Anadromous and Catadromous Fish Committee **ICES CM 1997/M:3**

REPORT OF THE

STUDY GROUP ON OCEAN SALMON TAGGING EXPERIMENTS WITH DATA LOGGING TAGS

August 1997

International Council for the Exploration of the Sea

Conseil International pour l'Exploration de la Mer

Palægade 2–4 DK–1261 Copenhagen K Denmark

TABLE OF CONTENTS

1 INTRODUCTION

1.1 Main Tasks

At its 1996 Statutory meeting, ICES resolved (ICES C.Res.1996/2:57) that the Study Group on Ocean Salmon Tagging Experiments with Data Logging Tags (SGOSTE) will be established under the co-chairmanship of Mr D.G. Reddin (Canada) and Mr J. Sturlaugsson (Iceland) and will work by correspondence in 1997 to:

a) advise on the feasibility and design of experiments to tag salmon with data logging tags in the North Atlantic area.

The Study Group will report on progress to the ANACAT Fish Committee at the 1997 Annual Science Conference.

The Study Group worked solely by correspondence using e-mail through Internet.

1.2 Participants

Friedland, K.D.	USA
Hansen, L.P.	Norway
Holm, M.	Norway
Jacobsen, J.A.	Faroe Islands
Karlsson, L.	Sweden
Moore, A.	UK (England & Wales)
O'Connell, M.	Canada
Potter, E.C.E.	UK (England & Wales)
Reddin, D.G. (Co-chair)	Canada
Sturlaugsson, J. (Co-chair)	Iceland
Welch, D.	Canada
Westerberg, H.	Sweden
Whoriskey, F.	Canada

The list of participants is provided in Annex 1.

2 PURPOSE OF EXPERIMENTS AT SEA USING DATA STORAGE TAGS

2.1 Definitions of Tag Types

The following terminology is used in this report to differentiate tag types. **Electronic tags** are those typically used in animal migration studies that actively record and/or transmit information regarding either their surroundings or position relative to the recorder. Electronic tags are of two basic types: **transmitting tags** and **data storage** or **logging tags** (DSTs). Transmitting tags, which relay information from the fish by acoustic or radio signals, must be actively or remotely monitored, in real time, by external recording devices. These tags may telemeter information such as the fishes' environmental or physiological condition or simply the presence of the fish. Transmitting tags do not require retrieval of the tag in order to obtain data. DSTs, also known as **archival tags**, record information about their surroundings on internal memory and operate independently of any external recording devices. DSTs are not actively monitored but rely on the tag being found and returned to retrieve the stored information. This report deals with the design of experiments based on DSTs solely.

2.2 Purpose of Experiments

The purpose of tagging salmon at sea with DSTs is to obtain and record information on the behaviour of fish, the migration routes they follow, and environmental conditions they experience during their migrations.

The objective of collecting this information is to learn more about the relationship between measured environmental conditions and migration behaviour and distribution of salmon in the sea. There is evidence that other factors such as abundance, sex, weight, and age composition of returning salmon stocks may be influenced by marine environmental conditions. Environment might also affect growth and maturation processes. Information on the dynamics of these processes is therefore fundamental to the management of salmon stocks and fisheries. Currently, there are several stocks for which catch advice is provided based on indices of marine condition. Although these relationships have proven fortuitous in being able to forecast returns, they have been based mainly on correlations with an implied cause and effect. The underlying biological principles of these relationships are poorly understood (ICES CM 1997/Assess:10).

Data storage tags can provide a means of collecting information about the geographical position and behaviour of salmon in the sea as well as the marine environmental conditions they experience. Also, in the case of movements over long distance or time, DSTs will frequently provide the only way of obtaining records of fish movements. However, of and by themselves, DSTs will not be able to completely answer all of our questions on the life of salmon in the sea. Consequently, it would be useful if the data from DSTs could be coupled with information acquired by other means that are already available or could be collected in parallel with DSTs. Such biological information includes that from both field and laboratory studies along with environmental measurements showing the conditions at the time the data were collected. Of these, sea surface temperature and productivity information provided from earth observation satellites would be most useful.

2.3 Hypotheses to be Tested

There are a number of hypotheses related to salmon and the marine environment that can be tested using data storage tags:

a) Describe the marine migration routes of Atlantic salmon.

   Hypothesis: Salmon returning to (or emigrating from) specific areas do/do not show different patterns of migration.

b) Determine the geographic distribution of salmon in the sea.

   Hypothesis: Salmon are/are not randomly distributed in the North Atlantic.

c) Determine the environmental conditions experienced by salmon during different parts of their marine migration.

   Hypothesis: Salmon are/are not found in areas with specific environmental conditions.

d) Determine differences in a), b), and c) for salmon of different age groups, wild and reared salmon and salmon originating from or returning to different areas.

   Hypothesis: Salmon of different ages or origins exhibit the same/different distributions and migration routes in the sea.

e) Determine the relationship between distribution/migration and environmental conditions in the ocean determined from satellite imagery and other sources.

   Hypothesis: Salmon distribution and migration routes are/are not related to areas or gradients of temperature/salinity.

f) Determine if salmon stay close to the surface during the marine phase.

   Hypothesis: Salmon prefer/do not prefer specific depths.

g) Determine the relationship between salmon body growth and ambient temperature during the marine phase.

   Hypothesis: The growth rates of salmon are/are not affected by the temperature that they experience during the marine phase.

2.4 Data to be Collected

What data do we need from experiments at sea with DSTs to answer the above questions? Data that could be recorded includes:

Date
Time
Temperature (ambient water and core body)
Depth (required to interpret changes in temperature and swimming depth)
Light (with time and possibly temperature might provide position)
Geomagnetic heading
Position (interpreted light and time)
Salinity (freshwater/estuary/seawater capabilities are available)
Physiological data (e.g., feeding activity)

Minimum data requirements from DSTs are:

Date/time
Temperature

Other data can also be linked with the data acquired by DSTs to enhance the information gained by applying DSTs to salmon. This information includes that from the salmon tagged with DSTs such as age, life history, etc. from scales, length, and weight and environmental data such as SST and productivity obtained from earth observation satellites.

3 LIFE STAGES TO TAG

A number of authors have compared our knowledge of salmon in the sea to a black box. Salmon enter the box but once in it we know very little of what happens from the time they leave their home rivers until they are caught in various fisheries or return to freshwater. Therefore, any information that can be gained about the life of salmon in the sea would prove useful. DSTs probably offer the only practical method of opening the black box, and tagging of salmon in the sea is likely to be the only feasible approach in the near future. Information obtained from application of DSTs on adult salmon in coastal waters clearly show the potential importance of DSTs in studies on salmon in the sea (Sturlaugsson, 1995a, 1995b; Karlsson *et al.,* 1996). The usefulness of the information to be gained from DSTs will depend on the rate of return and the length of time the salmon is in the sea prior to recovery. In addition, the type of information and data collected by the DST is also critical. The earlier in sea life that the DST is applied and the later in life it is recovered will determine the usefulness of the information gathered.

Mills (1989) separates Atlantic salmon after they have left freshwater as smolts into three main groups: post-smolt, adult, and kelt. All of these stages, in addition to smolt, are potential candidates for tagging with DSTs. However, the DSTs presently available are too large relative to the size of salmon smolt to make application at this life stage practical. However, as the technology improves tag size will eventually decrease to the point where smolt tagging will become feasible. Smolts are easily and inexpensively caught for tagging in the many enumeration facilities around the North Atlantic (ICES CM 1997/Assess:10). Post-smolt salmon caught and tagged at sea would be the next most valuable stage to tag, although consideration should be given to potentially high natural mortality rates. Post-smolts have been caught in sufficient numbers at several locations in the Northwest Atlantic (Reddin and Short, 1991) and the Northeast Atlantic (Holst *et al.*, 1996) to ensure the viability of tagging experiments with DSTs. Adult salmon, if tagged in sufficient numbers in the open sea or in coastal waters, will also provide useful information. In some instances, previously spawned salmon also return to rivers with enumeration facilities in sufficient numbers that would warrant tagging at the kelt stage. If the returning adults were also trapped in a way that the DSTs could be detected and removed, then recapture rates would be high enough to warrant tagging. However, before initiating tagging experiments based on kelt, consideration must be given to numbers and possible differences in migration patterns of individual stocks.

4 LOCATION AND TIMING OF OCEAN TAGGING EXPERIMENTS

Information currently available on the distribution of Atlantic salmon in the sea, suggests that it is highly likely they are not randomly distributed within the marine environment. There are undoubtedly many reasons for the contagious distributions of salmon at sea not the least of which is that salmon may be localized in relation to prey and predator species. Prey species may be localized in relation to high productivity zones such as areas of upwelling or along preferred thermal fronts. Information available from earth observation satellites on sea surface temperature and productivity (e.g., sea surface chlorophyll levels) would be beneficial and could be related to other environmental data and modelled with geographical position. Because the distribution of salmon in the sea is likely to be contagious rather than random, the location and timing of ocean experiments will be critical to the success of any experiments using DSTs.

Evidence on the distribution of salmon in the North Pacific provides some of the best information suggesting that the ocean distributions of salmon are likely to be non-random. This information suggests that different stocks and age-classes of salmon may have different ocean distributions and migration patterns. In the Pacific Ocean, salmon show extremely sharp species-specific thermal limits, which limit the area of the ocean available and change the distribution pattern in different months of the year (Welch *et al.,* 1997, in press). Within these general areas of distribution, there is evidence for different ocean distributions of different age-classes of a single stock (McKinnell, 1995), and evidence for coherent population-specific aggregations of steelhead trout over years at sea (McKinnell *et al.*, in press). In the North Atlantic, salmon also show sharp thermal limits and are known to be concentrated in certain areas at certain times of the year (Ruggles and Ritter, 1980; Swain, 1980; Reddin, 1985; Reddin and Short, 1991). Different stocks of Atlantic salmon may show fine scale differences in schooling patterns as well. These differences must be taken into account in the planning of ocean tagging experiments.

The location and timing of ocean tagging experiments applying DSTs to Atlantic salmon will depend on the life stage to be tagged and resources available for its capture. In the Northwest Atlantic, post-smolt salmon are commonly spread over much of the Labrador Sea and there are several areas in the mid-Labrador Sea where they are annually found in abundance. Post-smolts have been caught as by-catches in commercial fishing gear in the Gulf of St. Lawrence but directed experiments failed to capture them in any numbers (Dutil and Coutu, 1988). Adult salmon can be found in the Labrador Sea at any time of the year and are located in coastal areas at west Greenland and around most of the North Atlantic. During the winter to spring period, adult salmon are variously located in the southern Labrador Sea.

In the Northeast Atlantic, post smolts have been caught in surface waters along the shelf-edge to the west of Scotland and in the Norwegian Sea as far north as 70° N. Although no locations have been found where post-smolts are abundant, recent experiments in the northeast Atlantic have shown that they are widespread (Holst *et al.*, 1996). Adult salmon may also be found throughout the Norwegian Sea during much of the year, and particular concentrations may be found to the north of the Faroe Islands in the winter and spring.

5 FISH CAPTURE TECHNIQUES

Capture techniques depend on the life stage to be tagged and on the environmental conditions at tagging, particularly water temperature. For salmon, due to different spatial distributions, vulnerability of various stages to the capturing methods and to stress in general, four main life stages must be considered separately. The four stages are the smolt stage, the post-smolt stage, the adult stage (at sea), and repeat spawning adults.

5.1 Smolt Stage

Wild smolts migrating to sea, experience a natural stress factor when they leave fresh water and enter sea water and would have higher mortality rates for three to four weeks after entering the sea (Handeland *et al.*, 1996). They should thus be tagged prior to migration into the sea to allow some time for recovery in the river after tagging. The capture techniques for smolts in rivers include traps, electrofishing, and trapnets. It would be best to capture actively migrating smolts in traps or trapnets rather than electrofishing which may take fish not yet actively migrating to sea. Smolts caught in fresh water should generally be in suitable conditions for tagging; however, their small size limits the tag size and weight.

5.2 Post-Smolt Stage

Just after the smolts enter the sea in spring or summer and become post-smolts, they first utilize coastal and then oceanic waters. In coastal waters, post-smolts have been found to migrate rapidly, dispersing out toward the open sea (Sturlaugsson and Thorisson, 1995b; Lacroix and McCurdy, 1996), although water temperatures, high prey density and low predation pressure indicative of favourable conditions do occur in coastal areas (Reddin and Short, 1991; Sturlaugsson, 1994; Sturlaugsson and Thorisson, 1995b, 1995c; Thorisson and Sturlaugsson, 1995a, 1995b). Also, there are examples of post-smolts staying in coastal waters until autumn (Dutil and Coutu, 1988); although most post-smolts are thought to leave coastal waters soon after entry into the sea. The vast area of distribution implies that large amounts of fishing gear must be used to ensure capture of post-smolts in the sea. Furthermore the gear must be employed in the upper surface layer (Sturlaugsson and Thorisson, 1995b; Holm *et al.*, 1996a), probably in the uppermost 0–15 m (Karlsson *et al.*, 1996).

