining the reasons that we need to know more about salmon in the sea. It then goes on to consider the ways we may approach these problems and the research opportunities provided by the wide range of techniques that are available or are likely to be developed in the foreseeable future. Many of these techniques require the development of sophisticated equipment such as electronic tags or the use of research vessels which are costly to operate. The Workshop therefore considered the scope for collaborative studies to make the best use of available technical expertise and resources.

This report is based upon the wide ranging and detailed discussions that took place during the workshop along with additional reviews of relevant literature. References are made to contributions made in the form of unpublished reports (R) and during discussion (D), in addition to published papers.

Note: *Reference to particular products in this report does not constitute any form of endorsement of these products nor any criticism of other similar products not mentioned.*

Figure 1. Nominal catches of salmon in North America, Europe and distant water fisheries, 1970-92.



2 BIOLOGICAL BACKGROUND

The Workshop recognised the importance of having a clear understanding of the problems that needed to be addressed before considering the various techniques that might be used to study them. They considered three principal areas of concern:

- the reduced marine survival of some salmon stocks in recent years;
- the longer-term changes in the age composition and run timing of stocks in some regions; and
- the need to base management of stocks on a much clearer understanding of the factors affecting abundance.

Returns of salmon from the 1989 and 1990 smolt year classes to many rivers in the North Atlantic have been poor (Figure 1). Since all sea-age groups have been affected it appears most likely that there has been an increase in natural mortality during the first few months in the sea. Natural mortality during the post-smolt phase is thought to be relatively high and variable compared with that after the fish have been in the sea for about a year (Anon, 1988a) and may be particularly sensitive, directly or indirectly, to variations in environmental conditions. Work in the Baltic has, for example, shown a relationship between the survival of hatchery-reared smolts and sea surface temperatures in coastal waters at the time of emigration (Kuikka, 1991).

Longer-term changes in salmon stocks are also evident in parts of the North Atlantic. Many regions have experienced steady decreases in the multi-sea-winter components of their stocks over the past twenty years and consequent declines in spring runs. In some areas, these changes appear to be part of long-term cycles in the composition of stocks over periods of 50 to 100 years. A number of hypotheses have been proposed to account for these, and the role of environmental conditions, genetic factors, and exploitation have been considered. No clear answer has yet been found, and it is likely that more than one factor is involved. However, several studies have shown that there have been various physical changes taking place in the marine environment over similar time scales to the long-term trends in salmon catches (e.g. Martin and Mitchell, 1984; Friedland and Reddin, 1993). This suggests that there may be links between these environmental factors and processes controlling survival or maturation of the fish.

The Workshop also recognised that in order to manage marine salmon fisheries effectively, we need to know more about the behaviour of salmon in the sea. Information is required on:

- the proportion of a stock that may be within a fishery area;
- the movements of stocks between fishery areas;
- changes in the vulnerability of stocks to fishing gear; and
- the effects of marine environmental conditions on behaviour and distribution.

Many salmon stocks are under great pressure from environmental and human factors. More information is required on the biology of salmon in the sea if fisheries are to managed in such a way that spawning stock targets can be achieved.

3 METHODS FOR ASSESSING SALMON NUMBERS

3.1 The general approach

The Workshop was asked to review and evaluate methods for counting salmon at sea. In practice, the available approaches fall into two categories:

- those that provide estimates of the total numbers of fish, or the numbers from an individual stock, in the sea at a particular time; and
- those that estimate the numbers of fish in a localised area, perhaps available to a particular fishery.

The geographic range of the Atlantic salmon is extensive, and although little is known about their overall distribution in the sea, salmon from individual stocks are known to migrate over a wide area. There have been proposals for complete surveys of the distribution and abundance of salmon throughout the North Atlantic, but this would be a major task and could certainly not be undertaken as a routine assessment procedure with current technology. Estimates of total stock abundance are therefore likely to be based upon assessment methods, such as those currently used by the ICES Working Group on North Atlantic Salmon (e.g. Anon, 1993; Potter and Dunkley, 1993). On the other hand, stocks in localised areas (e.g. in known feeding areas) may be sampled by a variety of survey methods. Sampling may be carried out by directed fishing or using remote sensing techniques such as acoustic surveys. These methods may provide a snapshot of the composition and abundance of the population in a particular location and at a particular time, and also provide information on biological characteristics (e.g. age, sex, growth) of the fish.

All these studies suffer from the same fundamental difficulty that most populations of salmon in the sea are made up of fish from a number of different river stocks. Clearly, whether the purpose of a study is to provide assessment data for fishery management or to study the behaviour of individual fish, it may be necessary, or at least useful, to know the origin of the fish. In order to identify the fish from a particular stock, it is necessary to find natural or artificial means of discriminating them. Assessment of individual stocks are thus often based upon the use of artificial marking methods, but the Workshop recognised the advantages of using naturally occurring markers whenever possible. The Workshop therefore reviewed methods of discriminating stocks on the basis of naturally occurring differences before considering artificial marking methods.

3.2 Stock discrimination

In order to discriminate stocks without using artificially applied marks it is necessary to find some external or internal feature which can be used for recognition purposes. Such identifiers may reflect genetic differences between the stocks. Alternatively, differences in the environment to which they have been exposed may result in different patterns of growth or the presence, for example, of different elements or parasites.

There is good evidence that salmon from different rivers form distinct breeding populations and that there are varying levels of **genetic differentiation** between these stocks. However, so far, it has not been possible to find a genetic marker that would allow the river of origin of an individual salmon to be determined. Even discrimination between North American and

European salmon has been difficult to determine unambiguously (Payne and Cross, 1977; Verspoor and Reddin, 1989), although recent studies of Ribosomal RNA suggests that this may be possible (Cutler *et al.*, 1991). At present these methods are still fairly labour intensive and expensive. Even for the discrimination of stocks from Europe and North America, the problems of obtaining appropriate tissue samples and the costs of analysis have meant that genetic techniques have not been considered appropriate as a routine management tools. However, the Workshop recognised that molecular genetic technology was developing rapidly, and that methods such as DNA fingerprinting and DNA probes might provide practical management tools in the future.

One method that is routinely used for stock discrimination is the analysis of **scale characteristics** (Lear and Misra, 1978). This method is currently employed by the ICES Working Group on North Atlantic Salmon to assess the relative contributions of North American and European salmon to the West Greenland fishery (Anon, 1993). The standard approach employs a discriminant analysis of circuli counts (Reddin, 1986), but alternative analytical approaches from the field of artificial intelligence, such as neural networks (Potter *et al.*, 1991) and genetic algorithms (Potter *et al.*, 1993), have been examined in an attempt to improve the discrimination. As with the discriminant analysis, these methods use information from fish of known origin to establish rules which can be used to discriminate samples of unknown origin.

A detailed description of **neural networks** is provided by Beale and Jackson (1990). Neural networks are computer models that are designed to operate in a similar way to the brain by modelling mathematically the functions of biological neurons and synapses. Biological neurons accept and combine many inputs; if sufficient inputs are received at the same time, then the neuron will 'fire' and produce an output, otherwise the neuron will remain inactive. The learning process involves changing the efficiency of the contact (the synapses) between each input and the neuron. This is mimicked mathematically in the neural network. Data on different scale characteristics form the inputs which are combined in the network neurons. A set of example inputs are repeatedly presented to the network, and the network learns by adjusting multiplicative weighting factors on the inputs each time that it fails to correctly discriminate an example. This continues until the network is adequately trained. Neural networks can achieve more complex pattern separation than discriminant functions and have proved slightly more successful at identifying North American and European salmon (Potter *et al.*, 1991).

Genetic algorithms function by formulating logical rules and then assessing their predictive capabilities by testing them against the training data. The initial rules may be poor predictors, but new rules are generated from them by simulating natural selection, randomly varying and/or recombining earlier rules. If a new rule proves to be a better predictor, the old rule will be discarded in its favour. At any time, the current 'fittest' rule (the one with the best predictive properties) is left unchanged, although eventually it may be replaced by a fitter one. Hopefully, at the end of the training process (which is performed over a number of generations to allow for out-breeding and mutation) a set of rules will be produced that will be useful in prediction. Although genetic algorithms may not be as good at discriminating North American and European salmon as neural networks, the rules generated may be easier to understand and provide ideas about relationships within the data set, much like a brain-storming session (Potter *et al.*, 1993). This may help in understanding the data set that is being investigated and thus also aid in the interpretation of stock differentiation.

These methods may be particularly suited to the analysis of scale measurements derived by **image analysis** techniques. These allow large numbers of features to be measured from scales in a repeatable and semi-automated way. Modern image analysis packages also provide means for analysing more complex features of the scales such as the overall shape (e.g. Pontual and Prouzet, 1987). A two-dimensional shape can be described to whatever degree of precision is required by using Fourier analysis of its outline. The empirical shape is then partitioned in a series of components called harmonics, the coefficients of which can be used as shape descriptors. This method appears to provide better stock discrimination than circuli counts. Studies of **otoliths** suggest that similar regional differences may occur (Reddin, D), but these are less convenient to collect and it is more difficult to make measurements of features other than the overall shape.

The presence or levels of infestation by particular **parasites** have also been considered as methods of discriminating stocks. Ideally the parasite should be ubiquitous in one stock, or group of stocks, and absent in another. The proportion of infestation when the stocks are mixed can then be used to estimate the relative proportions of each group. In practice, it is more likely that a parasite will be common in one area and rare in another. Thus Moles *et al.* (1990), used the incidence of the brain parasite, *Myxobulus neurobius*, which was high in stocks from Alaska but low in stocks from British Columbia, to estimate the proportion of Canadian fish in catches in south-eastern Alaska. Similar methods have been examined for Atlantic salmon. For example, Pippy (1971) found that the parasitic nematode *Anisakis simplex* was more abundant in European than North American salmon, while the tapeworm *Eubothrium crassum* was more prevalent in salmon of North American origin. However, heterogeneity in the incidence of these parasite precluded their use as biological tags to discriminate stocks at West Greenland (Pippy, 1980).

Studies have also been carried out on the use of **chemical isotopes** to discriminate groups of fish (Yamada and Mulligan, 1990). Modern methods permit the identification of elements within very small samples of material. Thus, for example, the elemental composition of different parts of scales can be analysed and compared. Studies are being conducted to investigate whether this may provide a means of identifying fish that have originated in rivers with different chemical compositions (Moore, D).

3.3 Tagging and marking

In the absence of naturally occurring differences it is necessary to apply artificial marks to the fish. Such marks may take the form of numbered labels (tags), other additions to the fish (e.g. dye marks or chemicals) or changes to the integument of the body (e.g. fin clips or brands). The Workshop did not review the full range of available marking techniques, but considered some of the more novel methods available (Figure 2). Electronic tags and transmitters used for tracking and telemetry studies are discussed in Section 4.

Tags have long been used to investigate patterns of movement, exploitation and survival of salmon, particularly through the marking of emigrating smolts. However, many of these studies effectively treat the sea as a 'black box' because little information is obtained on the fish between their emigration as smolts and return as adults. Tag recoveries between these points come mainly from directed salmon fisheries which may provide information on exploitation but give only a fragmentary picture of the movements of fish.

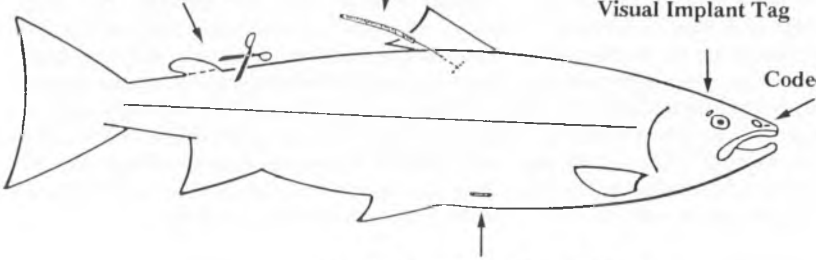


Figure 2. Modern tagging methods used on Atlantic salmon

The traditional method of tagging fish has been to attach small **external labels** (tags) by means of wire or thread. On salmon, these are normally attached below the dorsal fin. Comparative tagging studies carried out in the 1960s suggested that the Carlin-type smolt tag gave the best return rates (e.g. Swain, 1974) and thus presumably had the least effects on the fish. These tags are still used for smolt studies in most North Atlantic salmon producing countries (Anon, 1992c). On adult salmon, spaghetti-type anchor tags are easier to apply and give better survival rates than Carlin tags, but tag losses tend to be greater (Reddin, D). The tags are designed to be easily seen, and recoveries are derived mainly from voluntary returns by fishermen and merchants. As a result, In however, return data are prone to biases arising from people forgetting to send tags in or the perception of individuals that it may not be in their interest to return tags.

In many studies, external tags have been superseded by **coded wire tags** (CWTs) (also known as microtags)(Jefferts *et al.*, 1963), which are very small pieces of stainless steel wire (1.00 mm by 0.25 mm diameter) bearing a binary code of etched marks. These tags have been used very extensively on Pacific salmon and have also been adopted by many groups working on Atlantic salmon (Anon, 1992c). The tags are normally injected into inert tissue in the snout of young salmon, and because they cannot be seen externally, the adipose fin is removed to aid recognition of marked fish in recovery programmes. Unfortunately this fin clip is widely used for other studies, and so not all adipose clipped fish can be assumed to contain a CWT. The main advantages of CWTs are that large numbers of fish can be marked quickly and with minimal adverse effects. Fish are usually marked in large batches (e.g. 10,000) with the same tag code, but individually numbered CWTs are also available. The tags are normally recovered through scientifically-based sampling programmes, which have the advantage of eliminating some of the errors inherent in voluntary return systems. However, this also mean that it is difficult to obtain returns from small, dispersed fisheries. A further problem with CWTs is that they can generally only be recovered from dead fish. The Workshop emphasised the importance of investing sufficient effort and resources in tag recovery programmes.

Visual implant (VI) tags were developed in response to the need for an implanted tag that could be excised from a living fish or read externally (Haw *et al.*, 1990). The tags are small, numbered labels made of biologically compatible material, which are implanted into living transparent tissue, usually on the edge of the eye. Members of the workshop indicated that the tags were easy to use and worked well on young salmon for about six months . However, there were reports that after longer periods the tissue over the tag tended to become opaque making it difficult or impossible to read the number without removing the tag (Holm, D; Anderson, D; Heggberget, D). Similar problems have been reported by Kincaid and Calkins (1992), who found that although 100% of VI tags were readable in yearling Atlantic salmon after 10 months, none were readable in lake trout. They also reported that the retention rates for these tags after 10 months varied from 49% for yearling salmon to 84% for 2 year old fish.

A more sophisticated tagging system that may allow marked fish to be identified without being handled is the **passive integrated transponder** (PIT) tag. These tags comprise a microcircuit that transmits a coded, low-frequency (40-50 kHz) signal when externally energised by a electromagnetic signal (125 or 400 kHz) emitted by a scanning device. Prentice *et al.* (1990a) evaluated the use of the PIT tag developed by Destron-Identification Devices, Inc., Boulder, Colorado on juvenile and adult salmonids. These transponders are encapsulated in glass tubes 10 mm long and 2 mm in diameter and have about 34 billion unique pre-programmed codes. The tags may be implanted into the inter-peritoneal cavity or injected subcutaneously using a veterinary-style hypodermic implanter. They can be read with a hand-held scanner linked to a decoder unit, which may in turn be interfaced with a computer. The scanner must be held within about 3-15 cm of the tag to read the code. Alternatively the tags may be read automatically as they pass through a fixed scanning unit built around a tube up to about 30 cm in diameter (Prentice *et al.*, 1990b);

It was reported that PIT tags could be used on fish down to 6 cm in length and were therefore suitable for Atlantic salmon parr or smolts (Anderson D; Prentice *et al..*, 1990a). However, it was noted that these tags cost £3-£4 each (price at going to press), and that although the price might come down if large numbers were required, they were always likely to be considerably more expensive than CWTs. It was recognised that PIT tags had a valuable role to play in a variety of investigations, such as rearing experiments and behavioural studies, where there was a need to identify fish without handling or damaging them. However, the Workshop felt that for studies of salmon in the sea they offered only minor advantages over more conventional methods and these might not merit the considerably greater costs.

3.4 Fishing surveys

The distribution of many animal species is commonly assessed by sampling. The simplest approach is to attempt to capture the fish at various locations and, on the basis of the catch rates and the analysis of the samples, to evaluate the relative abundance of the fish in different areas. Such approaches are complicated in the case of salmon by the fact that the fish may occur at relatively low densities (numbers per km^2) in the sea and may be widely distributed. Care has also to be taken with the interpretation of data obtained from fishing surveys if the behaviour of the fish or the efficiency of the gear is affected by weather conditions.

Fishing vessels experienced at catching the target species are often the most efficient for carrying out surveys but may not have the necessary facilities for undertaking other studies such as keeping fish alive for tagging. On the other hand, unless specifically designed for the work, existing research vessels may not be well suited for the operation of the required fishing gear (Reddin, D). Gill nets and long lines, which are methods usually used for catching adult Atlantic salmon at sea, may be particularly difficult to operate from vessels that are primarily designed for trawling. Research vessels are also very expensive to operate; Mills (1988) gave a cost of £6,700 per day in 1988, and current costs for an ocean-going vessel are around £8,000 per day (Reddin, D).

Reddin (D) reported on gill netting surveys that were carried out from the Canadian research vessel RV Wilfred Templeman in the Labrador Sea (Reddin and Short, 1991). Gill nets with stretched mesh sizes of 3-4 inches and 5-6 inches were used to catch over-wintering post-smolts and adults respectively. Information was obtained on the distribution and relative abundance of salmon of different ages and on the diet of the fish in this area. Post smolts and one- and two-sea-winter were found together and appeared to be feeding opportunistically (capelin did not form a large part of the diet) (Reddin, D). The methods did not provide large numbers of fish in very good condition for tagging, although it was thought that sufficient fish could be obtained for tracking studies.

Gill netting has not proved successful as a means of catching emigrating smolts in trials carried out on the Scottish coast (Dunkley, D), although it is not clear whether this is because the fish avoid the nets or the nets have been placed in the wrong positions (e.g. depth in the water). Small numbers of smolts have, however, been caught using herring pair trawls up to 20 km off the Lussa estuary in Scotland (Morgan, D), and in Norway, a specially developed trawl towed at 1-2 knot has been used to catch about 100 smolts in coastal waters (Heggberget, D).

Purse seines and trolling are used to catch Pacific salmon commercially but these methods have not proved successful for Atlantic salmon. The failure of these methods with Atlantic salmon probably reflects the fact that the fish were too sparsely distributed to allow more than the occasional one to be caught. In addition, as little is known of the distribution and behaviour of Atlantic salmon, the technique may have been operated either at the wrong location, depth or time. A pelagic beam trawl has also be developed to sample Pacific salmon (Reddin, D). This net can be opened and closed at a chosen depth in order to sample fish at different levels.

Information on changes in the abundance of salmon in the sea may also be obtained from catch per unit effort data in commercial fisheries. In the Faroese fishery, for example, detailed data on catch rates have been collected routinely for at least 10 years (Anon, 1993). However any spatial or temporal changes in distribution of fish within a fishery on a year to year basis may significantly affect estimates. It was suggested that by-catches of salmon taken in commercial fisheries and research vessel cruises for other species could provide useful information on salmon distribution. These sources have been explored by ICES (Anon, 1993), and reported catches of salmon in most non-salmon gear were found to be too infrequent to provide useful data. The lack of reported catches may reflect the fact that salmon catches could not be legally landed from many of these fisheries.

3.5 <u>Acoustic surveys</u>

The Workshop also considered surveying salmon numbers or observing their behaviour by acoustic methods. Acoustic techniques are widely used both to locate fish and to estimate their abundance. The acoustic assessment of any fish stock depends on the ability, firstly to detect the fish by sonar or echo sounder, and secondly to make quantitative measurements from the data obtained (Forbes, R). In appropriate circumstances, acoustic methods may be used to estimate the number or weight of fish in a shoal or to count individual fish, estimate their size and study their behaviour.

Two methods are commonly used to obtain abundance estimates from sonar data: integration of echo energy and counting of individual fish or schools (Anon, 1988b). Although echo integration is usually used where the fish under investigation are distributed in schools, it can also be applied when the fish swim as individuals and occur at low densities as is the case for salmon. However, in such cases, counting is usually a more useful technique. One advantage of counting individual fish is that an estimate can also be made of their size.

Studies of tethered fish have shown that individual salmon should provide adequate echo signals for detection and recording. The relationships between target strength and length is similar to clupeiform fish, although values for small salmon are lower than expected (Dahl, 1982). Maximum target strengths from -35 to -24 dB have been observed for fish from 40 to 100 cm at frequencies of 38 and 120 kHz (Anon, 1988b). Such methods have been used successfully in the Pacific for example in the assessment of salmon stocks entering the Fraser River (e.g. Woodey, 1987) and some discrimination of Pacific salmon species has been possible. However, during periods in the marine life cycle when the Atlantic salmon are widely distributed, it may be difficult to assess stocks using such a technique because the number of targets detected might be small (possibly 20-30 targets per day).