Fishing gears suitable for catching post-smolts in the sea include floating long-lines, drifting gillnets, and purse seining. Purse seining, using a lift bag, would be advantageous compared to the other methods, due to gentler pre-tagging treatment of the fish. However, on the negative side are the low catch rates expected with a purse seiner considering the low density of post-smolt salmon in the sea; this may make the cost of employing purse seiners prohibitive. Long-lines and gillnets can be used from small boats, i.e., 40–50 GRT vessels during summer, and large amounts of fishing gear usually can be employed by one boat. These catching methods, however, can be detrimental to the long-term survival of small fish. Although alive, fish lose scales prior to tagging by encountering and being retained by the capture gear and many will be exhausted to the point at which survival is unlikely. Scale loss is considered a larger problem in salmon caught by gillnets than by long-lines, but the injuries from the hook, if it is removed, would reduce the survival rate from long-lines. Pelagic trawls fished at the surface have been used in the Northeast Atlantic; however, the scale loss of fish captured this way is considerable, and frequently lethal, to the fish (Holst *et al.*, 1996). Thus, this technique would not be a viable option for obtaining fish for tagging.

5.3 Adult Stage

Adult salmon are found on the high seas in the North Atlantic where they feed during the oceanic phase, usually for one or two years (occasionally up to five years) before returning to their river of origin to spawn. The relatively larger size of adult salmon compared to other stages makes them suitable for tagging with DSTs; however, the low density of salmon in the sea excludes certain catching methods. Typically, only long-lines and possibly gillnets could catch enough salmon for tagging. As for post-smolts, the long-lines and gillnets can be used from small boats, i.e., 50 GRT vessels through the period from October to June. Previous experiences from high seas tagging with long-lines at the Faroe Islands show that care must be taken in selecting the appropriate hook size. Also, the quality of the hook is important and it should not be galvanized, in case the hook is left in the fish esophagus or stomach at release. Use of an anesthetic on fish below 60 cm before tagging will reduce stress and improve survival. Based on survival of recaptures of salmon tagged at sea Hansen and Jacobsen (1997) found that one-sea winter salmon (below 60 cm total length) seem to be more vulnerable to tagging mortality and tolerate less stress than larger salmon. Furthermore, Hansen and Jacobsen (1997) found that the recovery rate was not significantly different between fish with the hook left in the fish at release than for fish without hooks.

A technique that has been used in tagging studies at sea to reduce stress and scale loss is to continually patrol the fishing gear from a small open boat removing, tagging, and releasing salmon as soon after they are captured as possible. For example, this technique has been used in the Gulf of Bothnia in the Baltic (Karlsson *et al.*, 1996) and during the International Tagging Experiment at West Greenland in 1972 (Møller Jensen, 1980). The use of this technique increases the number of fish suitable for tagging and the return rate of fish from the tagging experiment. Tanks have been designed that easily fit into a small boat so that the fish can be tagged and allowed to recover before release back into the sea. Of course, the use of this technique will depend on suitable weather, as crew safety must be paramount.

Migration studies based on DSTs applied during the homeward migration of Atlantic salmon in coastal waters have used traps and trapnets in estuaries for capture and recapture (Sturlaugsson, 1995a, 1995b, 1996; Sturlaugsson and Thorisson, 1995a, 1996; Sturlaugsson and Gudbjornsson, 1997). In these studies, the fish have been released up to 420 km away (shortest sea route) both inshore and offshore. Salmon tagged with DSTs were kept in net pens in the sea, enabling comparison with the released migrants. Trapnets have also been used to capture Baltic salmon (*Salmo salar* L.) outside estuaries in coastal waters for tagging with DSTs, enabling studies of their migration behaviour in the Gulf of Bothnia (Karlsson *et. al.*, 1996).

5.4 Kelt Stage

The tagging of kelts (repeat spawning adults) with DSTs should be considered as kelts are large enough to carry a full sized position fixing tag and would return to the release site if not captured or killed. Also, kelts can be easily captured in fresh water using seines, traps, or by simply retaining broodstock at hatcheries. The recovery rate of kelts could potentially be high if the appropriate stock was chosen and returning fish targeted for capture. At hatchery facilities, recovery rates might be enhanced through improved reconditioning. It is important to realize that the behaviour of kelts may differ from that of smolts. However, it is reasonable to assume that in the open ocean and on the second return their behaviour would be similar to that of virgin fish.

6 APPLICATION OF DATA STORAGE TAG

Once the fish have been captured, the DSTs must be attached in a manner to best ensure survival of the fish and return of the tag.

6.1 Tag Attachment

Salmon have been tagged with electronic tags both externally and internally. The method of tag application will depend on many factors. These factors include the life stage of the fish at the time of tagging, *in situ* environmental conditions (temperature, etc.), and the circumstances for tagging (on a small or large boat or land-based). Also, the configuration of the tag itself, including internal/external placement of tag/sensors, the fastening and identification features together with size, weight, shape, volume, and buoyancy of the tag, must all be considered.

Stomach implantation of electronic tags has been very successful during spawning migrations even for long periods of time. This is because feeding is decreasing closer to the home river or may be absent altogether. Regurgitation is less than 10 % over several months (Gordon Smith, pers. comm.; H. Westerberg, pers. comm.). Evidently stomach implantation causes the least trauma, minimizes interference with movement, and interactions with other fish or predators. However, for feeding fish a higher regurgitation rate and/or problems with growth are probable and stomach implantation may therefore be less attractive for DSTs during oceanic migrations.

Surgical implanting is now well developed for telemetry tags. The success rate is high if proven procedures and suture material are used. A tendency for tags to be overgrown by epithelia and to be expelled through the body wall has been seen in many species, also in salmonids. Otherwise, surgical implanting has the same advantages as placement in the stomach. Practical problems for the tagging of salmon at sea are that the operation must be performed on a moving ship and that the possibilities for monitoring the salmon during recovery are limited. Another major disadvantage with all internal attachment is that the DST may be lost if recaptured in a fishery during gutting of the fish. As light is an important parameter for DSTs, surgical implantation will require that a sensor penetrate the body wall. This will result in risk of infection and abrasion. In spite of the disadvantages of tagging at sea, possible tag loss and risk of infection, the good results of migration studies on sea trout (*Salmo trutta* L.) and cod (*Gadus morhua*) based on surgical implantation of DSTs into the body are very promising for long-term studies with DSTs (Thorsteinsson, 1995; Sturlaugsson and Johannsson, 1996, 1997). These studies showed high recapture rates of internally DST tagged sea trout and cod that were recaptured up to more than one year after tagging, in perfect condition, as shown by normal growth rate and rapid healing of incisions. Recapture rates of internally tagged sea trout and cod have proven to be better than from controls groups tagged at the same time using conventional external T-bar anchor tags (Floy).

External attachment has also been used for telemetry tags. The most common technique is fastening the tag at the base of the dorsal fin, with one or two sutures or stainless steel wires inserted through the base of the fin rays. In general, the tag should be rigidly fixed or abrasion can be a problem. A two-point attachment is recommended using a backing plate on the opposite side of the fin to stop the wires from cutting into the back and releasing the tag. External attachment has been used without problems in migration studies on Atlantic salmon in Icelandic coastal waters using DSTs, where time from release to recapture ranged from a few days up to 3 months (Sturlaugsson, 1995b; Sturlaugsson and Thorisson, 1996). External attachment has also worked well in studies on sea trout where the majority of fish tagged are recaptured during the first summer within 6 months of release. The recapture rate is similar to internally tagged sea trout (Sturlaugsson and Johannson, 1996, 1997). However, double tagging in these experiments has shown that electronic tags can come off sea trout by the wires being pulled up through the dorsal fin as the fish grows. The longest period that has been reported for sea trout carrying external DSTs has been one year while the shortest period was about 4 months. In these cases, the attachment wires were forced partly through the flesh towards the dorsal fin.

The above results show that the convenience of external tagging can be used in studies that involve relatively long as well as short periods prior to recapture provided that sufficient space in the tagging wire is allowed for growth. In addition, medical grade silicon has been used successfully to create a large, well-formed surface for attachment of the tag at the base of the fin (Clairaux, pers. comm.). However, the energetic considerations of external attachment for long periods are poorly understood and may need to be further elaborated in the laboratory.

6.2 Tag Buoyancy

The buoyancy of the tag may be a much more important factor influencing return rate than the attachment method (see Section 7.2, below). Usually DSTs and telemetry tags are made as compact as possible to decrease the size and lessen the impact on the fish. However, this results in DSTs that are relatively dense, about 2 g per cm^3. This high density results in extra force on the fish which is directed downwards, and for species such as salmon that lack a *rete mirabile*, this cannot be compensated for by the swimbladder. A simple calculation shows that if the size of the tag is increased by adding flotation so that it becomes neutral or slightly positively buoyant (viz. it floats), then the radius of a cylindrical tag increases by approximately $\sqrt{2}$. The drag on the cylinder is roughly $\frac{1}{2} C\rho A U^2$, where C is a drag coefficient, ρ is the density of the water, U is the swimming speed and A is the area of the cylinder which is exposed to the swimming direction. It can readily be shown that the extra drag that is created by increasing the size to make the tag buoyant is less than the initial downward force on the smaller tag if

$$U < (2gl/C)^{1/2}, \qquad (1)$$

where g is the acceleration of gravity and l is the length of the tag. If conservative values are used for l and C of 5 cm and 1, respectively, then U < 100 cm/s. Therefore, it is evident that the penalty of extra drag will be less than the advantage of eliminating the extra negative buoyancy in all practical circumstances.

There are other advantages over physiological ones for using buoyant DSTs. The value of increasing the probability of getting returns from stranded tags should be clear from Section 7.2. The special considerations needed are to add flotation material, which is incompressible and can withstand a pressure of 2000–3000 m depth. In addition, the recovery rate can be increased substantially by making the tag as highly visible as possible, i.e., colouring the tag with neon-orange color, although the potential effects on predation need to be considered.

Therefore, it is important that the tag design and method of attachment is suitably tested in the laboratory prior to large-scale releases to maximize tag recovery.

7 RECOVERY RATES FOR DSTs

A well-designed DST experiment will take into account the recovery rate in order to ensure successful results. As for other types of tags, DSTs require the recapture of the fish and return of the tag in order for the information on it to be recovered.

7.1 Appropriate Number of Salmon to Tag

The appropriate number of fish to tag will depend on the purpose of the study, the recovery rate that is envisaged from a particular experiment, the cost per individual tag, and their application (i.e., vessel-associated costs). When return rates are completely unknown and cannot be based on previous studies using conventional tags, it may be desirable to approach the task as a two-phase study. The first phase should concentrate on gathering information on long-term behaviour of individual fish, including tag return rates. After the successful completion of phase 1, phase 2 can then proceed using DSTs but basing the number to be tagged on the results of phase 1. Phase 2 would focus on experiments which can be undertaken using DSTs to obtain data on distribution, migration routes, relationships with environmental parameters and feeding rates, requiring data from a larger number of fish using DSTs. However, if the tag cost is sufficiently low and the return rate known reliably, it may be desirable to go directly to phase 2 using DSTs.

An initial study using less expensive 'dummy' tags might be conducted in place of or prior to Phase 1 in order to improve estimates of the number of DSTs required to be released at a particular site. In such experiments, the 'dummy' tags should be identical in weight and shape and attachment to the functional tags. However, the usefulness of a dummy tag study has to be weighed against the cost and time (1–3 years) that will be required before any results are available.

In order to be effective, long-term studies directed at salmon on feeding and spawning migrations must utilize sufficient releases of tagged fish. The number of fish that must be tagged is the required number of tracks divided by the expected recapture rate, further divided by a failure rate to account for poor tracks or failed tags. Commercial and rod fisheries should be monitored for tag recoveries, and the results used to determine the release sites which will provide the largest number of tag returns. For example, if a return rate of 10 % was achievable and data from 10 individual fish were deemed sufficient then 100 fish tagged with DSTs would initially need to be released. If more rigorous statistical analyses are to be applied to the results then 25–50 tracks would be required and a higher number of fish would have to be initially tagged.

7.2 Methods to Increase Return Rates

7.2.1 Fisheries dependant recovery of tags

If it is deemed that sufficient recoveries can be obtained from fisheries (including open ocean, coastal, estuarine or freshwater) and in the case of hatchery fish from returns to rearing facilities, then steps should be taken to ensure as high a rate of return as possible. Tagged fish will therefore need to be recognized and a sufficient reward offered as an incentive to return the tag and data. This will require that internally tagged fish have an additional visible external tag such as a Floy or some other means of identifying individual fish as bearing a tag. Advertisements will also be required to notify and inform fishermen, fish markets, and anglers of the presence and means of identifying tagged fish, the scientific rationale behind the study, level of reward, and address to which the tag should be returned. This advertising would be similar to that already in place for microtagged fish, which could act as a springboard for the DST scheme. In cases where a programme continues for several years, it will be necessary to update information every year. However,. in some countries such as Ireland, Iceland, and Norway, the infrastructure is already in place to tag, release and monitor returning tagged fish with DSTs, but this may need to be extended to other river systems to increase the recovery rate.