All studies to date suggest that Atlantic salmon are usually found close to the surface, although there is some evidence that they can make large, rapid vertical migrations (Jákupsstovu, 1988). They may also move closer to the surface in rougher weather conditions (Potter, 1985). Various transducer arrays have therefore been considered for acoustic surveys. Staff from the Marine Laboratory, Scotland and Fiskirannsóknarstovan, Faroes took part in trials in 1989 using a 330 kHz horizontally scanning sonar (Anon, 1989). The scanning sonar was attached to a buoy and operated at a depth of 20-40 m and had a vertical beam angle of 30° and a range 50-70 m. The system was linked to the research vessel by a 1000 m cable and drifted at about 1-1.5 knots.

Owing to bad weather the system was only operated for 50 h. Although 40 h of these trials were conducted in areas where vessels had recently reported good catches of salmon, the results were inconclusive. Single targets were seen on the sonar, but in no case could they be confirmed as fish rather than noise and it was not possible to track any echoes from one scan to the next. Although the trials were severely disrupted by bad weather, various lessons were learnt, and the ICES Working Group on North Atlantic Salmon recommended that, if suitable equipment was available, further tests should be conducted using a laterally scanning towed sonar operating between 35 and 120 kHz (Anon, 1989). Holm (D) noted that with improved algorithms and modification of the transducer arrays it should be possible to obtain better results. It was also suggested that neural networks, described previously, may also have an application in identifying and characterising echo signals obtained during acoustic surveys. It was reported that a Norwegian research vessel was to be used to conduct further acoustic survey trials for adult salmon in the Northern Norwegian Sea in 1993 (Heggberget, D).

In Norway, acoustic methods have also been used to observe smolts (Holm, D). A shoal of ranched smolts released from a cage were subsequently detected migrating through a small estuary and into coastal waters using a horizontally mounted echo sounder (SIMRAD EK500), with an array of 4 transducers. Fish were tracked for up to 12 hours using this technique and the smolts moved seaward in the direction of the prevailing current but at twice the speed. .

One of the difficulties with acoustic surveys is knowing whether the targets observed on the sonar are the species in which you are interested. A secondary technique is required to identify and validate the target before accurate assessments may be carried out. Confirmation may be obtained by experimental fishing in the same location, but the fishing method must not be selective for a particular species. In the acoustic survey of smolts described above, Holm (D) used video cameras to confirm the identity of the shoal of fish before it was followed within a fjord. However, video cameras do not have a very long range underwater and their use may be restricted by both the clarity of the water and the ambient light levels.

The Workshop considered that acoustic methods are most likely to be successful in coastal waters where post smolts or adults may be more concentrated and accurate validation of targets may be simpler.

4 TRACKING AND TELEMETRY METHODS

4.1 The principles

The Workshop was asked to review and evaluate techniques for tracking the movements of salmon at sea. Tracking and telemetry are used to obtain information on free-ranging animals by remote means. The main difference between these approaches and those described above is that the purpose is to collect data on the fish over an extended period rather than to take a snap-shot of the population at one time and location. This section will describe electronic tags that may be used to follow fish or obtain information on their behaviour in the sea. These tags fall into two categories: those that transmit a signal to allow the position and other information on the fish to be recorded remotely; and those that store information that may be recovered subsequently.

There are a number of constraints on the types of transmitters that can be used to track fish at sea. The first problem is that although tags emitting VHF radio signals are widely used for tracking terrestrial animals, birds and freshwater fish, they cannot be used in saline water because of the rapid attenuation of the signal. Thus radio telemetry can only be used to track animals in the marine environment if the tag can be got to the surface; in the case of salmon this would probably require the tag to be released from the fish (see 'pop-up tags' below). Satellite transmitters have also been used in the marine environment, but their present size permits them only to be used on large fish such as sharks, and because they use radio frequencies, they must be on the surface for the signal to be detected. Marine fish tracking studies have therefore tended to use acoustic transmitters. Unfortunately acoustic tags generally have a shorter range than radio tags, and the acoustic signal is effectively confined within the water.

The second constraint is on the size and shape of the transmitter. It is important that the tag should have as little effect on the fish as possible and this means that the weight and size must be minimised. One of the largest and heaviest components in most tags is the battery and so there is a trade-off between power output (i.e. range), operating life and the weight/size. The size and shape of the tag will also affect the drag if it is attached externally and will be important factors in how easily the tag may be inserted into the stomach or body cavity. In fish with swim-bladders, the weight of the tag can, within limits, be compensated for by the fish itself. Cochran (1980) suggested that for mammals up to 2-3 kg, the transmitter weight should not exceed 3-5% of the body weight. A similar ratio is suggested for birds by Caccamise and Hedin, (1985), but it is not known whether this ratio can be translated to fish. It is therefore advisable to assess the effects of each tag on behaviour and survival of the fish before it is used in the field (Moore *et al.*, 1990a).

Another trade-off in the construction of acoustic tags is that related to operating frequency. This occurs because the maximum range that can be achieved from a transmitter increases as the frequency decreases. The size of the transducer used to generate the acoustic signal also increases as its resonating frequency decreases, and so as a general rule, the smaller the transmitter, the shorter its range. This constraint may be overcome at the cost of efficiency by operating transducers off-frequency (e.g. on harmonic frequencies), but it is not possible to predict what the net effect on the range will be (Storeton-West, D).

In an ideal world, it might be possible to put an electronic tag on an emigrating smolt in order that it could record information on the fish's behaviour or allow the fish to be tracked throughout its marine life. However, as a result of the above constraints there is no tag that is small enough to be attached to smolts but has the power to transmit or collect data for 1 to 2 years. Thus the migration of the salmon in the sea must be studied by dividing the life cycle into discrete segments and studying each separately using appropriate techniques.

4.2 Electronic transmitters

4.2.1 Pinger tags

Two types of acoustic tags are currently used for tracking salmon; these are referred to as pinger and transponding transmitters. The majority of studies on the movements of both smolts and adults have used **pinger tags**, which emit acoustic signals at predetermined frequencies and rates and are detected by acoustic hydrophones operating on the appropriate frequency. Directional hydrophones, which have a relatively narrow field of detection, will indicate the approximate bearing of the fish from the tracking vessel, but, with a single hydrophone, the distance can only be estimated from the strength of the received signal. Additional information on the behaviour of the fish or its environment (e.g. depth or temperature) can be transmitted by modulating the frequency or pulse rate of the signal. Such **telemetry tags** can provide accurate information on the conditions actually experienced by the fish during migration.

Members of the Workshop reported on a range of pinger tags that they had used for marine tracking studies:

- Aberdeen University Deep Sea Pinger: operates at 76 kHz and is 55 mm long by 16 mm in diameter; pulse duration can be set at 1-50 ms and pulse rate at 30-300 beats per minute; tag life is about 30 days (with pulse length 10 ms at 1 Hz); designed for use at depths up to 6000 m (Priede, D). A similar tag has also been developed which will transmit heart rate by varying the pulse repetition rate.

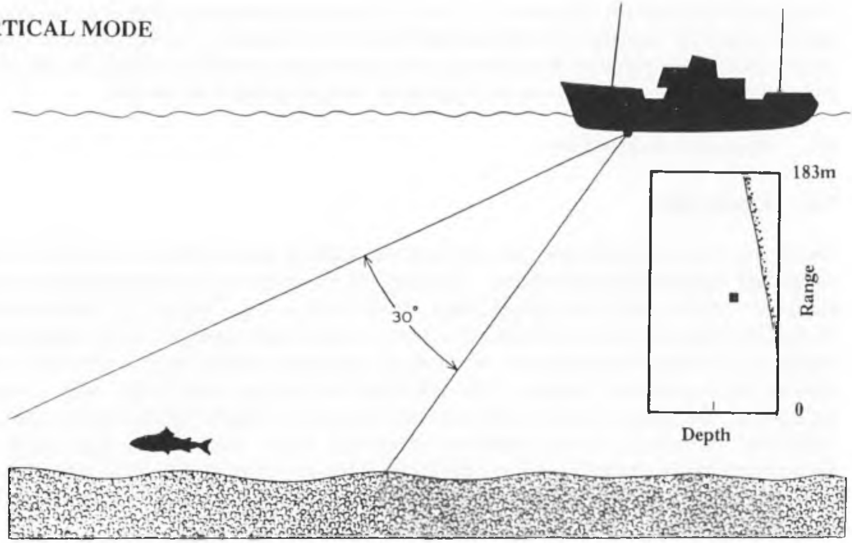
- Vemco V3 Series Transmitter: operates at 50-77 kHz and are 16 mm in diameter by 48-90 mm in length depending upon the type and number of batteries; tag life is 9-310 days (at 1 Hz) depending upon power output and batteries; the tags are rated for use up to 300 m depth. (Vemco Ltd, 1992). Versions of the same tag are available with depth/pressure, temperature, electromyogram, heart rate and differential pressure sensors.

- MAFF Fisheries Laboratory, Pinger: operates at 76 or 300 kHz and is 58 mm long by 15 mm in diameter; weighs 23 g in air and 10 g in water; pulse rates are normally set between 20 and 120 beats per minute; and the tag life is about 30 days (Potter, D; Smith, D; Smith *et al.*, 1981). A variety of sensors have also been developed including heart rate and pressure.

Other acoustic pinger tags known to have been used in salmon tracking studies included 161 kHz and 21 kHz transmitters built by SINTEF (Norway) (Jákupsstovu *et al.*, 1985) and used with shipboard sonar on the same frequencies and 95 kHz tags used by Westerberg (1982a) in the Baltic. Some of these tags also incorporated depth or temperature sensors.

The Workshop members also reported on the use of smaller pinger transmitters that had been used to track salmon smolts, although it was noted that few attempts had been made to track smolts into the open sea:

VERTICAL MODE



HORIZONTAL MODE

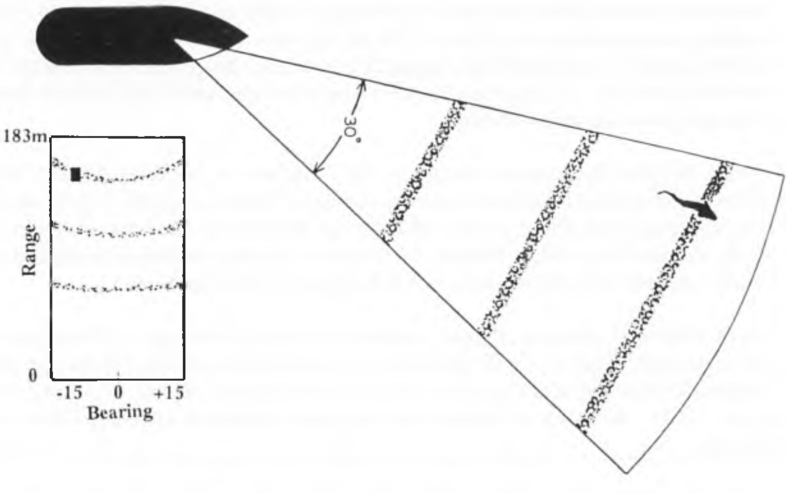


Figure 3. Tracking in the open ocean using transponding tags and a sector scanning sonar. The range and bearing of the fish from the ship are measured in horizontal mode. The depth of the fish is measured in vertical mode using trigonometry. The inset squares show the display on the tracking console in each mode.