If studies are carried out at ocean tagging sites there will be considerable difficulty in advertising to fishermen and others, because of the wide range of recovery sites. In these cases, it is especially important that the tag be supplied with sufficient information for their recovery and return to the tagging agency. Because the cost of tagging programmes is high, the reward must be sufficiently high to induce a high reporting rate. Also, there should be a clearly readable text on the tag informing the finder of the reward. The recovery rate may also increase if the tag has a clearly visible colour (e.g., fluorescent orange).

Recovery rates in earlier studies

In 1995 and 1996, a DST and dummy tagging experiment on spawning salmon in the Gulf of Bothnia in the northern part of the Baltic, resulted in recovery rates of 29 % and 50 %, respectively. For the North Atlantic area, there have been numerous studies that can provide us with example recovery rates. In Iceland, DST tagging studies have resulted in 20–62 % recapture rates. Information obtained from the tagging of kelts have shown that they usually return to spawn after one summer or one year in sea, but seldom after two year sea migration. Recapture rates, in Iceland, have been 3.4–15.8 % (N = 1213) in case of releasing from ocean ranching stations (Gudjonsson, 1970) and 4.7–12.7 % (N = 751) in rivers (Gudjonsson, 1954). In Ireland, during the last two years, recovery rates of tagged salmon from various stocks has ranged from 2–5 %. In Norway, results from tagging experiments (Lea tags) with salmon post-spawners in twelve Norwegian rivers showed that reported recapture-rates varied between 2 % and 25 %. Small adults had higher survival second time spawning than large ones (Jonsson *et al.,* 1991, 1997). In North America, tagging studies on kelt in association with a salmon counting facility on the Campbellton River, Newfoundland showed return rates of 25–40 % (Reddin and Downton, 1994). Survival for smolt to adult returns to counting facilities in North America range from less than 1 % to a high of 10 %; variation is high among years and river systems (ICES, 1997).

It is known that in certain circumstances only a small percentage of tagged fish will be recovered through commercial or sport fisheries. Recent tagging studies of feeding salmon at sea in the area of the Faroe Islands showed recovery rates of about 2.2 % for wild fish. Tagging studies using Carlin tags applied to adult salmon at west Greenland in 1965–1972 resulted in overall tag returns ranging from 5 % to 8 % (Møller Jensen,1980). A tagging study using Carlin tags on adult salmon conducted on and to the east of the Grand Banks of Newfoundland gave return rates of 7 % (Reddin, 1985). Other tagging studies in the area of Newfoundland and Labrador and Northwest Atlantic summarized by Reddin and Lear (1990) indicate on average about 25 % recoveries. Since many of the fisheries from which the recoveries were made are either closed, under moratoria, or greatly reduced, it is unlikely that current tagging studies would achieve these levels of recoveries in North America. European fisheries have not been cut to the same degree.

Factors influencing recovery rate in earlier studies

In the tagging study in the Baltic Sea, mentioned above, there was a considerable difference in recovery rates at different tagging sites. In some cases, the difference was related to the length of the migration route to the home river and probable exploitation rates. In addition, the return rate of Carlin tagged fish was less than half of the return rate for DST tagged salmon. This indicates that even if an internally tagged fish has a small external tag, it may not necessarily give a good probability of recovery. Other tagging studies indicate variable rates of return. These studies were conducted at a time when exploitation rates in commercial fisheries were relatively high compared to the present. This indicates that improving return rates of DST studies is important.

The DST studies on salmon and sea trout in Iceland have taken advantage of recapture facilities at ocean ranching stations. In these facilities, every fish is checked and fish stocks known to have high recapture rates in the fishery are used. This, together with advertising and rewarding programmes have given very good tag recoveries, even in rivers where tag recovery is completely based on angling (Sturlaugsson and Gudbjornsson, 1997; Sturlaugsson and Johannsson, 1996, 1997).

Therefore, tagging sites with known high return rates from previous tagging studies should be chosen and alternate methods of recovery other than fishery-related should be examined.

7.2.2 Fisheries independent recovery

DSTs, to be effective, rely on voluntary returns from commercial fisheries, angling fisheries, and counting facilities. In recent years, there have been major reductions in commercial fisheries exploiting Atlantic salmon. However, significant fisheries continue to operate at Greenland, along the Labrador coast, in home water fisheries in the Northeast Atlantic and in the Baltic Sea. Thus, overall exploitation in commercial fisheries is much lower now than was previously the case and this will affect tag recovery rates. In addition, angling fisheries in many rivers also have low exploitation rates due to the inefficiency of the gear, regulations designed to reduce exploitation, and from policies like hook-and-release now commonly practiced in North America. Thus, the low return rate, in combination with the high cost of DSTs per unit, could severely limit their use. The dependence on tag returns from fisheries is particularly problematic for non-commercial species or for life stages that have low exploitation rates. In the case of studying the ocean life of Atlantic salmon, the lower rates of return due to present restrictions on the fisheries, and the need to gain information on the early post-smolt stage when higher natural mortality occurs, will make it difficult to get an unbiased and detailed picture of the behaviour of salmon in the sea.

When there are no fisheries exploiting a species or when overall exploitation is low, then at best few returns can be expected. This is because the present design of DSTs seeks to minimize size which in turn leads to a high density and tags that will sink when the fish dies. If the tags were made slightly larger and buoyant, an additional mode of return would be available from tags that are detached from salmon that die and are then found on beaches. The probability for this might seem to be remote. However, looking at the frequency of returns of drift bottles and drift cards that were released to study ocean currents, suggests that stranding might give a much better return rate than from fisheries. In addition to buoyancy and the colouring of tags, return rates from strandings will presumably also be directly influenced by tag size. Because DSTs suitable for smolt and post-smolt salmon will have to be small, return rates from strandings of these tags may be lower than from the bigger tags that can be used on adult salmon.

Drift bottles as an oceanographic technique are no longer in use and most date from the first half of this century. Consequently, data have been collected from many sources (Anon., 1913; Brückmann, 1919; Carruthers, 1925, 1927; Summer, 1924; Hermann and Thomsen, 1946; Hognestad, 1968 to 1974; Olsson, 1968; Richard, 1900; Schultz, 1935, 1936; Tait, 1948 to 1955; Tomczak, 1964). In all, data from 211 experiments using drift bottle or drift card releases (drifters) in the North Atlantic have been compiled into a database. A selection has been made primarily to cover the range of the Atlantic salmon. The total number of drifters released was 17 950 and of those 48 % were found and sent to the return address. This very high return rate is because most experiments were made in the North Sea or the Baltic Sea where recovery rates are high. However, even for releases in the open Atlantic Ocean and the Nordic seas, the return rate is impressive, as is shown in the following table:

Table 7.2.2.1. Mean recovery of drift bottles released in various experiments in the open North Atlantic or in adjacent seas. The grand mean has been calculated based on either the unweighted mean of each release or weighted by the number of drifters.

Release area	Percentage recovered	Number of experiments or drifters
Based on experiments		
North Atlantic	18.4	174
North Sea and Baltic	50.6	37
Based on number of drifters		
North Atlantic	20.5	5905
North Sea and Baltic	61.8	7444

The difference between mean return rates using weighted and unweighted methods is not very large. In the following analysis, all data are presented as unweighted means which were thought to provide a more representative estimate of what can be expected from a single release experiment. The number of releases has varied with time but, as is shown in Figure 7.2.2.1, there is no evident decline in the mean return rate. The very high value in the early 1920s is based on a few releases made in the North Sea. This result is somewhat surprising, as it was expected that the increased amount of litter on the shores in recent years would make detection more difficult and reduce the rate of return. The influence of increased garbage on the detection rate may have been offset by an increase in the number of people combing the shores. Indeed even common-place objects such as bathing ducks were recently reported to such an extent that 1.4 % could be accounted for from a container of toys lost in the central Pacific (Ebbesmeyer and Ingraham, 1994). This is close to the recovery rate from drift bottle experiments made in the same area during the 1960s.

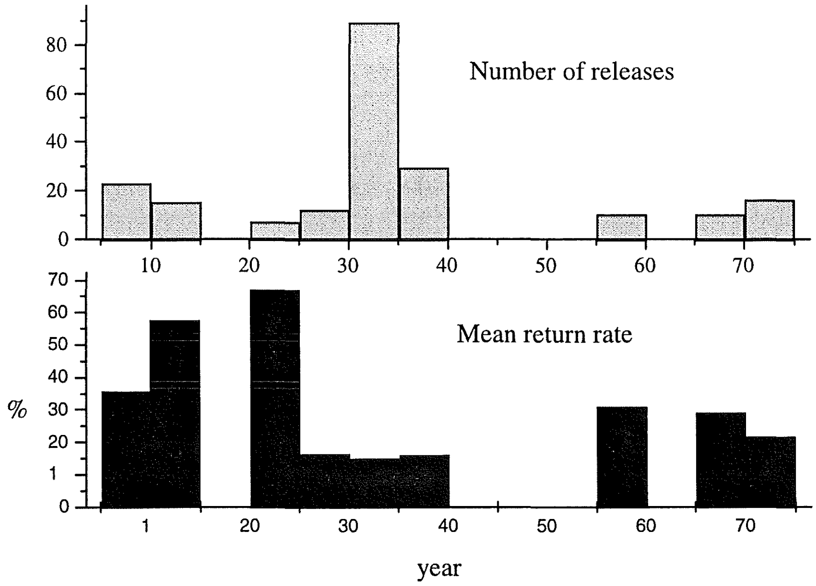


Figure 7.2.2.1. The number of drift bottle experiments and the corresponding mean return rate shown for five-year periods, 1910–1980.

Most releases were made during the summer. There is no clear relation between release time and the return rate of the experiment (Figure 7.2.2.2). The autumn experiments show high return rates but they are based on only a few releases.

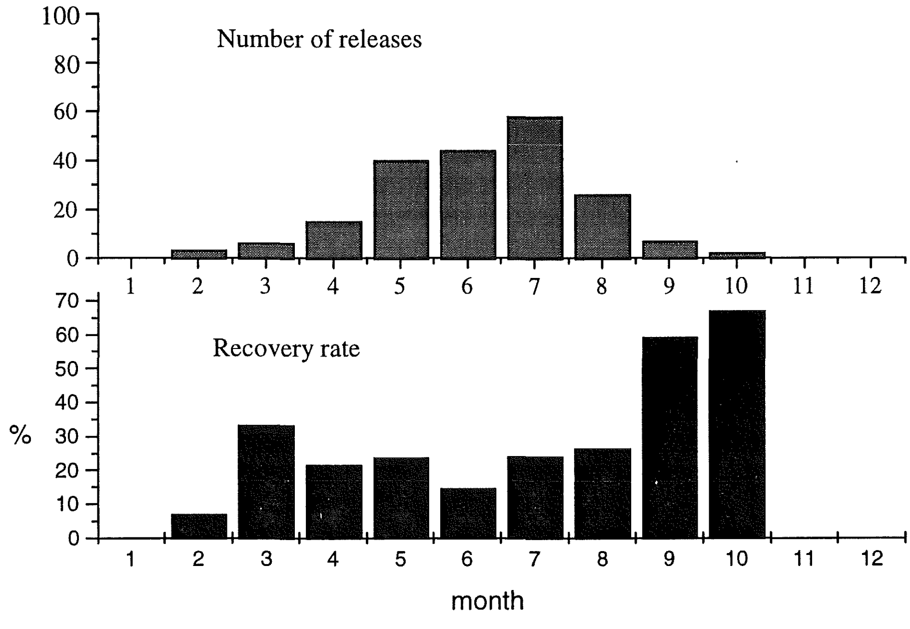


Figure 7.2.2.2. The recovery rate as a function of time of year when the release was made.

An impression of the geographical spread of the releases is given by Figure 7.2.2.3. The experiments that have been chosen cover much of the open-sea range of the Atlantic salmon, and show that the return rate is higher for releases in the Nordic seas than in the area south of the North Atlantic Current.

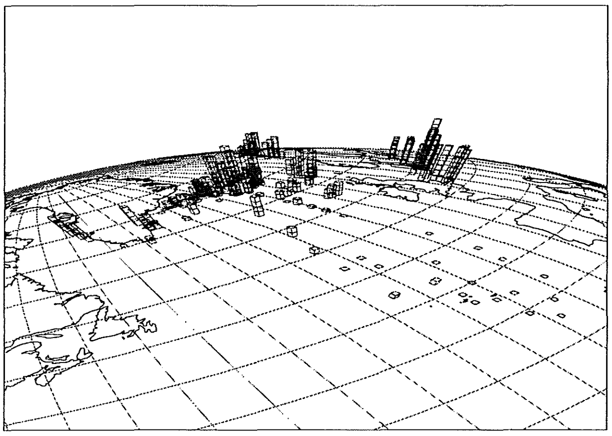


Figure 7.2.2.3. The individual releases of drift bottles shown from two perspectives. A column is drawn at the release point, with a height proportional to the recovery rate.