- Stirling Mk VI transmitter: a 250-270 kHz transmitter, which was fitted within a pannier, 55 mm x 12 mm, weighed 1.2 g in water and had a range of up to 220 m in freshwater (Tytler *et al.*, 1978; Thorpe *et al.*, 1982; Greenstreet, 1992);

- MAFF Fisheries Laboratory, Lowestoft, Micro-pinger: a 300 kHz transmitter which is 17 mm in length x 8 mm in diameter, weighs 0.35 g in water, has a range of between 50-120 m in saltwater and has a battery life of 30-40 days (Moore *et al.*, 1990a, 1990b and 1992);

- Vemco V2 Series Transmitter: a 66-77 kHz transmitter, 8 mm diameter by 33-38 mm length depending upon batteries; the tag life is 3-12 days depending upon power output (Vemco Ltd, 1992; Moser *et al.*, 1991)

- Technical University of Trondheim, miniature transmitters: a 120 kHz pinger transmitter, which was 18 mm in length by 9 mm in width, weighed 1.5 g in water and had a range of 50-1000 metres in saltwater depending upon hydrographical conditions (Holm, D). Miniature ultrasonic telemetry transmitters were also developed which provided data on the depth and ambient temperature; changes in pressure (depth) were transmitted by frequency modulation and changes in temperature by altering the pulse rate (Holm *et al.*, 1982). The telemetry transmitters operated at around 125 kHz frequency were 22 mm long x 9 mm in diameter, weigh 2.5 g in water and had a battery life of 10-21 days.

4.2.2 Transponding tags

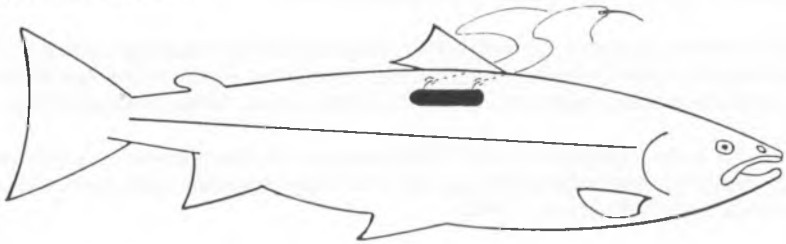
Transponding transmitters differ from pinger tags in that they only emit a pulse when they are triggered by an acoustic signal. Thus they are normally operated in conjunction with an acoustic sonar. The sonar transmits an interrogation pulse towards the fish with its transponder tag. On detection of the pulse, the transponder emits a pulse of its own which is received by the sonar. The signal is therefore picked up on the sonar display in the form of an enhanced reflection. As with a normal sonar image, the distance of the tag from the sonar can be calculated from the time delay between the interrogation signal and the tag response. Knowing the distance of the fish from the ship greatly simplifies tracking in the open ocean.

Two tracking systems for use with transponding tags were described to the Workshop:

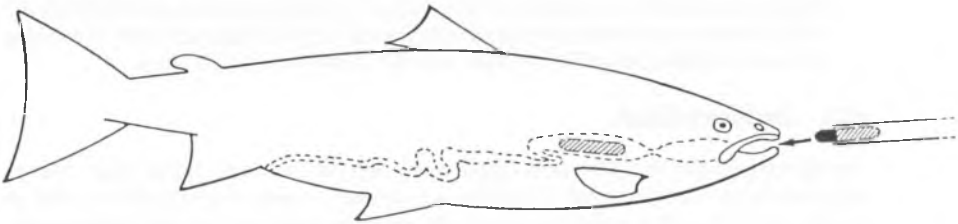
- Aberdeen University Deep Sea Code Activated Transponder: a 77 kHz transmitter (65 mm by 16 mm in diameter) which is activated by dual acoustic pulses separated by a hardware programmable time period. The programmable activation codes allow unambiguous individual identification when several transponders are deployed simultaneously. The system has a maximum operational depth of 6000 m (Priede, D)

- MAFF Fisheries Laboratory, Lowestoft, Sector Scanning Sonar and Transponder Tags: a 300 kHz transponding tag (50 mm by 10 mm in diameter) has been developed to operate with a high-resolution sector-scanning sonar (Figure 3) on a MAFF research vessel (currently RV Corystes) (Mitson and Storeton-West, 1971; Arnold *et al.*, 1990). The sector scanner is an imaging sonar, which can reveal details of fishing gear, wrecks and the bottom topography. It provides accurate (± 1°) horizontal and vertical bearings on the fish, which enables the position of the fish to be fixed in three dimensions. Two telemetric tags have been developed; one telemeters heart rate (Storeton West *et al.*, 1978); the other measures the compass heading of the fish (within 45° sectors) (Pearson and Storeton-West,

a. External attachment



b. Stomach insertion



c. Surgical implantation

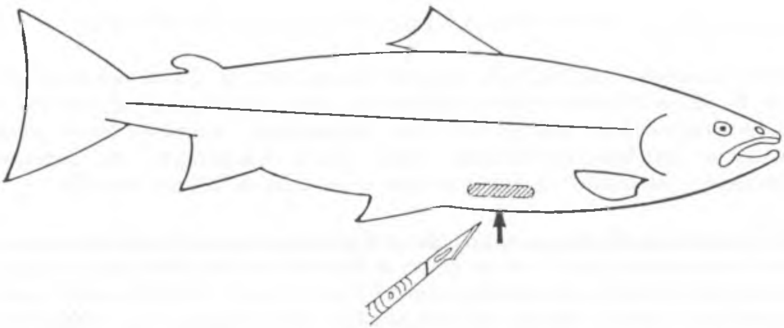


Figure 4. Methods for attaching transmitters: (a) external attachment with absorbable sutures, (b) stomach insertion with a tube and plunger and (c) surgical implantation into the interperitoneal cavity through a ventral incision.

1987). The compass tags were 65 mm in length x 22 mm in width, weighed 7g in water and had a life of 60 hours.

Transponder tags have not yet been developed that are small enough to use on smolts. The Workshop noted, however, that such developments would be very valuable in assisting with tracking smolts in coastal waters.

4.3 Tag attachment

The method of attachment of a transmitter as well as its size may significantly affect the subsequent behaviour and survival of the fish. There are three main attachment techniques (Figure 4):

- external attachment to musculature or fins;
- insertion into stomach; and
- surgical insertion into peritoneal or body cavity.

Tag attachment tends to be more critical for smolts than for adults because of the size of the transmitters in relation to that of the fish. The following section will therefore concentrate mainly upon attachment techniques for smolts although similar principles will apply to larger fish.

Handling of fish normally requires the use of an anaesthetic to minimise stress and damage to the fish. The anaesthetics most often used are MS222 (Sandoz) (e.g. Greenstreet, 1992) and 2-phenoxy-ethanol (e.g. Moore *et al.*, 1990b). Care must be taken that the anaesthetic does not affect the behaviour of the fish. MS222 has been shown to have effects on the orientation of fish for as long as 14 days (Taylor, 1988), but most other anaesthetics have not been assessed in such detail. An alternative method of anaesthetisation is slowly to chill the fish to about 1°C. This method was successfully used by Jákupsstovu *et al.* (1985), but again the effects of this method on the fishes' behaviour has not been assessed.

External attachment of transmitters (Figure 4a) has been used in a number of smolt tracking studies (Tytler *et al.*, 1978; Thorpe *et al.*, 1982; Holm *et al.*, 1982; Greenstreet, 1992) and in marine tracking of adult salmon (Potter, 1985; Westerberg, 1982a). This technique uses thin wire or threads to attach the transmitter to the dorsal musculature or fin. However, external attachment of the Stirling Mk VI transmitter using a pannier attachment significantly effected the growth and behaviour of juvenile Atlantic salmon up to 180 mm in length in comparison to control groups (Greenstreet and Morgan, 1989). These authors concluded that care should be taken when interpreting the results of longer tracks when using smolts of this size. External attachment of transmitters has also been shown to impede movement and cause irritation and infection at the locus of attachment (Roberts *et al.* 1973a and 1973b; McCleave and Stred, 1975), and may increase the risk of entanglement within the aquatic environment. In addition, externally mounted transmitters will increase drag on the fish (Haynes, 1978); this may cause it to reduce or discontinue swimming activity in high water velocities in rivers (Mellas and Haynes, 1985) and may thus also affect behaviour in the sea.

Insertion of transmitters into the stomach (Figure 4b) is routinely used as the methods for radio tagging adult salmon in freshwater. However, it can result in regurgitation of the transmitter

(Moser *et al.*, 1991, Holm 1982) or inhibit feeding in juvenile salmon (Armstrong and Rawlings, in press). Regurgitation may be particularly prevalent when fish are actively feeding. However this method was successfully used by Jákupsstovu *et al.* (1985) on feeding adult salmon in the open ocean and by Smith *et al.* (1981) on salmon in coastal waters that had probably stopped feeding. The Workshop considered that, where possible, transmitters should not be inserted into the stomachs of salmon during any phase of the life cycle when they are actively feeding.

Surgical implantation of transmitters into the peritoneal cavity (Figure 4c) has been described for a number of different species of teleosts (Hart and Summerfelt, 1975; Stasko and Pincock, 1977; Chapman and Mackay, 1984; Lucus, 1989; and Moore *et al.*, 1991b) and the technique has been successfully used in tracking studies on the estuarine behaviour of Atlantic salmon and sea trout smolts (Moore *et al.*, 1992). (In some countries (e.g. United Kingdom) there are strict controls on the use of this method.) Laboratory studies have demonstrated that the technique has negligible effects on the behaviour and physiology of juvenile Atlantic salmon as small as 125 mm when used in conjunction with the MAFF 300 kHz micro-pinger (Moore *et al.*, 1990a). Tracking studies are therefore no longer reliant on large, hatchery-reared fish but are possible on smaller, wild smolts. It should be noted that with this technique Atlantic salmon smolts may expel the transmitters from the body cavity through the body wall. This is a normal response of a fish to a foreign body. However, this process normally occurs after 4-5 months which is in excess of the battery life of the transmitters used in most migration studies (Moore *et al.*, 1990a).

The Workshop recommended that all attachment/insertion methods should be carefully evaluated before being used in experimental studies.