It is concluded that over a wide area of the North Atlantic, strandings of buoyant DSTs have the potential to give a much higher rate of return than through fishery-related recoveries. This is true even for heavily fished regions such as the North Sea. In order to be effective, this technique would require that manufacturers of DSTs ensure that their products are buoyant, easily visible, and supplied with a return address. The additional recovery of tags from strandings may be expected to be in the order of 10 % in the North Atlantic and 50 % in the Baltic. In Icelandic tagging experiments on sea trout, strandings in rivers gave recoveries of 3 %.

In addition, future tag designs could include a miniature, low-power VHF radio beacon which would increase the detection rate of tags either stranded or when in fresh water. The radio beacon would only require a single frequency and fish identity could be obtained from the DST. The pulse rate could be cyclical to reduce power consumption (e.g., five rapid pulses every two minutes). The use of aerial searches along coastlines or home rivers would be required to locate stranded tags or tags remaining attached to returned salmon. Fish in fresh water could then be located and recovered by netting or electrofishing. Buoyant tags could also be detected when on the surface of the marine environment and this would facilitate both recovery and also provide a geographical position fix. A VHF signal transmitted by the tag could be detected from the air but the limited range of a small transmitter would still make searching for the tags costly. Nevertheless, the time of detachment of the tag from the fish could be calculated from the pressure/depth data and the subsequent position of detachment modelled from SST and local current data. Alternatively, the tag could include an electronically or chemically controlled fusible link that would permit the tag to become detached from the fish after a predetermined period. Knowledge of the precise time of release might reduce costs of an aerial search for tags.

8 DATA STORAGE AND ARCHIVAL TAGS

8.1 Manufacturers of Data Storage Tags

In the past twelve months information has been obtained on Data Storage or Archival Tags produced by the following manufacturers and research groups:

1) Alec Electronics Co., Ltd. (Japan)
2) Birmingham University (England)
3) CEFAS/LOTEK (UK/Canada)
4) Northwest Marine Technology, Inc. (USA)
5) Stjornu Oddi hf. (Iceland)
6) Vemco (Canada)
7) Wildlife Computers (USA)
8) Zelcon Technic Pty Ltd. (Australia)
9) Alec Electronics Co., Ltd.

The Micro Data-Recorder System is a series of recorders to measure water temperature, pressure (depth), and light intensity and have been developed for underwater studies on various mammals and fish. Each recorder has the facility for one sensor and therefore measures only one environmental parameter. The recorders are either 109 or 127 mm in length and 18 mm in diameter and weigh either 28.4 or 33.6 g in air depending on the model. The recorders have 32 kb of memory, which is sufficient for 440 days of continuous recordings at 20-minute intervals. The rates at which each recorder samples data can be varied and the collected data can be downloaded to a PC for analysis using the available interface unit and software.

The recorders have been used to study the movements of turtles and yellowtail tuna. Attachment was external during these studies. The recorders are commercially available; however, as they are relatively large and only have the facility for one sensor, they are unlikely to be suitable for use on Atlantic salmon.

<u>University of Birmingham, England</u>

An implantable data logging system for heart rate and body temperature has been developed at the University of Birmingham to study the physiology of birds and pinnipeds. A number of the units have been deployed in the Antarctic to study the energetics of marine predators and in the laboratory to study the relationship between oxygen consumption and heart rate in fur seals. The loggers are of a suitable size (55 mm in length x 24 mm in width x 6.5 mm in height), to be implanted in penguins but have so far not been used on fish.

The loggers do not measure environmental data or determine geographic position and are not commercially available at present. They are thus not thought to be a suitable choice for an international study of Atlantic salmon in the sea.

CEFAS/Lotek Data Storage Tag

The CEFAS Lowestoft Laboratory has developed and used a data storage tag to record temperature and pressure at specified time intervals. The first model (hemispherical) was designed for attachment to flat fish, and has been used successfully on plaice in the North Sea. The latest model is marketed by Lotek as the LTD_100 Data Storage Tag with sensors for temperature, depth, and ambient light and is cylindrical in shape.

The LTD_100 tag is encapsulated in a 18 mm diameter x 57 mm length tube. The weight in water is about 1 g (weight in air: 16 g). Communications are achieved through an infrared optical link. The tag has 1 mb of non-volatile FLASH memory, which provides 18 months of recording of three parameters at 4-minute intervals. The separate channels can be programmed by the user to record data at 1 sec to 99-day intervals. The start of data logging can be delayed for up to 1 year. A sampling cut-off feature is activated if the operating power drops below a certain value; the tag ceases sampling and the remaining power is used to maintain the data memory. The manufacturer specifies data retention for 20 years.

The tag is programmed and downloaded using an IBM-compatible PC running MS-DOS or Windows version 3.11 with a RS232 serial port. A storage tag reader is employed to establish communications between the two. The communications software TAGTALK, is used to program, test, and activate the tag, and download and review stored data. The program is operated by highlighting options on drop down menus and editing windows.

Sampling protocols are programmed into the tag for each particular sensor to provide the number of samples to be taken and the sampling interval. The program will not allow the user to set a sampling regime that would result in the number of samples being greater than the tag capacity.

The CEFAS/Lotek tag technology has been proven by the successful use of the temperature/pressure tag in the wild. The latest model, the LTD_100 tag also has an ambient light sensor which is relatively small. It is suitable for use on adult salmon especially in oceanic studies.

Northwest Marine Technology Inc. - Archival Tag

The NMT archival tag has been developed principally as a position-fixing tag for oceanic migrating fish. The tag records internal and external temperature, depth, and light intensity. The light intensity is used to calculate the longitude of the tag and the external temperature is used to calculate the latitude.

The archival tag is housed in a 96 mm (length) x 16 mm (diameter) stainless steel cylinder. A 2 mm diameter flexible wand extends from one end of the cylinder. The wand is sealed into the steel cylinder by a silicon rubber collar. The end of the wand houses light and temperature sensors. The length of the wand is optional, although the minimum length is 30 mm. Within the main body of the tag, there is a pressure sensor and a second temperature sensor. The tag is interrogated and programmed through two optical fibres that extend through the silicon rubber.

The specifications from the manufacturer suggest that the internal battery provides sufficient power for a life in excess of seven years. Once the tag has been programmed and activated, it operates by 'waking up' every 128 seconds and logging the programmed environmental parameters. The user can specify the rate at which the samples are recorded by setting the time series interval (N) during the programming. The tag will then store a record every Nth measurement. The tag has a series of different data recording methods and undertakes some of the data processing before the information is stored. This allows better use to be made of the 256 kb of data memory.

The NMT tag is programmed and down-loaded to an IBM compatible PC running MS-DOS with an RS232 serial port. Communications are established through an Adapter Box and a Tag Connector. The adapter box is either powered by the computer to which it is connected, an internal 9 volt battery or a 9–12 volt AC source. The Tag Connector is linked to the Adapter via two optical fibres which, through the Connector, couple with the optical fibres protruding through the silicon rubber collar on the tag. The connection needs to be covered and kept in the dark.

The communications software HOST is used in conjunction with the above to program the tag and down-load stored data. All the functions of the HOST program are accessed through one display. When communications are established, the screen lists the tag's details including its identity, information about its contents, the sampling parameters, current tag data, and a menu of command key strokes. The tag is programmed by editing that screen. All the sampling parameters are clearly listed. The host value of these parameters is listed alongside the value of the tag. The tag is programmed by editing the host value and then using one of the command keys to send that value to the tag.

The tag has position-fixing capability, which is essential for most studies of salmon in the open sea. However, it is rather large for use on all but the largest Atlantic salmon.

Star Oddi

Star Oddi have two archival tags (DST200 and DST300), both cylindrical in shape, for use on fish. The larger tag (DST200) records temperature, pressure, and salinity. The tag weight in water is about 1 g (weight in air: 12 g) and its size is 54 mm (length) x 18 mm (diameter). The smaller tag (DST300) records temperature, depth, and tilt. The tag weight in water is about 1 g (weight in air: 8 g) and its size is 46 mm (length) x 13 mm (diameter). Both tag types can store 8 100 measurements. The manufacturer gives the life of the tag as 12 months.

The tags can be programmed with a start time (time from removal of trigger magnet to the first measurement) with sampling of measured variables made at specified time intervals. The programming can include two different sampling intervals that are repeated while the tag is running or it can have the same sampling interval. All timers can be programmed from 4 seconds up to 1 year with the recording continuing until the memory is full or battery voltage is low. A voltage security check is constantly performed by the microprocessor. The user selects the measurement range for the sensors. Each tag is separately and automatically calibrated and contains on board its own calibration data that are temperature compensated.

The tag is hard-wired to recover data from a non-volatile memory that is specified to store the data for minimum of 10 years without any battery backup. The communication to the tag through an interface box is based on an IBM-compatible PC (MS-DOS with an RS232 serial port), that does not need an external power supply.

The tags have been used successfully in external and internal applications to record the changes in temperature, pressure, and salinity experienced by salmon, sea trout, and anadromous arctic charr (*Salvelinus alpinus* L.) moving through coastal waters, estuaries, and rivers, and by cod in coastal and oceanic waters (temperature, pressure, and tilt). The results from the tags have been used to study the relationship between migration behaviour and environmental parameters that were measured by other means (temperature and discharge of rivers, light intensity, tidal periodicity, and coastal currents). In addition, the temperature data from the tags have been used in conjunction with sea surface temperature data from NOAA AVHRR satellite images, to get the approximate geolocation of salmon at a reasonable cost, both in the Baltic Sea and in Icelandic coastal waters. Star Oddi tags currently have no position-fixing capability.

Vemco

The Vemco Minilog TDR has been developed to record time, depth, and temperature. The Minilog TDR is encapsulated in a 95 mm (length) x 21 mm (diameter) PVC cylinder. At one end are the sensors and at the opposite end is a 6 mm diameter hole to allow attachment to the animal. The internal mini-processor was developed to record and store temperature and depth readings at intervals from 1 second to 6 hours. These sampling intervals equate to 2.25 hours to 5 years full deployment. The internal Lithium battery also has a five-year life span (full deployment) and can be replaced. The manufacturers stated that the memory EPROM has a data retention of 20 years. With the sample interval set at 128 seconds the tag would have a sampling life of approximately twelve days.

The TDR is programmed and down-loaded to an IBM-compatible PC/AT (with a RS232C serial port) via a communication interface - the MINILOG PC. The MINILOG PC has an internal 9 volt battery which powers the TDR during communications. The communication link between the TDR and the interface is an infrared LED. The communications software MINILOG.EXE is used for programming the TDR and for downloading stored data.

Two standard temperature scales are available with the TDR (–4° to 20° with 0.1° resolution; and –5° to 35° with 0.2° resolution) and seven full scale depth ranges (17, 34, 68, 136, 204, 340 or 680 m (resolution 1 % of the scale; accuracy $\pm$ 3 %)).

The tag does not have position-fixing capabilities.

Wildlife Computers

Wildlife Computers Dive Recorders have been developed to collect and digitally record data on the behaviour of diving animals. Depending on the model chosen, data on depth, ambient water temperature, heart rate, swimming velocity, and light intensity may be recorded. The recorders have up to eight channels each, which can be programmed independently by user-defined sampling protocols to sample at rates from 1 second to 255 minutes. The sampling software is inside the recorder and the sampling parameters are entered prior to deployment via PC-driven software and a serial interface.

The smallest model (Mk 5) may be suitable for use on Atlantic salmon. The Mk5 time/depth recorder (TDR) was developed to record temperature, depth and light intensity. The light intensity and temperature data are used in conjunction with a GEOLOCATION analysis software package to calculate the position of the TDR with an accuracy of ± 60 miles (manufacturers specification). The TDR has principally been used to study the diving behaviour and migrations of birds and mammals such as seals.

The electronics and batteries of the TDR were enclosed in a 65 x 16 x 37 mm block of epoxy resin. The light sensor and pressure transducer was situated on one face of the block, together with a conductivity sensor and a four-pin communications connector. On the opposite face is a window for an LED, which indicates whether the TDR is active.

The TDR was powered by an internal 3.5 volt lithium battery which the manufacturers specifications suggest should provide approximately 10 years of seasonal deployment. If the battery voltage falls below a cut-off level, the TDR stops collecting data and the remaining power is used to maintain the collected data stored in 512 kb of memory.