4.4 Tracking methods

4.4.1 Active tracking

Most tracking of salmon in the open sea has been carried out by actively following individual fish. Active tracking requires that the tracking vessel remains in constant contact with the tagged fish as it migrates. The pulses from the transmitter attached to the fish are detected by a suitable hydrophone, and the tracking vessel has to be kept within detection range. The position of the vessel is fixed periodically (e.g. every 15 min) using GPS Navigation information or triangulation to known co-ordinates. With a transponding system the fish position can then be accurately calculated within a few meters, while with a pinger transmitter it can only be estimated.

Relevant environmental data (e.g. current speeds, water temperature, sea state, etc.) need to be collected throughout each track. Telemetric transmitters can provide additional information on the environmental conditions experienced by the fish or the behaviour or physiological state of the fish during the track.

Active tracking is a simple procedure and thus fairly flexible but may be limited by the range of the transmitter being used and the endurance of the tracking crew, particularly in poor weather conditions. In addition only one fish can be tracked at a time.

Smolt studies

As previously mentioned there have been few attempts to track smolts in the open sea. Holm *et al.* (1982) tracked nine smolts (one wild and eight hatchery) using both standard micro-pinger transmitters and transmitters providing information on depth and ambient temperature. The smolts tended to move seawards in the direction of the prevailing currents in brackish water layers close to the surface, although they also made a number of dives into deeper, more saline water layers.

Most other active tracking studies of Atlantic salmon smolts have been carried out on large hatchery-reared fish because of the size of the available tags (McCleave, 1978; Tytler *et al.*, 1978; Thorpe *et al.*, 1982; Holm *et al.*, 1982; Greenstreet, 1992). However, there is some debate as to whether hatchery-reared smolts will demonstrate the same behaviour patterns as wild fish (Moore *et al.*, 1992). Although it has been suggested that large, wild smolts and hatchery smolts do show similar behaviour patterns (Holm, D), release of hatchery-reared smolts directly into an estuarine or marine environment when they may not be physiologically adapted may also result in higher mortality and aberrant behaviour. It was also noted that while wild smolts were seen to feed after being released into an estuary, hatchery reared fish did not (Heggberget, D).

Adult salmon in the open sea

There have been few studies of the movements and behaviour of Atlantic salmon in the open sea. Jákupsstovu (1988) described the movements of salmon tracked in the Norwegian Sea to the north of the Faroe Islands, using acoustic transmitters (SINTEF, Norway) inserted into the stomachs. The transmitters were detected using a 21 kHz sonar mounted on a vessel, and position was fixed every ten minutes. The salmon generally swam close to the surface making shallow vertical dives of 1-4 m, but two fish made occasional rapid dives to depths of over 100 m. Accurate position fixing was found to be difficult and the study was affected by adverse weather conditions. It was noted that it may not be possible to track salmon with high frequency (e.g. 300 kHz) tags if the fish frequently dive to depths greater than about 200 m as this may take them out of range (Storeton-West, D).

Tracking and other telemetry studies on the open sea migratory behaviour of fish have been carried out on a range of other species including Pacific salmon. Ogura and Ishida (1992) tracked four adult coho salmon in the open sea using depth sensing ultrasonic transmitters (Vemco Ltd., Canada). The transmitters were attached externally, anterior to the dorsal fin and detected using a receiver and three directional hydrophones (Vemco Ltd) mounted to a research vessel. The tracking vessel's location was recorded by Navy Navigation Satellite System. The average swimming depths of fish ranged from 7-13 m and most time was spent in the upper 15 m of the water column. Although swimming depths during the day were deeper than at night, no regular daily patterns of horizontal or vertical movements were recorded.

Other telemetry studies on open sea fish behaviour have included blue marlin (Holland *et al.*, 1990a), the tunas (Carey and Lawson, 1973, Holland *et al.*, 1990b), albacore (Laurs *et al.*, 1977), swordfish (Carey and Robison, 1981) and blue shark (Carey and Scharold, 1990). These studies have attempted to relate the migrations of the fish to environmental conditions such as temperature fronts and other ocean features. The Workshop recommended that similar studies should be carried out on Atlantic salmon in an effort to understand their distribution and migration patterns in the open sea.

Adult salmon in coastal waters

Studies on the return coastal spawning migration of adult Atlantic salmon have been reported by Hawkins *et al.* (1979), Smith *et al.* (1981) and Westerberg (1982a and 1982b), Doving *et al.* (1985) and Potter (1985).

Hawkins *et al.* (1979) and Smith *et al.* (1981) used 76 kHz ultrasonic pinger transmitters (MAFF) to track returning adults. The salmon were intercepted in coastal waters, tagged and released. The tracking vessels then remained in constant contact with the fish for as long as possible with the aid of directional Lawson tuneable hydrophone systems. The tracks lasted up to 36 h, but the studies were labour intensive, logistically difficult and affected by adverse weather conditions. In addition position fixing and storage of data were problematic although recent developments in satellite navigation systems should alleviate such problems.

A number of species of fish including Atlantic salmon have been studied using 300 kHz transponding transmitters (Mitson and Storeton-West, 1971) and a sector scanning sonar (see Arnold *et al.*, 1990). Twenty adult Atlantic salmon were tracked during their coastal spawning migration off the North East coast of England using this system (Potter, 1985). The fish were tagged using either the 300 kHz transponding transmitters or larger transponding compass transmitters (Pearson and Storeton-West, 1987). Some of the salmon tracked showed diurnal variations in depth, swimming close to the surface during daylight hours but at depths of up to 40 metres during the night. Individual salmon also exhibited large vertical migrations close to river mouths. This pattern of behaviour has also been demonstrated by Westerberg (1982b) and Doving *et al.* (1985) who suggested that it was related to olfactory discrimination of fine scale hydrographic features during the search for the home stream. Analysis of tracks using the transponding compass transmitter (Potter, 1985; Greer Walker and Potter, in prep.) indicated that Atlantic salmon in coastal waters were able to follow a particular compass heading over large distances irrespective of the prevailing tidal direction.

The problems encountered with these tracking studies were the possible effect of capture and transmitter attachment on behaviour and the loss of the signal due to fish moving into shallow water or swimming close to the surface or into shoals of other fish. In addition the studies were affected by adverse weather conditions (> force 6), surface obstructions (e.g. nets) and rapid movement of the fish outside the range of the scanner.

4.4.2 Sonar Buoys

Fish may also be tracked using strategically placed fixed stations (sonar buoys) to detect the passage of tagged individuals. These buoys normally have omni-directional hydrophones so that they will record any fish coming within detection range. Records of fish movements may be stored on the buoy or transmitted to remote automatic listening stations. Several fish can be tracked simultaneously, and the maximum number is limited by the number of identifiable tag codes (e.g. pulse rates) available. The buoys will only record the presence or absence of the tag and so the resolution of the system is limited by their detection range. Thus, if low frequency tags are used in order to give long range, then the resolution of the track may be poor. Sonar buoys can be used to provide precise position fixing (e.g. by triangulation) (Voegli, D; Russell *et al.*, 1990), but such methods are unlikely to be appropriate for tracking in the open ocean.

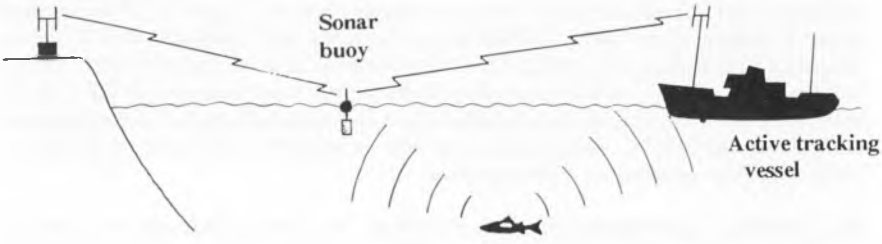


Figure 5. The use of active tracking and sonar buoys to follow salmon

Sonar buoy tracking systems have been developed by both the MAFF Fisheries Laboratory, Lowestoft and Vemco Ltd. The Lowestoft system (Solomon and Potter, 1988) is based upon acoustic sonar buoys operating either at 76 kHz or 300 kHz frequency. Information on fish movements is transmitted to listening stations positioned on land (Figure 5) which record the time and date along with the identities of the fish and of the buoy which has detected it. The Vemco system operates in a similar manner but can employ a two-way radio link to the buoys (Vemco Ltd, 1992).

Sonar buoys have generally been used to track fish in semi-enclosed waters such as estuaries (e.g. Potter, 1988; Potter *et al.*, 1992; Clarke *et al.*, 1991) where they can be positioned at locations that the fish are expected to pass. If the movements of fish cannot be predicted, as is probable for salmon in the open sea, then an array of buoys may be set out around the release position. However, such an array would have to be very large to detect the fishes' movements over any length of time; for example a 400 km^2 array would be required to guarantee tracks of only about 10 km. If the detection range of the buoys was 1 km, then 100 buoys would be required to give reasonable (but not complete) coverage of this area. (In such tracks, each fish might be detected by only 5 of the 100 buoys.) The number of buoys could be reduced if the range of the buoys was increased by operating at a lower frequency, but this would result in a corresponding reduction in the resolution of the track and thus in the information obtained.

Clearly the size of the array and thus the number of buoys required to follow the fish over longer periods could increase exponentially. However, the size of the array could be restricted for studies of fish movements in coastal waters or around river mouths where the movements of the fish may be more restricted. An alternative approach might be to deploy buoys ahead of a fish as it migrated, although this would be logistically very difficult, possibly requiring the use of aircraft or several vessels. This is unlikely to have any benefits over actively tracking of individual fish, expect possibly as a means of finding a tagged fish if it was lost.

The Workshop felt that one of the main constraints on using sonar buoys in the open sea was the high cost of the large number of buoys required. However, it was suggested that it might be possible to obtain sonar buoys previously used militarily to detect the presence of submarines, and that these might be adapted for tracking salmon (Voegli, D). There are three types of military sonar buoys, LOFAR (Low Frequency and Ranging), DIFAR (Direct Frequency and Ranging) and DIFAR-AIS (DIFAR with Acoustic Intercept System). The life of these buoys is short (1-8 hours) and they operate at very low frequencies (in the 5 Hz-2.5 kHz range), but it may be possible to modify them to detect the frequency of existing pinger or transponding transmitters. Modifications may also be required to the radio transmitters to avoid frequencies allocated for military purposes.

The Workshop recommended that the availability of military buoys and the costs of appropriate conversion should be investigated further.

4.5 The Next Generation Of Tracking Equipment

4.5.1 Developments to existing equipment

The previous sections have described the systems currently available for tracking salmon in the open sea and some of the studies that have been undertaken. A number of constraints have been described on, for example, the size of the tags and the number that can be used simultaneously. Clearly, one basic requirement for the future will be to make the transmitters smaller so that they can be used on younger fish and to provide better coding so that more tags can be distinguished. The Workshop recommended that work to further miniaturise both pinger and transponder tags and develop further tag sensors should continue.