The programmed sampling intervals range from 1 second to 255 minutes. A 'Duty cycling' option, when programming the TDR, allows data to be collected at these sampling rates, but only during defined time periods. The 512 kb of memory equates to approximately 158 000 records. This is approximately 195 days worth of records at a sampling interval of 2 minutes.

The TDR is programmed and down-loaded using an IBM-compatible PC running MS-DOS or PC-DOS (version 2.0 or later) with a RS232 serial port. To establish communications between the two, a communications interface box also had to be purchased. This provides the necessary hardware and power. The power is supplied by an 8 pack of AA batteries. A voltmeter on the box indicates whether the power is within the safe range of 10–15 volts. The communications link between the DST and PC is via a cable from the TDRs 4-pin connector. The communications software PROCOMM is used to activate and program the TDR, and down-load stored data. Each environmental parameter can be sampled at different rates and conditional sampling is possible. These programming options are provided to make efficient use of the TDR's sensors, storage space, and battery life, and to limit sampling to the times and conditions when data are required to be logged.

The GEOLOCATION software uses the time of local apparent noon to calculate longitude and the length of day to calculate latitude. SST data could be used in conjunction with satellite imagery to improve the latitude estimate close to the equinoxes. To reduce the margin of error caused by the loss of light intensity with depth, when activating the TDR, a depth limit could be set below which light data is not collected.

Zelcon Technic Pty Ltd.

Zelcon Technic Pty Ltd. has developed the SBT100 Fish Logger to be used on free-ranging fish, in particular southern blue fin tuna. These data loggers record light, temperature, and depth with time and may be used for geolocation using data from sunrise and sunset. The loggers are 77 mm (length) x 27 mm (width) x 14 mm (height), and 55 g in weight. They record depth in the range 0–500 m with a resolution of 2 m and temperature in the range −10°C to 30°C ± 0.2°C. The logger has a 256 kb memory and a life-span of 8 years. The data are stored in an ASCII format.

8.2 Accuracy and Precision of Geolocation

Several studies suggest that estimates of longitude from DSTs are perhaps on the order of ± 1°, and that estimates of latitude are significantly worse. However, only one published experiment comparing the *known* position of the tag with the estimated position is available to directly assess the accuracy of geoposition estimates (Gunn *et al.*, 1994). This experiment involved towing a cage with a tagged tuna and gave encouraging results but was necessarily limited by the short duration and distances covered (250 kms).

8.2.1 Basic Principles

Recent work in the Northeast Pacific provides a more accurate assessment of the likely reliability of position estimates for latitudes where salmon migrate. Estimates of the position of a tagged fish on the surface of the earth (geoposition) can be obtained either from records of light level alone or from the use of light records in combination with temperature. As SST decreases to the north, auxiliary information on temperature may be used to help fix the north–south position of a tagged animal. However, even with good satellite maps of SST, it is likely that the uncertainty in estimates of the north–south position of an animal cannot be resolved to an accuracy of less than several hundred kilometers. For this reason, attention has focused on estimating latitude either directly from the light record, or from the inclination of the earth's magnetic field (Klimley and Holloway, 1997). Currently, it is only possible to estimate geoposition from records of light variation with time.

If the rotational axis of the earth was perpendicular to the plane of the earth's orbit around the sun, then the sun would rise or set four minutes of time later for each degree of longitude the farther west an observer moves, irrespective of latitude (1° of latitude equals 111 kms at all longitudes; at 50°N, 1° of longitude equals 111•cosine (50°) = 71.4 kms). This sets a fundamental limitation on the accuracy of light-based estimates of geoposition. This is because at a sampling rate of δt = 4 minutes, position estimates to an accuracy greater than ± 1° longitude must be based on interpolation of the light curve to intermediate times that were not directly measured. Thus, light must be recorded sufficiently often to allow reliable estimation of the time of dawn or dusk. The data storage capacity of the tag therefore will limit the length of time a DST can remain operational.

In principle, latitude can also be estimated from the light record because the rotational axis of the earth is tilted, and the length of a day varies with latitude and time of year as a result. However, near the spring and fall equinoxes, day length is almost 12 hours at all latitudes, so small errors in estimating the length of a day can have very large effects on the estimated accuracy of latitude (Figure 8.2.1). The period of time during which the light record cannot provide a satisfactory estimate of latitude depends on both a degree of estimation error that is acceptable and the absolute error in estimating day length. For errors of ± 5 minutes there is roughly a span of ± 17 days during which latitude cannot be estimated with an accuracy of less than ± 5° of latitude, or ± 330 kms. If the error in estimating day length can be reduced to less than ± 1 minute, then the period around the equinox when latitude is inestimable shrinks dramatically. Estimates of longitude are much less susceptible to such misspecification errors and are not shown.

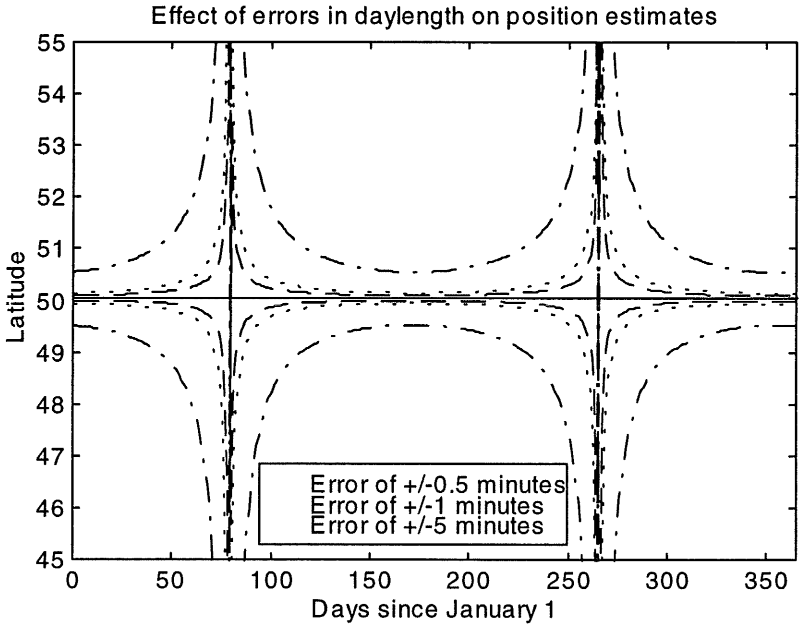


Figure 8.2.1. Calculation of the estimated latitude and longitude resulting from an incorrect specification of day length of ± 0.5, ± 1.0, and ± 5 minutes as a function of time of year. Outside of a span of ca. ± 17 days centred on the equinoxes, latitudinal estimates are not strongly affected by small misspecification errors in day length; during these periods latitude is estimable. Estimates of longitude are mainly dependent on the estimated time of dawn or dusk, and are not as strongly influenced by errors in estimating dawn or dusk or, equivalently, day length. The actual accuracy with which the time of dawn or dusk can be estimated is currently the subject of a field study in the Northeast Pacific.

Current methods of estimating dawn and dusk depend on estimating the time at which ambient light reaches 5 % of the difference between daytime and night-time levels of illumination, which is defined as civil twilight. This involves estimating a daytime and night-time reference level of illumination (both of which are measured with error), taking the difference, fitting a curve to the increase or decrease in light with time, and then interpolating to estimate the time at which the 5 % light level is reached. Error can therefore be introduced at several points in this calculation.

An alternative definition of the times of dawn and dusk with a clear physical basis can be derived by considering the rate of change in light level with time. Light changes most rapidly at dawn and dusk, with the most rapid change occurring as the centre of the sun's disk reaches the horizon. At this point the greatest unit surface area of the sun is hidden or revealed by the horizon per unit time. This definition is clearer technically than the definition for civil twilight, but it is unclear at present whether the use of a relative light level such as civil twilight is preferable to estimating geoposition on the basis of the maximum rate of change in light level.

There are a number of practical details involved in the estimation of geoposition that complicate these basic schemes. However, the basic principle is that two measurements must be derived from the light record (e.g., dawn, day length) in order to calculate geoposition (latitude, longitude) each day. Interpolation when combined with measurement error therefore will result in potentially significant errors in the estimation of geoposition. Error can be introduced from several sources, but two are obvious. Firstly, the level of illumination varies with cloud cover, sea state, and intrinsic noise within electronic circuitry in addition to the time of day. Secondly, the estimation of a daytime reference level of illumination is not clear-cut, because the time over which this average is defined does not have a clear technical definition.

A subsidiary but related question involves whether it is better to use the original light record or a filtered version that can potentially increase the signal to noise ratio. Preliminary work on the development of a digital signal processing technique suggests that a significant improvement in estimates of geoposition is possible over the use of the original unfiltered light record (Welch *et al.*, in prep). For simplicity, only the numerical results from the filtered light records are reported below. Results using unfiltered light records are similar, but to date suggest that accuracy and precision of the estimates appear to be significantly poorer when the original unfiltered light record is used to estimate geoposition.

8.2.2 Accuracy and Precision

To date, two field studies in the Northeast Pacific to assess the accuracy of DSTs have been completed. These are described below, and illustrate some of the difficulties in clearly assessing the potential accuracy of DSTs. A third field study involving 6 replicate tags from each of four manufacturers (CEFAS/Lotek, Onset Computers, Star Oddi, and Wildlife Computers (4 tags only)) is currently underway, with tag retrieval from a fixed offshore ocean mooring location set for the end of June 1997 (D. Welch, pers. comm.). The CEFAS/Lotek and Wildlife Computer tags used in this study are capable of estimating geolocation and, as described in Section 8.1, are small enough to potentially be of use in studies of salmon migration in the ocean.

Vessel Studies- October 1995

The first field experiment involved DSTs from Northwest Marine Technology (NMT) and Zelcon. Two tags each from Northwest Marine Technology and Zelcon were fixed to the bow of the *F/V* Columbia during salmon research in the Northeast Pacific (Gulf of Alaska) in October 1995. (Only the Zelcon tags, serial numbers 633 and 639, were capable of estimating latitude as well as longitude). Figure 8.2.2 shows two examples of the effect of movement on estimated geoposition in the Gulf of Alaska. There are large latitudinal errors in the estimated position of the vessel and smaller errors in the estimated longitude.

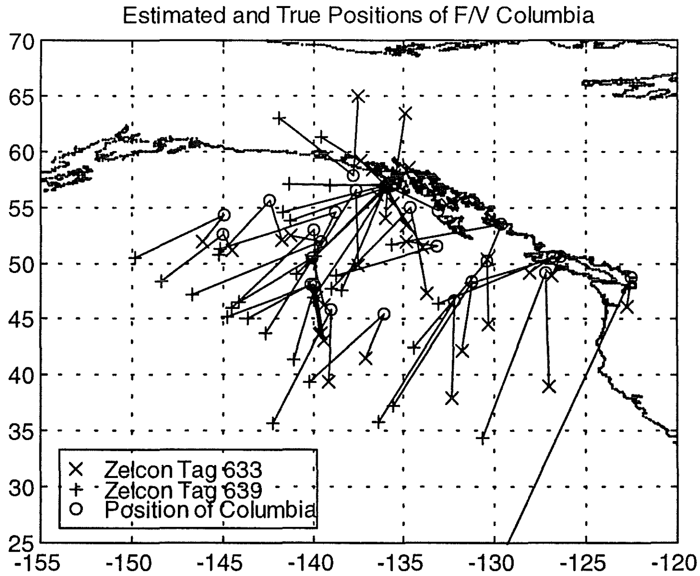


Figure 8.2.2. Estimated versus recorded geopositions for DSTs mounted on a ship moving around the Gulf of Alaska. The ship's position was taken as the noontime position recorded in the ship's log, based on GPS. These data was collected during the first experiment described in the text.

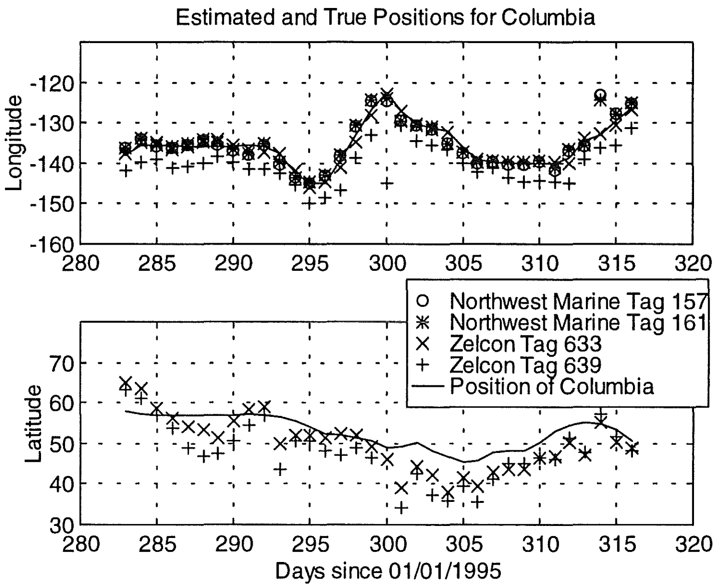


Figure 8.2.3. Comparison of true (line) and estimated (symbols) longitude and latitude as a function of time (only a longitude estimate is available for the Northwest Marine Technology DSTs). Estimates of latitude are significantly poorer than estimates of longitude. Note that Tag 639 consistently performed worse than Tag 633, despite being identical models.

Figure 8.2.3 shows the time series of estimated longitudes for the 2 NMT tags and the 2 Zelcon tags relative to the true position, and the estimated latitude for the 2 Zelcon tags. In general, the NMT DSTs performed better than the Zelcon tags at estimating longitude, and also showed less variability between tags. However, the NMT tag is incapable of providing an estimate of latitude, making this improved performance somewhat moot. As expected, latitude was estimated with considerably greater uncertainty than longitude for the Zelcon tag.

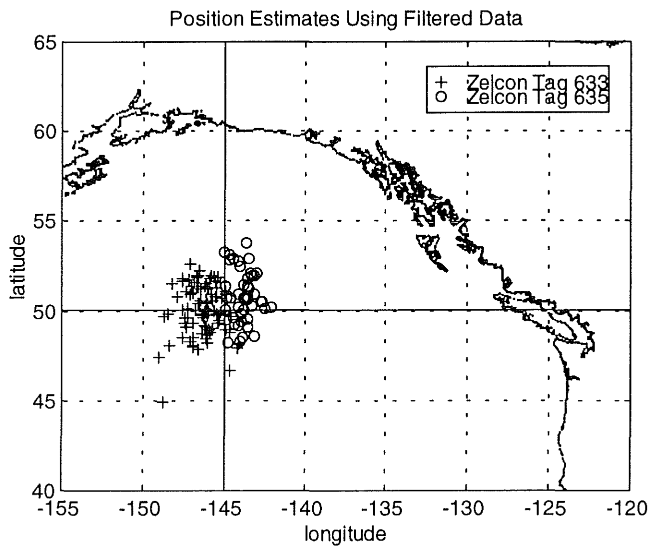
The latitudinal error was very large and was at least partially caused by the ship's movement. Over a day's sailing, the times of dawn and dusk change from those that would be observed for a fixed observer. When a ship heads west, dusk comes later than if the vessel stays at the position where dawn was observed. This effectively increases the length of day and results in an incorrect calculation of the latitude. A similar effect occurs when the vessel heads east, but this time the length of day is reduced. As Figure 8.2.1 indicates, misspecification of the estimated length of day can significantly affect estimates of latitude; however, it is unlikely that this is the full explanation for the variability observed.

An important point that needs to be emphasized is that the two DSTs manufactured by the same company frequently gave very different estimates of geoposition. This was inspite of the light records being treated identically and the light sensors for the DSTs being in close proximity. Thus, some tags are better at recording aspects of the light record that are useful for estimating geoposition than others. Intrinsic variability in the tag's hardware therefore contributes to some of the variability in estimation position that is observed. There is a clear need to be certain that the variability caused by the hardware is reduced substantially prior to moving to ocean tagging experiments where replicate observations are possible.

Although the effect of movement will be smaller for a fish or mammal, which migrates at a slower rate than a fishing vessel, it is still of concern. For a 50 cm salmon migrating due east or west, the change in day length would be one-tenth that observed for the ship, which is still potentially significant. However, the effect can likely be compensated for by estimating the average daily east–west (i.e., longitudinal) component of the migration (calculated over several day's of record), and then applying a correction to the latitude estimates that reflects this expected rate of movement.

<u>Moored Studies (I) - February–August 1996</u>

The second experiment used a fixed ocean subsurface mooring (Station P) to eliminate the bias caused by movement. In addition, sporadic illumination from artificial light sources on the vessel or the presence of mountains on the horizon will disrupt the estimation of the time of sunrise or sunset and are important factors that will degrade the potential accuracy of any tested tag. Station P is located some 1,500 kms offshore in the Gulf of Alaska, at 50°N, 145°W, so the horizon is unobstructed by mountains that could disrupt the time of actual sunrise or sunset. The mooring was located in 4,235 m of water, and rose to 38 m below the surface. As the mooring had no flashing lights or other navigational aids which could influence the light readings, the deployment provides a realistic assessment of the potential accuracy of any DSTs that might be used for studying migrations of Pacific salmon.



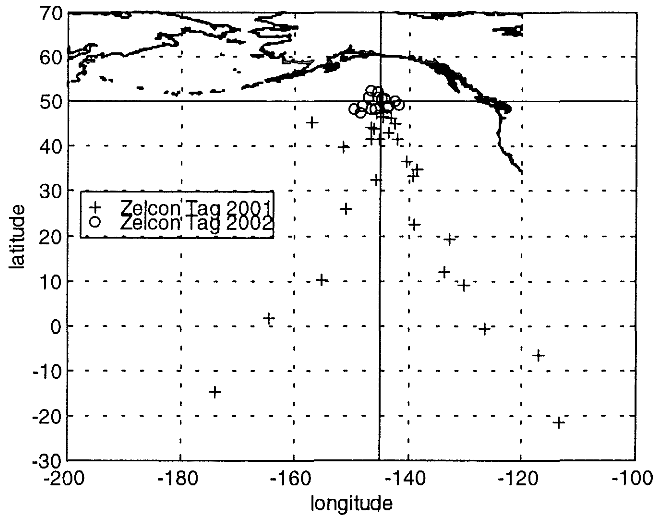


Figure 8.2.4. Comparison of daily estimates of geoposition based on the light record measured and stored in two Zelcon Model 200 DSTs, and two prototype Zelcon Model 2000 DSTs. The DSTs were fixed to the top of a subsurface mooring at Station P (50°N, 145°W; indicated by crosshairs), and the recorded light data used to generate a daily estimate of the DST's position. There are significant errors in the estimated position, and systematic differences between tags. Estimates of latitude are significantly poorer than estimates of longitude. The prototype Model 2000 series tags (2001, 2002) performed worse than the Model 200 tags (633, 635).

Two Zelcon Model 200 DSTs were mounted at the top of the subsurface mooring on 29 February 1996 (these tags had been previously used during the ship experiment described above). Both tags were mounted in a protective PVC sleeve and the light sensors were oriented to be essentially unobstructed by the mooring and located within 4 centimeters of each other. The mooring was retrieved on 20 May 1996, the initial pair of Model 200 tags removed, and two more Model 200 tags fixed to the mooring along with two prototype Zelcon Model 2000 DSTs. The deployment protocols were similar, and care was taken to place the light sensors close together (within 4 centimeters for each pair of tags) and in an unobstructed location. The mooring was retrieved again and the second pair of tags removed on 27 August 1996.

Both sets of Zelcon tags showed significant problems (Figure 8.2.4). The position estimates for the original Model 200 DSTs showed significant variability despite the mooring position remaining fixed. There was also a significant difference between the two tags. If these tags had been fixed to migrating salmon rather than to a fixed position, it likely would have only been possible to resolve the largest scale migration movements of the tagged fish. (Note, however, that in the Northeast Pacific, the SST over the range of estimated positions would probably have only varied by 1°C, so the temperature record would not have done much better at resolving position).

During analysis of the original light records obtained from the ship experiment, the light records from the Model 200 tags were found to contain a large jump in recorded light levels. This was caused by an imperfect automatic switching between a high and low sensitivity recording mode that the manufacturer had implemented to improve the dynamic range of the light sensor. However, during the analysis of the data from the October 1995 vessel experiment it became clear that this technique was potentially the cause of several problems. The prototype Model 2000 tags (serial numbers 2001, 2002) were based on several new technological innovations that included photodiode rather than photoresistor based light sensors, and had been rushed into production partly to meet our deployment schedule. However, despite being located within 4 cms of each other, the two tags again recorded very different light histories and consequently very different positions were estimated from them. Both tags also stopped recording well before the end of the experiment, and in the case of one DST indicated that it had moved into and out of the southern hemisphere during the deployment on the fixed mooring. Thus, neither could be considered sufficiently accurate or reliable for field deployment.

The Zelcon Model 200 DSTs, which were in commercial production, fared better. However, even here the tags showed significant differences in accuracy, with one tag yielding substantially smaller standard deviations on its position estimates (Table 8.2.1). We have not shown standard errors in this table. Although the standard errors on the estimated positions would be impressively small in some cases if we calculated them, these are a measure of the uncertainty in estimating the position of the *fixed* location Station P, from *N* repeated daily positional fixes. The standard error on the estimated position for a moving tag is only based on a single daily observation, and is therefore the same as the standard deviation. As Table 8.2.1 indicates, we found the smallest standard deviations on daily estimates of longitude still ranged from 1–2°, and were obtained by filtering. Minimum standard deviations on estimates of latitude were on the order of 1.4°, and were again obtained by filtering. For the prototype Model 2000 tags, estimates of geoposition were significantly improved using our filtering technique, but were still unacceptably large.

Several minor problems were also noted in the temperature sensors on the Zelcon tags, and a major problem was found with the pressure sensor from one Model 200 DST, which indicated that it was sinking over the duration of the experiment on the fixed mooring. (The other tag indicated a relatively constant depth.) During post-deployment calibration and testing, the tag with an unstable depth record turned out to have a very nonlinear pressure response, with the depth sensor unresponsive to pressure changes in the 0–75 m depth range. This hardware defect was present in a number of tags, but not detected until post-deployment calibration.

From an optimistic viewpoint, the higher accuracy of one tag over the other indicates that there are aspects of the measurement and recording of light which can be further improved with additional R & D work. Identifying the differences in the measuring and recording of light that lead to such different responses from two supposedly identical tags would lead to better insight into what aspects of the light record are most important to record for estimating geoposition, and would likely significantly improve even the better tag. Thus, there are good prospects for a highly accurate tag being available from a different manufacturer now, or being developed in the next year or so. However, from a pessimistic perspective, the large differences in estimated position for supposedly identical DSTs indicates that there are aspects to the technology that are not yet sufficiently resolved for use in field studies of salmon migration.

Table 8.2.1. Comparison of the standard deviations (SD) on estimates of longitude and latitude for the Station P (50°N, 145°W) experiment; errors are expressed in degrees of latitude or longitude. Station P results compare estimates of geoposition based on both the filtered and unfiltered (original) versions of the light records recorded by the Zelcon tags. The results using the unfiltered light measurements were significantly poorer than with the filtering technique described in the text. All geoposition estimates were based on estimating the time of maximal rate of change in light level. A comparison with the performance achieved by estimating the time of the 5 % light level (civil twilight) is not yet complete. Tags 2001, 2002 were prototypes of a new photodiode-based DST, and were not commercially available.

Tag	Begin Date	End Date	# Days		St. Dev. Latitude (degrees)	St. Dev. Longitude (degrees)
NMT (Columbia) 157	283	316	34		NA	2.3
161	283	316	34		NA	2.1
(Ricker) 154	271	295	25		NA	1.8
165	271	295	25		NA	2.1
Zelcon (Columbia) 633	283	316	34		3.8	0.9
639	283	316	34		13.6	3.4
Zelcon (Stn P) 633	506.5	599.5	94	Filtered:	1.4	1.0
				Raw:	2.8	1.1
635	460.5	504.5	45	Filtered:	1.4	0.7
				Raw:	2.0	0.7
2001	506.5	535.5	29	Filtered:	20.9	12.2
				Raw:	52.6	84.7
2002	506.5	521.5	15	Filtered:	1.5	2.2
				Raw:	48.8	61.6

Moored Studies (II) March - June 1996

A third field study involving 6 replicate tags from each of four manufacturers (CEFAS/Lotek, Onset Computers, Star Oddi, and Wildlife Computers (4 DSTs only)) is currently underway. This is part of an INPATE (International North Pacific Archival Tag Evaluation) Working Group project (D.W. Welch, pers. comm.). Tag retrieval from the fixed offshore meteorological mooring is scheduled for the end of June 1997. The CEFAS/Lotek and Wildlife Computer tags used in this study are capable of estimating geoposition and, as described in Section 8.1, are small enough to be of use in salmon migration studies in the ocean. Initial results on the accuracy and precision of these replicate tags are expected by the end of summer 1997, and a recommendation on the choice of a DST for an international tagging programme on Pacific salmon is expected by the fall.

9 PREVIOUS STUDIES USING DATA STORAGE TAGS

Since the mid-1980s when the first archival tags of use for field experiments were developed, there has been a rapid development of the tags making them increasingly useful for practical scientific studies of behaviour and physiology of marine organisms. The first DSTs were big and 'bulky' making them suitable for application only on larger species such as sharks, tunas, and marine mammals. During the last 5–6 years, manufacturers have been striving to miniaturize and diversify both tags and sensors, which is reflected in the growing number of experiments performed on smaller pelagic species (Table 9.1). The first studies using DSTs on salmon were carried out in coastal waters in Iceland in 1993 and yearly since then (Sturlaugsson, 1995b; Sturlaugsson and Thorisson, 1996; Sturlaugsson and Gudbjornsson, 1996). DST studies on salmon have also been carried out in the Baltic Sea (Karlsson *et al.*, 1996) and in Japan (Tanaka, *et al.*, 1996; Ogura, 1997).