The MAFF Fisheries Laboratory, Lowestoft was also developing a transponding tag that would operate on the same frequency as conventional sonar equipment (Arnold, D). Such a transmitter would not require a specialist tracking vessel such as the MAFF, RV Corystes, but might be used from other research vessels or even commercial vessels.

Voegli (D) also reported on developments in tracking systems that would allow automatic decoding and recording of data from telemetric tags. Tracking information could also be displayed on a screen and automatically logged to computer with GPS data. Such systems were continually being improved and would greater reduced the difficulties of tracking fish for long periods.

4.5.2 Data storage tags

The concept of a miniature fish tag that collects and stores both environmental and positional data over extended periods for later retrieval and analysis was described almost a decade ago. In 1985 Northwest Marine Technology completed a feasibility design for a tag (60 mm in length x 10 mm in diameter) to be used on tuna which would allow storage of 8 kbytes of data (Hunter *et al.*, 1986). At the same time a study on the design of a data storage tag to record position and environmental data was underway at the MAFF Fisheries Laboratory, Lowestoft (Robinson, 1985). The North West Technology Archival Position Recording Tag would record the elapsed time along with data from three environmental sensors for eventual analysis when the tag was recovered through a fishery. In addition to collection of environmental data, the most important application of the tag was to record a series of geographic positions. Longitude could be determined by including a photoreceptor and measuring the Greenwich mean time of sunrise and latitude from depth-specific temperature measurements. It was estimated that using this technique would give a resolution of 1^{O} longitude and a minimum precision of 5° latitude. Arnold (D) noted, however, that there may be difficulties with using light sensors to provide position data if the fish may be swimming at a wide range of depths and moving through water masses of differing turbidity.

A data storage tag produced in Japan has already been deployed on fish and turtles (Sakamoto and Yuzurita ,1993). The tag 145 mm in length and 18 mm in diameter weighs 37g in air and weightless in water. The tag has sensors to measure depth, light and temperature and, recording at 60 min intervals, storage for 333 days before recovery. A similar design of tag is being developed by CSIRO, Australia to be used to study the behaviour of the indigenous tuna populations although specific technical details are not yet available (Storeton-West, D).

A geographic location, time and depth recorder has been recently developed to overcome the technical difficulties encountered in satellite tracking pinnipeds using the ARGOS DCLS satellite system (DeLong *et al.*, 1992). The position of elephant seals was calculated using recorded light intensity and water temperature with reference to an internal electronic clock (see DeLong *et al.*, 1992 for full description of analysis of position).

The Data Storage Tag being developed at the MAFF Fisheries Laboratory is a microprocessor-based, programmable data logger with provision for up to eight on-board sensors and capable of surviving several years at sea (Storeton-West, D). The tag is programmed via a PC interface programme using "pull-down" menus and a dedicated on-screen editor which allows testing, calibration, programming, data display and data transfer. The size of the memory, which can be up to 8 Mbytes (equivalent to more than 2 million samples), is dependent on the sensor sampling regimes and the capacity of the batteries.

The MAFF tag has been designed initially to record depth and temperature for studies of plaice in the North Sea (Arnold, D). Developments in tag and sensor design are also underway to permit the tag to be used to study other species, particularly salmon. In the future, the tag will include sensors to record compass heading, water speed, tilt angle, angle of magnetic dip, light and salinity. Temperature and depth sensors would provide information on feeding behaviour; movements in relation to thermal and other oceanic features; and the relationship to available food resources. The use of a light sensor in conjunction with the angle of magnetic dip are being investigated to provide information on the latitude and longitude and thus give the geographic position of the salmon. Studies are underway at the Lowestoft Laboratory to improve the design of the tag and assess the most appropriate method and site of attachment to adult Atlantic salmon.

4.5.3 Pop-up Tags

Another alternative approach to active tracking that would provide fishery-independent information on the distribution of salmon in the sea would be a **pop-up tag**. Such a tag would become detached from the fish after a specified condition was met (e.g. elapsed time, temperature or salinity). It would then float to the surface where it would transmit a VHF radio signal to an aircraft or via the ARGOS satellite system. A VHF signal could have a range of around 300 nautical miles and would require the aircraft to be within this range when the tag reached the surface. This would require a knowledge of the precise time of tag release to reduce aircraft flying time. The ARGOS system has been used successfully to track a variety of animals tagged with satellite transmitters including birds (Howey, 1992) and turtles (Hays, 1992). At present the size of ARGOS satellite tags are prohibitive for use on salmon. Further developments and miniaturisation of ARGOS tags in the future would however produce a very powerful tool for use in the studies on salmon in the sea.

It may also be possible to recover information from a data storage tag using the pop-up mechanism. This might overcome the high cost of using archival tags where the recovery rate in fisheries is expected to be low. The tag might be similar to the data storage tag described above but would also incorporate the mechanisms of the pop-up tag which would detach it from the fish at a particular time and transmit the stored data by radio link. Such a tag would be an ideal biological tool to study salmon in the sea as it would be truly independent of fisheries. The rate of recovery of data should be high and this should offset the possible high cost of such a tag. At present it would not be possible to make such a complex tag small enough for use on salmon and the message length permitted by ARGOS is currently too short to permit the transmission of the amount of data collected by a data storage tag.

5 ENVIRONMENTAL DATA COLLECTION

5.1 Introduction

Temporal and spatial distributions of many populations of teleosts are closely controlled either directly or indirectly by the environment. Direct control of distribution may arise, for example, through the preferred thermal range of a species and indirect control through mechanisms regulating the availability of food resources. Changes in the environment may therefore have a regulating effect both on population structure and distribution. There is evidence that Atlantic salmon are similarly influenced by the environment (Reddin and Friedland, 1993) and that environmental mechanisms are important in controlling and influencing the marine life cycle. The mechanisms that link the marine environment to the behaviour and movement of Atlantic salmon are neither well defined nor understood. It is therefore important that the physical environment inhabited by the salmon is described along with the ways that temporal and spatial changes in this environment may effect abundance and behaviour.

The Workshop recommended that environmental data should be collected during all studies of salmon whether they be to assess stocks or to investigate the behaviour of individual fish. An idea of the marine environmental variables that may be important to the Atlantic salmon is provided by studies of other fish species. For example, albacore are not able to effectively thermoregulate at temperatures below about 10°C (Graham and Dickson, 1981) and this is why the species is not usually found in waters below this temperature. Distribution of tuna within their range is often related to the availability of prey and is therefore greatest in the vicinity of oceanic fronts were food availability is high (Uda, 1973; Laurs *et al.*, 1984). Movements of chum salmon in the open sea off the coast of Japan are strongly related to the direction of the currents and food availability. Tuna and swordfish distribution is closely linked to the 16°C isotherm in the Pacific which is an area of high productivity and prey abundance. Ocean gyres are also thought to be important in relation to the distribution and abundance of many oceanic species.

There are now a number of techniques that are available to monitor environmental variables within the open sea. However, the collection of large data sets on the environment in an effort to relate these to existing data sets on general abundance of salmon may not provide the best way forward. The Workshop felt that a sound scientific rationale for the study should be described, and specific questions should be asked in order that relevant data are collected and suitably analysed. There are a number of ways that environmental data from the open sea can be collected and these are described below and discussed in relation to their potential use in salmon assessment and behaviour studies.

5.2 Direct measurements.

Environmental data have traditionally been collected by a variety of direct methods including research vessels, ships of opportunity, weather ships, land observations, etc. However, such approaches generally provide very incomplete coverage of an area of the sea and the continuity of records may be poor. Reddin and Friedland (1993) used data from the Comprehensive Ocean Atmospheric Data Set (COADS) to investigate the possible area of over-wintering habitat for salmon. This information, issued by the National Centre for Atmospheric Research at Boulder, Colorado consists of two data sets: the first is 'in situ' SST data for 1970-81 covering an area up to latitude 60°N and is derived from ships of opportunity, land observations and sea ice limits; the second set, from 1982-1991, is derived from a blend of 'in situ' and satellite data.

It is still most convenient to measure some environmental parameters directly from a research vessel, for example as a fish is being tracked. Current speed and direction are important parameters to measure in order to provide a complete description of a fish's behaviour. Such measurements have been simplified by a recent development, the Acoustic Doppler Current Profiler (ADCP), which can be operated from a research vessel and provides continual vertical current profiles. Information is produced on the current within number of strata (known as "bins"), the width of which is related to the frequency at which the ADCP operates. For instance an ADCP operating at 600 kHz will produce a vertical current velocity profile in 0.5 metre strata. Various other sensors are available that will record vertical salinity and temperature profiles. ADCP recordings have been successfully used to measure current profiles during smolt behaviour studies in the River Conwy estuary (Moore, D). A 300 kHz frequency ADCP has now been deployed on the MAFF Fisheries Laboratory vessel RV Corystes to provide current speed and direction data whilst fish tracking with the sector scanner sonar system (Arnold, D).

Other data that can be measured using conventional techniques during salmon studies are light levels, oxygen concentrations and meteorological factors.

5.3 Satellite sensors

Earth Observation data, which are defined as data collected by sensors mounted on earth observation satellites, are used to investigate oceanic features on spatial and temporal scales that cannot be studied with classical shipboard techniques (Whitehouse, D). Through comparisons of different types of earth observation data (e.g. surface temperature and pigments) and coincidental wind fields, remote sensing data can be used to investigate the effect of physical conditions upon relevant biological processes. The Workshop agreed that satellite data was therefore likely to be important in investigations of temporal and spatial variations in Atlantic salmon populations.

Such satellites may be used to investigate surface currents, current boundaries, coastal upwelling, surface pigments, wind, waves, suspended sediments and sea ice and especially the variability in time and space of these oceanic features (Whitehouse, D). Similar environmental data may also be obtained from aircraft which may provide more detailed information for local areas, and airborne sensors have also been used to detect shoals of fish such as capelin. Data from satellites or aircraft could be sent directly to a vessel carrying out surveys or tracking studies.

Measurements of **pigments** provide information on chlorophyll levels and are therefore an indication of plankton and primary production in the oceans. Historic data are available from 1978-1986, although high latitude studies are rare, and information relevant to Atlantic salmon in the NE Atlantic may be unavailable. Pigment sensors operate in the visible spectrum and are therefore limited by cloud cover and darkness (i.e. night). A new satellite SeaWIFS is to be launched in late 1993 which will continue to measure pigment concentrations.