10 RECOMMENDATIONS FOR OCEAN EXPERIMENTS USING DSTs

10.1 Tag Developments

It is recommended before DSTs are used that they be tested for accuracy and precision of their functions. Ideally, this should include trials at sea by attaching the tags to moored buoys and to gear towed from research vessels so that the position recorded by the tag can be compared to a known position. Formal links should be established with researchers in the Pacific where tests are currently carried out, to ensure that tag trials are not needlessly duplicated and the information obtained from any tag trial is optimally used.

It is recommended that manufacturers consider tags with an option of conditional sampling to save on memory. (e.g., temperature or light data collected only when the fish was within 5 m of the surface).

It is recommended that manufacturers develop and test tags with geomagnetic field sensors and investigate their use for geolocation. Manufacturers should also maintain close contacts with research groups to ensure that other micro-sensors can be developed for inclusion in tags as technological developments allow.

It is recommended that manufacturers ensure that their tags be built in forms that are negatively buoyant but can withstand pressure at depths up to 3000 m.

10.2 Tests of Tag Attachment Methods

Although DSTs are commercially available, they have not been designed for use on salmon. Although tags are getting smaller as the technology improves, it is still necessary to investigate methods of minimizing the hydrodynamic drag of the tag and optimizing its shape for attachment to salmon for internal and external attachment. The use of towed bodies as an attachment method may be one way of reducing drag. It is recommended that laboratory-based studies in large flume tanks and cages be carried out to determine the effect of tag shape and the different methods of tag attachment on the survival and behaviour of salmon.

10.3 Experimental Design of Ocean Tagging Experiments

It is the opinion of SGOSTE experiments using DSTs in the open sea should be feasible if the information and recommendations presented in this report are followed and appropriate trials prove successful. It is recommended that current studies in the Baltic Sea, where recovery rates tend to be relatively high, should continue. Furthermore, the

Table 9.1. Summary of selected papers on the application of data storage tags (DSTs) in research on marine species.

Species and number tagged with DSTs / number of tags recovered by 1996	Purpose of Experiment	Sensor types	Memory capacity or log time	Life stage	Tag attach-ment	Fish size	Problems encountered	Reference(s)
Salmonids								
Atlantic salmon (*Salmo salar*) 60/30 DSTs	Homing migration in relation to vertical movements and sea temperature	Pressure (depth) and temperature	1980 recordings	Maturing fish	External (dorsal fin)	Range not stated	Not stated	Sturlaugsson, 1995
Atlantic salmon 35/14 DSTs	Detailed study of individual migratory behaviour	Pressure (depth) and temperature	990 h	Maturing fish	External (dorsal fin)	Not stated	Solar heating of tag; Uncertainty of pressure calibration.	Karlsson *et al.*, 1996
Atlantic salmon 70/24 DSTs	Homing migration in relation to vertical movements and sea emperature	Pressure (depth) and temperature	Not stated in abstract	Maturing fish	External attachment	Not stated	Not stated in abstract	Sturlaugsson and Thorisson, 1996
Sea trout (*S. trutta*) 44 DSTs 50 % recovery	Timing of anadromous migrations. Distribution and growth in sea	Pressure (depth) and temperature	Not stated, 5 month recor-ding	4–8 yr. spawners and immature fish	Body cavity or dorsal fin	36.6–66 cm	Tag loss from external DST tagging reported year from tagging	Sturlaugsson and Johansson, 1996, 1997
Atlantic salmon 310/ DSTs sea trout 110 DSTs (No. of tags used in the period, 1993–1996)	Homing/feeding migrations, swimming behaviour, diurnal rhythms, tag development	Pressure (depth) temperature, tilt, angle and salinity	8100 recordings possible 5 months	Maturing & immature fish	Body cavity or dorsal fin	39–96 cm (size at tagging of recaptured fish)	Not stated	Sturlaugsson and Gudbjornsson, 1997
Chum salmon DST number not stated	Thermoregulation and vertical behaviour of homing fish	Time, depth, external temperature	Not stated	Maturing fish	External	Not stated in abstract	Not stated	Tanaka *et al.*, 1996
Chum salmon 10/7,13/1 and 27/12 DSTs Masu salmon 5/0 DSTs	Review of several Japanese experiments: Swimming behaviour in relation to temperature, to coastal fishing gear, environment change, estuarine behaviour	Temperature and depth	Not stated	Homing fish	External	Not stated	Not stated	Ogura, 1997

Species and number tagged with DSTs / number of tags recovered by 1996	Purpose of Experiment	Sensor types	Memory capacity or log time	Life stage	Tag attach-ment	Fish size	Problems encountered	Reference(s)
Salmonids sp.	Review of cur-rent knowledge of DST technology and applications, future developments	Various sensors						Boehlert (Ed.), 1997
Other species								
Atlantic cod *Gadus morhua* *81 DSTs/7*	Horizontal and vertical migrations of spawning cod; evaluation of tag loss and non-reporting rates	Depth and temperature	2 kb 13 months	Spawners	Body cavity	60–119 cm	Infections, abrasions near tag wound Recapture methods insufficient	Thorsteinsson, 1995
Plaice (*Pleuroectes platessa)* *140 DSTs/20 DSTs*	Spawning & feeding migrations, seasonal patterns related to environmental events, migratory models as an aid to stock assessment	Depth and temperature	8 months	Maturing fish	Dorsal attach-ment	> 40 cm	Not stated	Metcalfe *et al.*, 1994,1996
Southern bluefin tuna *Thunnus maccoyii* 157/1 (Data recorded shortly after release)	Lab. exp. for validation of geoposition esti-mates and field trials for assessing tuna movement as an aid to fisheries management	Time, pressure, light intensity, external (water) and internal (body cavity) temperature	256 kb min. 12 months	Immature fish	Body cavity and dorsal attachment	82–100 cm	Low survival of external tagged fish	Gunn *et al.*, 1994
Sharks (Title only)	Review, various purposes							Stevens, 1996
Sharks (Title only)	Individual migratory behaviour							Dulvy and Metcalfe, 1996
Elephant seals *Mirounga angustirostris* (number not stated in abstract)	Recording of pelagic distribution	Geographic location, time/depth	Not stated in abstract		External			DeLong *et al.*, 1992
Elephant seals (Title only)	Population ecology behaviour, physiology							Hill, 1994

information from these studies should be used to aid DST studies in the Atlantic Ocean where recovery rates tend to be lower and in certain instances may restrict experimental studies.

It is recommended that in the North Atlantic, initial trials (Phase 1) with DSTs on salmon should be conducted by tagging reconditioned or wild kelts at several sites around Europe and North America (e.g., experimental rivers in Iceland, Norway, and Newfoundland, and hatcheries in the USA and maritime provinces of Canada).

It is recommended that tagging salmon in the open ocean (in the Labrador Sea and/or Norwegian Sea) should be planned as Phase 2 of the study, to determine the relationship between salmon and marine climate during the post-smolt and adult stages. These should be internationally co-ordinated and jointly funded experiments.

Labrador Sea: Studies have shown that salmon are available in quantities suitable for tagging. The Labrador Sea would be a feasible starting point for these experiments because production of North American origin salmon in relation to thermal habitat, a measure of marine climate, is used by ICES to provide catch advice for fisheries exploiting them in North America and Greenland.

Norwegian Sea: Commercial fisheries have operated in the Norwegian Sea exploiting salmon mainly from European countries. Conventional tagging studies have been conducted in recent years and will provide base-line data for project planning.

West Greenland: The west coast of Greenland is the only area where fish from both North America and Europe are present in reasonable numbers. Conventional tagging studies have been conducted in the past which should provide base-line data for project planning.

Main aim:	Collect information on salmon and its environment in support of pre-fishery abundance prediction that is used as part of a model to provide catch advice on North American and European salmon.
Location of tagging:	Mid -Labrador Sea/ North of the Faroe Islands.
Time of capture/tagging:	Labrador: 3 weeks, from mid-September to October Faroes: November or March
Features of DST:	Geolocation, sea temperature, and pressure (previously tested for reliability and accuracy)
Attachment:	As determined by previous trials
No. of tags to be applied:	~500 per study area

Cost per study (indicative):

Preparatory phase (preparation, arrangement, ordering etc.)	=	$50.000
Tags	=	$500.000
Survey (boat, fishing gear, etc.)	=	$150.000
Evaluation of data (experiment)	=	$100.000
Total cost	=	$800.000

10.4 Co-ordination of Future Work and Maintenance of Links

It is recommended that links be maintained between groups involved in SGOSTE to ensure the optimum co-ordination and collaboration on future studies. The future work programme should be divided between research groups to make optimum use of research funds. For an Ocean Tagging Experiment with DSTs to be successful, collaborative research funding will be required and should be sought.

11 REFERENCES

Some of the references are cited directly in the text while others are included below because they use or report on the tagging of fish with electronic tags. The latter references were included because members of the Study Group thought it worthwhile to have as complete a reference list as possible on the use of electronic tags.

Anon. 1913. Flaschenposten an der deutschen Nordseeküste. Ann. d. Hy Dr Mar. Meteor., 7: 351–360.

Arnold, G.P., Greer, M., Walker, L.S., Emerson, L.S., and Holford, B.H. 1994. Movements of cod (*Gadus morhua* L.) in relation to the tidal streams in the southern North Sea. ICES Journal of Marine Science, 51: 207–232.

Arnold, G.P., and Holford, B.H. 1994. A computer simulation model for predicting rates and scales of movement of demersal fish on the European continental shelf. ICES CM 1994/Mini:17. 16 pp.

Boehlert, G.W. (Ed.) 1997. Application of acoustic and archival tags to assess estuarine, nearshore, and offshore habitat utilization and movement by salmonids. NOAA Technical memorandum. NOAA-TM-NMFS-SEFSC-236. 62 pp.

Brückmann, R. 1919. Strömungen an der Süd- und Ostküste des baltischen Meeres. Forsch. Deutsch. Landes- u. Volkskunde, Band 22, Heft 1.

Carruthers, J.N. 1925. The water movements in the southern North Sea. Part I: The surface drift. Fishery Investigation Series II, VIII (2).

Carruthers, J.N. 1927. Investigations upon the water movements in the English Channel. Summer 1924. J. Mar. Biol. Ass. U.K., 14: 685–721.

DeLong, R.L., Stewart, B.S., and Hill, R.D. 1992. Documenting migrations of northern elephant seals using day length. Mar. Mamm. Sci., 8: 155–159

Dulvy, N., and Metcalfe, J.D. 1996. Data storage tags: individual behaviour-based approaches to migration. Shark News, 7: 10–11.

Dutil, J.D., and Coutu, J.M. 1988. Early marine life of Atlantic salmon, *Salmo salar*, post-smolts in the Northern Gulf of St. Lawrence. U.S. Natl. Mar. Serv. Fish. Bull., 86(2): 197–212.

Ebbesmeyer, C.C., and Ingraham, W.J., Jr. 1994. Pacific toy spill fuels ocean current pathway research. EOS, 75: 425–430.

Gudjonsson, T. 1953. Laxamerkingar 1947–1951 (Tagging of salmon 1947–1951, in Icelandic). Veidimadurinn, 28. 7 pp.

Gudjonsson, T. 1970. The Releases and Returns of Tagged Salmon at Kollafjördur, Iceland. ICES CM 1970/M:6. 6 pp.

Gunn, J.S., Polacheck, T., Davis, T.L., Sherlock, M., and Betlehem, A. 1994. The application of archival tags to study the movement, behaviour and physiology of southern bluefin tuna, with comments on the transfer of the technology to groundfish research. ICES CM 1994/Mini:21. 23 pp (mimeo).

Handeland, S.A., Järvi, T., Fernö, A., and Stefansson, S. 1996. Osmotic stress, anti-predator behaviour, and mortality of Atlantic salmon (*Salmo salar*) smolts. Can. J. Fish. Aquat. Sci., 53: 2673–2680.

Hansen, L.P. 1988. Status of exploitation of Atlantic salmon in Norway, pp. 143–161. *In* Atlantic salmon: planning for the future. Edited by D.H. Mills and D.J. Piggins. Croom Helm, London & Sydney, Timber Press, Portland, Oregon.

Hansen, L.P. 1990. Exploitation of Atlantic salmon (*Salmo salar*) from the River Drammenselv, SE Norway. Fisheries Research, 10: 125–135.

Hansen, L.P. 1993. Movement and migration of salmon at sea, pp. 26–39. *In* Salmon in the sea and new enhancement strategies. Edited by D. Mills. Fishing News Books.