High quality **sea surface temperature** (SST) data has been collected since the early 1960's. Data collected by the NOAA AVHRR (Advanced Very High Resolution Radiometer) sensor are available for most areas and are widely used to study marine processes. Satellite data can provide SST resolution of 0.2°C and readings every 6 h. Current boundaries, and in some instances current speed and direction, can be studied using these data as can coastal upwelling and the location and drift of sea ice (the AVHRR sensor also has spectral bands in the visible and near-infrared). In addition, the AVHRR 's relatively fast repeat cycle and extensive historical records make it particularly useful in studies requiring temporal analysis of physical processes. Most importantly the data are free of charge to any one having a down-link and are distributed almost free of charge by several agencies (Whitehouse, D).

Synthetic aperture radar (SAR) data can produce information on determining **ice cover**, type, location, boundaries and drift. It has an advantage over visible sensors in that it is not affected by cloud cover or darkness. However, a limitation is that the repeat cycles of the satellites are in the order of a month or so and thus have limited application in studies of temporal variability. Altimeter (ALT) sensors measure relative sea surface height and therefore are useful in investigations of large scale **ocean currents**. **Surface wind** data can be used in estimates of relevant oceanic physical forcing functions and can therefore provide an indication on possible changes in oceanic processes.

5.4 Telemetered data

Environmental data relevant to the salmon can also be obtained from telemetry transmitters attached to the fish (see Section 4). In addition to providing positional data, these tags may transmit information on one or more environmental or physiological parameters. Temperature, light and depths sensors have been described above. The development of other sensors that provide data on compass heading, magnetic dip, conductivity, tilt angle and water speed can all be included in existing acoustic transmitters to provide information with respect to specific scientific problems.

6. STUDIES ON SALMON IN THE SEA

6.1 Stages in the marine phase

As has been explained above there is currently no technique that would allow us to investigate the behaviour of an individual salmon throughout the marine phase of its life. The migration of the salmon in the sea is thus best divided into the following three stages (Figure 6):

- smolt emigration through coastal waters;
- migrations of post-smolts and adults in the open seas; and
- coastal movements of homing adults after making landfall.

These stages of the marine migration are discussed in relation to the appropriate techniques required to study the relevant behaviour. The behaviour and movements of the fish during each phase may differ due to the varying motivational states of the animals. The feeding behaviour of the salmon in the open sea, for example, will differ from the orientated movements of fish during the coastal spawning migration. It is important therefore that at each stage any study is based both on a clear scientific question and scientific principles.

6.2 Smolts in coastal waters

6.2.1 The problems

This phase of the migration covers the movement of the fish from the mouth of the estuary until they move off-shore into the open ocean. It has been suggested that the strength of a sea year class may be set early in the post-smolt stage (Anon, 1988a). Although there was some uncertainty about whether there is a critical period in the marine phase (Reddin, D), it is felt that natural mortality on emigrating smolts is high and variable at this stage because the fish may be more vulnerable to variations in environmental conditions or predation.

The behaviour and patterns of movement of smolts on leaving the estuary are largely unknown. The timing of movement into coastal waters, direction and speed of movement, position in the water column and importance of tidal currents are all areas of research that need to addressed. In Newfoundland the marine survival of smolts to one-sea-winter returns had declined between 1989 and 1991, and in these years the smolts had moved out of the rivers under the ice when the sea temperature was as low as -1.7°C (Reddin, D). Information was required on the survival of smolts in these conditions. A knowledge of the movements of smolts in coastal waters will also provide much needed information to target areas for sampling in support of assessment and feeding studies of smolts in the sea.

The Workshop felt that it was important to investigate the factors affecting the survival of smolts at this stage in more detail. This could be achieved by both survey and tracking techniques. It was also felt that laboratory studies of behaviour could complement the investigations in the wild.

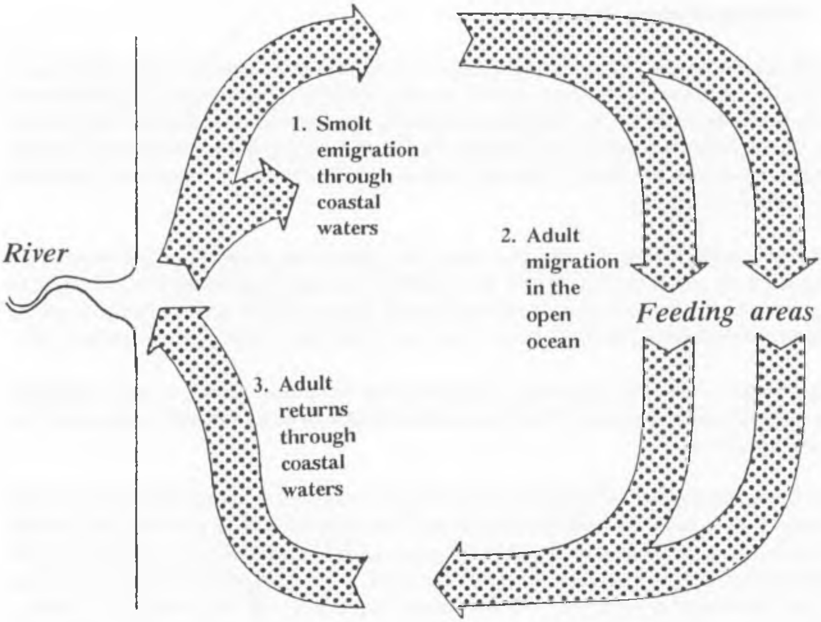


Figure 6. **Three stages in the marine migration of Atlantic salmon**

6.2.2 Surveys for smolts in coastal waters

Previous fishing surveys for smolts in coastal waters have met with mixed success. However, acoustic survey techniques operated either separately or in conjunction with conventional tracking technology could be utilised to track smolts in the open sea. Shoals of hatchery-reared smolts have been followed, but it is not known whether wild smolts will migrate in similar shoals or whether their behaviour is comparable to that of hatchery-reared fish. It is possible that release of smolts directly into the marine environment may significantly affect feeding behaviour and subsequent survival. The Workshop recommended that further studies of this type should be carried out on both hatchery-reared and wild smolts. Efforts should be made to follow shoals of smolts until they disperse in order to assess how fast fish move out of coastal waters and how they behave. Conducting such studies in a number of areas, including those where smolts move out into either warm or cold sea temperatures, should provide more information on the response of smolts to these conditions.

Video cameras might also be used to identify shoals of smolts and study further aspects of behaviour. It was suggested that tracking techniques might also be used to enhance these studies and to enable the fish to be identified more easily. Individual fish could be marked with acoustic tags to assist with the identification of shoals. Also, if a number of tagged fish were released into a shoal it might be possible to see how the shoal behaved and whether it split up and reformed with other fish. Such studies may be complemented by tank-based studies of smolt behaviour.

6.2.3 Tracking of smolts in coastal waters

Tracking studies on the behaviour and patterns of movement of smolts in the open sea is feasible using available technology. Active tracking using a vessel-mounted hydrophone is likely to be the best method for studying movements of smolts in coastal waters in the near future. These studies are logistically difficult and time consuming, but the Workshop felt that our knowledge during this phase of the life cycle is so limited that every endeavour should be made to obtain information.

The lack of a suitably sized transponding transmitter means that miniature pinger transmitters must be used for active tracking. Holm *et al.* (1982) have previously used this technique to study the coastal migration routes of hatchery reared Atlantic salmon smolts, and wild smolts have been successfully followed for about 3 km out of the Conwy estuary, Wales (Moore, D).

Tracking studies should use miniature transmitters that have been proven to have negligible effects on behaviour and survival of fish and attachment should be by surgical implantation into the peritoneal cavity.

Smolts should be trapped and tagged in freshwater and allowed to migrate normally through the estuary before being tracked in the open sea. This protocol will ensure that any possible effects of handling on behaviour are minimised when the fish is tracked out of the estuary. The fish should also be trapped using a technique that does not cause significant stress or damage. After the transmitters are attached, the fish should be retained only long enough for them to recover from the effects of anaesthesia before being released back into the river with other untagged smolts trapped at the same time. Retaining fish in recovery tanks for longer periods may result in increased levels of stress. Active tracking may begin after fish are detected passing sonar buoys in the lower part of the estuary; this approach has been successfully used by Moore (D).

Suitable sites for such studies could be the River Avon, England or the River Lussa, Scotland where previous smolt tracking studies have been conducted and smolts migrate through the estuary within a few hours of being released in freshwater. Every effort should be made to collect environmental data on current direction and speed, as well depth and temperature during each track.

Smolts may be tracked in coastal waters either by using a number of strategically placed fixed stations to detect the passage of the fish or by continuous active tracking of individual fish over a period of time. The use of acoustic sonar buoys to monitor the movements of smolts through estuaries has been described previously (Moore *et al.*, 1990a and 1992). Sonar buoys within the estuary can be used to detect the passage of fish as they move towards the sea. However, their use in coastal waters would depend upon having some previous knowledge of smolt movements so as to effectively deploy the buoys. In most cases this is unknown and because of the limited range of the transmitters, a large number of expensive buoys would need to be deployed to ensure the detection of individual fish. (See recommendation on military buoys - Section 4.4).

Once the smolts have moved away from the shallower coastal areas it may then be possible to continue the track using larger purpose-built research vessels such as the MAFF, RV Corystes. However, this would again require the development of an appropriate transponding transmitter.

It was suggested that a large number of acoustically tagged smolts might be released in an estuary and a research vessel could then survey an area around the river mouth to see which way they moved. However, as has been suggested above, smolts released into an estuary may not behave normally. In addition, even if the vessel could detect a tag at a range of 300 m and travelled at 4 m s^{-1} it could, in theory, survey an area of only about 200 km^2 in a day. If the fish were able to swim at 15 cm s^{-1} (about one body length per second) the area within which they might be found would be about 260 km^2 after one day and over 1000 km^2 after 2 days. Thus after quite a short period the area that could be occupied by the fish would soon greatly exceed the area that could be surveyed. Thus without some initial idea about where the fish went this was unlikely to be a practical proposal. This may, however, be a suitable technique for following the movements of smolts under ice, where active tracking would not be possible.

6.2.4 Kelts

The Workshop considered whether studies of the movements of kelts in coastal waters could be used in a surrogate fashion for interpreting smolt migrations. Although the size of the kelts allow the use of a larger range of transmitters, such as transponding tags or data storage tags, their behaviour may differ substantially from that of smolts. However, the behaviour and survival of kelts are in themselves areas of importance.

6.3 <u>Salmon in the open ocean</u>

6.3.1 The problems

Little is known about the distribution of salmon in the sea and the factors affecting mortality. Stocks from different regions and, in some rivers, salmon of different ages return to home waters at different times and therefore appear to respond differently to environmental conditions. More information is required on the conditions most favoured by feeding salmon and how changes in environmental conditions may affect distribution, maturation and survival.

Information on diet is also required to assess whether fisheries for other species may be affecting salmon by depleting food supplies. It is known that some prey species such as capelin and sandeel are heavily fished, but the effects on salmon are not known. The Workshop felt that studies were also required to provide basic data on the natural history of the species in the sea.

6.3.2 Surveys of salmon in the open ocean

Relatively few surveys for Atlantic salmon have been carried out in the open ocean other than the regular Canadian research vessel cruises in the north-west Atlantic. However, the Workshop emphasised the value of such sampling methods for investigating the abundance of stocks in the sea and collecting biological data, for example on diet. It was felt that the period requiring the greatest attention was the first 100 days in the sea. In particular information was required on the location of European salmon during the early phases of the life cycle. It was suggested that studies of Canadian fisheries might provide information on the environmental conditions that might be favoured by salmon at this stage (Reddin, D). Surveys might then be carried out in similar types of area in European waters.

Elsewhere, surveys have tended to be carried out by sampling catches taken in commercial fisheries. Thus, catches in the West Greenland fishery have been sampled for many years, principally by Canadian and Danish scientists to provide basic assessment data for ICES. This sampling has provided biological data and estimates of the composition of the catch, and an important observation has been that the fish caught in this area have been getting smaller over the past decade. Similarly, sampling was carried out from 1982-90 in the Faroes salmon fishery (e.g. Anon, 1992a), and since the buy-out of the Faroese quota by interested parties in 1991, a research fishery, employing a commercial vessel, has continued to operate in the area (Anon, 1993). The Workshop recognised the importance of these studies and felt that every effort should be made to ensure their continuation.

An alternative method for the assessment of salmon numbers based on previous work on deep sea fish has potential for further studies (Priede, D). The principal is based upon the assumption that the numbers of fish in a particular area can be estimated from the time taken for the first fish to appear after a bait is deployed (Priede *et al.*, 1990). The assessment worked well on deep sea fish which use olfactory cues to locate the bait but would require modification for use on salmon, which use mainly visual cues in feeding. Nevertheless, the Workshop recommended that this approach should be evaluated further.

Acoustic survey methods have not yet been used successfully to assess Atlantic salmon stocks in the open ocean. The Workshop heard that trials were to be carried out in 1993 by a Norwegian research vessel operating in the Northern Norwegian Sea. This vessel would use a towed transducer array with both vertically and horizontally mounted sonars (Holm, D). The Workshop felt that the results of these trials would be very important. Some doubts were expressed about whether surveys were ever likely to be practical because of the widespread distribution of salmon in the sea. However, if acoustic surveys proved to be a viable approach they could provide a means of surveying areas where fish congregate.

6.3.3 Tracking salmon in the open ocean

The major constraints of size that were encountered with smolt tracking studies are to a certain extent alleviated with the larger adults. Similar techniques may be used to study adult behaviour during the open sea and return coastal spawning migrations. However, it was recommended that, prior to field based programmes, behavioural and physiological studies should be undertaken with each transmitter to assess its effects and those of the attachment method on the behaviour of the fish.

The Workshop felt that every effort should be made to pursue an international collaborative tracking programme to test a range of hypotheses relating to salmon in the sea. In particular such a study should consider differences in behaviour between feeding and non-feeding fish and the movements in relation to water temperatures. A tracking programme in conjunction with an acoustic survey may be the best way forward. The Workshop concluded that the MAFF research vessel RV Corystes, with the sector scanning sonar system and ADCP, provides a valuable facility for tracking salmon in the open sea.

The Workshop recommended that every effort should be made to continue the development of transmitters and data storage tags together with the appropriate sensors to address specific management and scientific questions. They also supported further studies for the development of pop-up, ARGOS satellite transmitters for use on salmon. This would include the miniaturisation of satellite transmitters.

6.4 Adult salmon in coastal waters

Similar survey techniques may be used in coastal waters as in the open ocean. However, the Workshop considered that acoustic methods were more likely to be successful here because of the probable greater concentrations of salmon at appropriate times of year.

The tracking techniques used to study salmon in the open sea can be used in a similar way to monitor the behaviour of homing fish in coastal waters. During this stage it is important to relate the behaviour of fish not only to environmental factors but also to physiological parameters such as reproductive state. This can be carried out by taking blood samples from fish that are to be tracked and analysing them for relevant reproductive hormones (Moore, D).

Military buoys, if suitably modified at low cost, may be used in arrays to study the patterns of movement of fish in confined areas such as bays, mouths of estuaries or under ice sheets.

6.5 Environmental studies

Earth observation data may have an important role in describing changes in the open sea environment. In addition, it may be possible to relate temporal and spatial changes in salmon abundance and mortality with a particular environmental variable. However, this option is only possible if the both the abundance and distribution of salmon in the sea is known; this is not the case with most European salmon stocks. In areas such as Newfoundland, where there is a greater knowledge of salmon distribution, correlations between times series of salmon abundance and environmental variables may be feasible. The Newfoundland fishery could provide a good test bed to examine the theory that the Labrador Gyre results in upwelling and high productivity and time series of environmental data could be related to the abundance and distribution of salmon.

Salmon may frequent areas of open ocean where the temperature is closely correlated to their physiological requirements. If this is so, sea surface temperature data may provide a starting point for focusing on specific areas to carry out assessment and acoustic surveys. Sea surface temperature data may also provide an indication of boundaries, such as polar fronts, where high productivity occurs and where feeding salmon may be concentrated. The Newfoundland Sea would be a suitable area to test a number of theories on the relationships between salmon abundance, distribution and environmental variables.

Earth observation data of coastal zones adjacent to UK salmon rivers could provide data on temporal and spatial changes that might be related to years of poor smolt survival. The initial stages in the marine life history of the salmon are considered to be a period of population regulation. The mechanisms operating during this period are unknown although one theory is that there may be a mismatch in temporal or spatial availability of prey (Moore, D). Time series of sea surface temperatures and currents together with data from the Continual Plankton Recorder (CPR) could be related to the distribution and availability of known prey items and correlated with areas and years of poor smolt survival. Further work on the diet of smolts in the sea would be required if this approach was to be a viable option.

The Workshop proposed that retrospective analysis of oceanographic and CPR data should be undertaken to identify possible marine environmental causes for perceived changes in the dynamics of maturation and survival of salmon in the sea. In particular, studies should concentrate upon conditions in years when marine survival of salmon is thought to have been poor. They also recommended that earth observation data should be collected in conjunction with tracking and assessment studies in order to assess the factors affecting the behaviour and abundance of salmon in the sea. Suitable sites might include the international waters in the Northern Norwegian Sea, where the Norwegians have an existing survey programme.

7. INTERNATIONAL COLLABORATION

7.1 Introduction

The Workshop considered a wide range of alternative sources of information relating to the behaviour and abundance of Atlantic salmon in the sea. In addition, having obtained an overall assessment of what was available in terms of expertise and technology, an effort was made to identify areas of collaboration where specific problems may be addressed.

7.2 Dissemination of information

The Workshop considered methods by which information on current research relating to salmon in the sea could best be disseminated. It was felt that the annual Report of R&D Activities prepared by the Anadromous and Catadromous Fish Committee (ANACAT) of ICES was a useful basis for such communication (e.g. Anon, 1992d and 1992e). It was noted that this document also provided the basis for the NASCO reports on R&D activities, which extended the dissemination of this information. However, countries should be encouraged to try to ensure a more comprehensive coverage of research underway, particularly by universities. ANACAT also compiles an annual bibliography of papers relating to migratory fish species produced in the past year.

It was suggested that the Atlantic Salmon Trust might consider sponsoring a literature review of research on specific problem areas.

7.3 Development of techniques

The Workshop strongly recommended continued development of survey and tracking methods. It was recognised that this work was likely to be carried out by groups with particular expertise. However, efforts should be made to collaborate wherever possible to improve the efficiency of research programmes. One example was the development of a low frequency (95 kHz) transponding tag which might be used with standard sonar equipment on a number of vessels.

A number of the organisations present at the Workshop have existing programmes developing tag and telemetry equipment for use in fish behaviour studies. In an effort to target developments where it is needed an ICES mini-symposium has been proposed for 1994 to examine the requirements of interested parties. This may act as a forum for the development of collaborative studies.

7.4 Survey and tracking studies

It was noted that, for several years, surveys of the fisheries at West Greenland and Faroes had been undertaken by international collaboration organised through ICES. This had proved a useful way of obtaining data in order to provide management advice and efforts should be made to continue such programmes as appropriate..

It was agreed that Canadian scientists should conduct a feasibility study and report on the use of military buoys in fish tracking studies. They should pursue contacts with defence departments to investigate the availability and cost of appropriate buoys. The technical problems and costs of modifying them to operate on the required acoustic frequency should be considered along with the need (and possible cost) to modify the radio frequency and battery life. Possible involvement of UK scientists should await the outcome of these enquiries.

A model should also be developed for the way these buoys could be deployed in a marine study and the possibility of collaborating with military units in the deployment or scanning for buoys should be investigated. The Atlantic Salmon Trust should also pursue contacts with the UK Ministry of Defence along similar lines and the possibility of NATO funding should be explored.

7.5 Availability of research vessels

The Workshop heard that several countries were proposing to conduct research vessel cruises to study salmon in the sea during the forthcoming years. Norway were planning a series of cruises and their studies would include investigations of acoustic survey techniques on salmon. The Department of Fisheries and Oceans, Canada were also planning further research vessel cruises with RV Wilfred Templeman. Both groups reported that space would be available for visiting scientists if people were interested.

NERC vessels were thought to be too large and thus both impractical and expensive for studies of salmon. English and Scottish research vessels could also be used for studies of salmon although it was unlikely that time could be made available before 1994 at the earliest. The MAFF research vessel RV Corystes currently offered the best facility for tracking salmon in the sea.

It was noted that commercial fishing vessels often provided cheaper options for survey work. A research fishery was continuing to operate in the Faroes area using one commercial fishing vessel. The investigations included a tagging programme, using external tags, and it was possible that additional studies could carried out.

7.6 Environmental studies

It was agreed that there was a need to extract and collate various satellite data (e.g. the AVHRR data). As these data were likely to be of use to scientists from a number of organisations it was appropriate that the work should be funded collaboratively. It was understood that various groups (including INMARSTAT (London) and the Atlantic Centre for Remote Sensing of the Oceans) were likely to be interested in collaborative studies on the relationship between salmon stocks and temporal and spatial changes in environmental conditions.

7.6 Sources of funding

It was recognised that research on salmon in the sea was very expensive. Costs could be spread between interested parties by conducting collaborative studies, but other sources of funding should also be considered. It was suggested that NATO might be approached for funding, particularly for tracking studies which might utilise ex-military equipment. It was felt that European Community (EC) funding might be available for studies in the NE Atlantic although no new EC funding programmes were being considered at the time. Limited funds might also be available from organisations like the Atlantic Salmon Trust.

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