Hansen, L.P., Doving, K.B., and Jonsson, B. 1987. Migration of farmed adult Atlantic salmon with and without olfactory sense, released on the Norwegian coast. Journal of Fish Biology, 30: 713–721.

Hansen, L.P., and Jonsson, B. 1991. Evidence of a genetic component in the seasonal return pattern of Atlantic salmon (*Salmo salar* L.). Journal of Fish Biology, 38: 251–258.

Hansen, L.P., and Jonsson, B. 1991. The effect of timing of Atlantic salmon smolt and post-smolt release on the distribution of adult return. Aquaculture, 98: 61–67.

Hansen, L.P., Jacobsen, J.A., and Lund, R.A. 1993. High numbers of farmed Atlantic salmon, *Salmo salar* L., observed in oceanic waters north of the Faroe Islands. Aquaculture and Fisheries Management, 24: 777–781.

Hansen, L.P., Jonsson, N., and Jonsson, B. 1993. Oceanic migration of homing Atlantic salmon, *Salmo salar*. Animal Behaviour, 45: 927–941.

Hansen, L.P., Reddin, D.G., and Lund, R.A. 1997. The incidence of reared Atlantic salmon in the commercial fishery at West-Greenland. ICES Journal of Marine Science, 54: 152–155.

Hansen, L.P., and Jacobsen, J.A. 1997. Migration and dispersion of Atlantic salmon (*Salmo salar* L.) in the Northeast Atlantic. ICES CM 1997/Assess:10.

Hermann, F., and Thomsen, H. 1946. Drift-bottle experiments in the Northern North Atlantic. Medd. Kom. Danm. Fiskeri- Havunders. Ser Hy Dr, III (4).

Hill, R.D. 1994. Theory of geolocation by light levels. pp. 227–236. *In* Elephant seals, population ecology, behavior and physiology. Edited by B.J. LeBoeuf and R.M. Laws. University of California Press, Berkeley, California.

Hognestad, P.T. 1968. Forsök med strömflaskor i Nord-Norge i 1967. Fiskets Gang, 54: 175–179.

Hognestad, P.T. 1969. Forsök med strömflaskor i Nord-Norge i 1968. Fiskets Gang, 55: 38–44.

Hognestad, P.T. 1970 Forsök med strömflaskor i Nord-Norge i 1969. Fiskets Gang, 55: 841–844.

Hognestad, P.T. 1971a. Forsök med strömflaskor i Nord-Norge i 1970. Fiskets Gang, 57: 128–131.

Hognestad, P.T. 1971b. Forsök med strömflaskor i Nord-Norge i 1971. Fiskets Gang, 57: 847–851.

Hognestad, P.T. 1972 Forsök med strömflaskor i Nord-Norge i 1972. Fiskets Gang, 59: 289–293.

Hognestad, P.T. 1974. Forsök med strömflaskor i Nord-Norge i 1973. Fiskets Gang, 60: 347–349.

Holm, M., Holst, J.C., and Hansen, L.P. 1996a. Sampling Atlantic salmon in the North East Atlantic during summer: methods of capture and distribution of catches. ICES CM 1996/M:12. 12 pp.

Holm, M., Holst, J.C., and Hansen, L.P. 1996b. Distribution of Atlantic salmon in the open sea. Preliminary results of the "Mare Cognitum" research programme in the Norwegian Sea and adjacent areas. The Salmon Net, 27: 27–30.

Holst, J.C., Hansen, L.P., and Holm, M. 1996. Observations of abundance, stock composition, body size, and food of post-smolts of Atlantic salmon caught in the North East Atlantic during summer. ICES CM 1996/M:4. 15 pp.

ICES. 1997. Report of the Working Group on North Atlantic Salmon. ICES CM 1997/Assess:10.

Jacobsen, J.A., and Hansen, L.P. 1996. The food of Atlantic salmon, *Salmo salar* L., north of the Faroe Islands. ICES CM 1996/M:10. 21 pp.

Jonsson, B., Jonsson, N., and Hansen, L.P. 1991. Differences in life history and migratory behaviour between wild and hatchery reared Atlantic salmon in nature. Aquaculture, 98: 69–78.

Jonsson, N., Hansen, L.P., and Jonsson, B. 1991. Variation in age, size and repeat spawning of adult Atlantic salmon in relation to river discharge. Journal of Animal Ecology, 60: 937–947.

Jonsson, N., Jonsson, B., and Hansen, L.P. 1997. Changes in proximate composition of energetic costs during upstream migration and spawning in Atlantic salmon, *Salmo salar*. Journal of Animal Ecology, 66: 425–436.

Karlsson, L., Ikonen, E., Westerberg, H., and Sturlaugsson, J. 1996. Use of data storage tags to study the spawning migration of Baltic salmon (*Salmo salar* L.) in the Gulf of Bothnia. ICES CM 1996/M:9. 15 pp.

Klimley, A.P., and Holloway, C. 1997. Benchmark tests of accuracy of two archival tags, p. 34. *In* Application of acoustic and archival tags to assess estuarine, nearshore, and offshore habitat utilization and movement by salmonids. Ed. by G.W. Boehlert. NOAA-TM-NMFS-SWFSC-236.

Lacroix, G.L., and McCurdy, P. 1996. Migratory behaviour of post-smolt Atlantic salmon during initial stages of seaward migration. J. Fish. Biol., 49: 1086–1101.

McKinnell, S. 1995. Age-specific effects of sockeye abundance on adult body size of selected British Columbia sockeye stocks. Can. J. Fish. Aquat. Sci., 52: 1050–1063.

McKinnell, S., Pella, J.J., and Dahlberg, M.D. In press. Population-specific Aggregations of steelhead trout (*Oncorhynchus mykiss*) in the North Pacific Ocean. Can. J. Fish. Aquat. Sci.

Metcalfe, J.D., Arnold, G.P., and Holford, B.H. 1994. The migratory behaviour of plaice in the North Sea as revealed by data storage tags. ICES CM 1994/ Mini:11. 8 pp. (Mimeo.)

Metcalfe, J.D., Arnold, G.P., and Holford, B.H. 1996. Studies of plaice migration in the open sea using new electronic data storage tags. Book of abstracts. Fifth European Conference on Wildlife Telemetry. Strasbourg, France, 25–30 August 1996. 1 pp.

Mills, D.H. 1989. Ecology and management of Atlantic salmon, p. 351. Chapman and Hall, Ltd.

Møller Jensen, J. 1980. Recaptures from international tagging experiments at West Greenland. *In* ICES/ICNAF Joint Investigation on North Atlantic Salmon. Rapp. et Proc. Verb. des Réunions, 176: 122–135.

Ogura, M. 1997. Acoustic and archival tagging work on salmonids in Japan, pp. 16–27. *In* Application of acoustic and archival tags to assess estuarine, nearshore, and offshore habitat utilization and movement by salmonids. Edited by G.W. Boehlert. NOAA Technical memorandum. NOAA-TM-NMFS-SEFSC-236. 62 pp.

Olsson, B. 1968. Report on Investigations of some Drift Bottles in the Baltic. Medd. Havsfiskelab., Lysekil. Nr. 57.

Reddin, D.G. 1985. Atlantic salmon (*Salmo salar* L.) on and east of the Grand Bank. J. Northw. Atl. Fish. Sci., 6: 157–164.

Reddin, D.G., and Lear, W.H. 1990. Summary of marine tagging studies of Atlantic salmon (*Salmo salar* L.) in the northwest Atlantic area. Can. Tech. Rep. Fish. Aquat. Sci., 1737: iv + 115 pp.

Reddin, D.G., and Short, P.B. 1991. Post-smolt Atlantic salmon (*Salmo salar*) in the Labrador Sea. Can. J. Fish. Aquat. Sci., 48: 2–6.

Reddin, D.G., and Downton, P.R. 1994. Status of Atlantic salmon (*Salmo salar* L.) in Campbellton River, Notre Dame Bay (SFA 4), Newfoundland in 1993. DFO Atlantic Fisheries Res. Doc. 94/86. 28 pp.

Richard, J. 1900. Resultats des Campagnes de S.A.S. le Prince de Monaco. Exposition Universelle de 1900.

Ruggles, C.P., and Ritter, J.A. 1980. Review of North American salmon to assesss the Atlantic salmon fishery off West Greenland. *In* ICES/ICNAF Joint Investigation on North Atlantic Salmon. Rapp. et Proc. Verb. des Réunions, 176: 82–91.

ANNEX 1

LIST OF PARTICIPANTS

Name	Address	Telephone	Fax	Email
Dave Reddin Co-chair	Dept of Fisheries & Oceans P.O. Box 5667 St. John's, NF Canada A1C 5X1	+1 709 772 4484	+1 709 772 3578	reddin@athena.nwafc.nf.ca
Johannes Sturlaugsson Co-chair	Institute of Freshwater Fisheries Vagnhöfda 7 112 Reykjavik Iceland	+354 567 6400	+354 567 6420	johannes.sturlaugsson@itn.is
Kevin Friedland	Northeast Fisheries Science Centre NMFS/NOAA Woods Hole MA 02543 USA	+1 508 495 2369	+1 508 495 2147	kevin.friedland@noaa.gov
Lars Petter Hansen	Norwegian Institute for Nature Research Tungesletta 2 7005 Trondheim Norway	+47 735 80500	+47 739 15433	lars.petter.hansen@nina.nina.no
Marianne Holm	Institute of Marine Research P.O. Box 1870 Nordnes 5024 Bergen Norway	+47 55 23 68 92	+47 55 23 69 01	marianne.holm@imrno
Jan Arge Jacobsen	Fiskirannsóknarstovan P.O. Box 3051, Noatún FR–110 Tórshavn Faroe Islands Denmark	+298 15092	+298 18264	janarge@frs.fo
Lars Karlsson	Salmon Research Institute 814 94 Älvkarleby Sweden	+46 2677150	+46 2677160	employee@lfi.se
Andy Moore	Centre for Environment, Fisheries & Aquaculture Sciencel Lowestoft Laboratory Pakefield Road, Lowestoft Suffolk NR33 0HT UK	+44 1 502 524260	+44 1 502 524260	a.moore@cefas.co.uk
Ted Potter	Centre for Environment, Fisheries & Aquaculture Science Lowestoft Laboratory Pakefield Road, Lowestoft Suffolk NR33 0HT UK	+44 1 502 524260	+44 1 502 524260	e.c.e.potter@cefas.co.uk
Mike O'Connell	Dept of Fisheries & Oceans P.O. Box 5667 St. John's, NF A1C 5X1 Canada	1 709 772 2866	1 709 772 3578	oconnell@athena.nwafc.nf.ca
Dave Welch	Dept. of Fisheries & Oceans Pacific Biological Station Nanaimo, BC V9R 5K6 Canada	1 250 756 7218	1 250 756 7333	welchd@pbs.dfo.ca

Name	Address	Telephone	Fax	Email
Håkan Westerberg	Institute for Coastal Research Nya Varvet 31 S-426 71 V Frölunda Sweden	+46 31 697822	+46 31 691109	h.westerberg@fiskeriverket.se
Fred Whoriskey	Atlantic Salmon Federation Box 429 St. Andrews, NB E0G 2X0 Canada	+1 506 529 1039	+1 506 529 4985	atlsal@nbnet.nb.ca

Schultz, B. 1935. Flaschenpostenuntersuchungen im südlichen Kattegatt, 10 bis 17 August 1931. Ann. d. Hy Dr Mari. Meteor., LXIII (1): 1–10.

Schultz, B. 1936. Die Ergebnisse der internationalen hydrographischen Beobachtungen im Kattegatt im August 1931. Rapp. p.-v. Reun., XCV.

Stevens, J. 1996. Archival tagging of sharks in Australia. Shark News, (7) 10.

Sturlaugsson, J. 1994. The food of ranched Atlantic salmon post-smolts (*Salmo salar* L.) in coastal waters, West Iceland. Nordic Journal of Freshwater Research, 69: 43–57.

Sturlaugsson, J. 1995a. Notkunarmöguleikar íslenskra rafeindafiskmerkja viðrannsóknir á fari og vexti laxa í sjó. (The possible usage of data storage tags to study the migration and growth of salmon in sea - in Icelandic). Institute of Freshwater Fisheries Research, res. report. VMST-R/95007. 12 pp.

Sturlaugsson, J. 1995b. Migration Study on Homing of Atlantic salmon (*Salmo salar* L.) in Coastal Waters West Iceland - Depth movements and sea temperatures recorded at migration routes by data storage tags. ICES CM 1995/M:17. 13 pp.

Sturlaugsson, J. 1996. Measuring tags and their application in Iceland. Institute of Freshwater Fisheries Research, Anniversary Conference, September 26, Book of Abstracts. (Abstract.)

Sturlaugsson, J., and Thorisson, K. 1995a. Notkun mælimerkja við rannsóknir á gönguhegðun laxa á grunnsævi undan Vesturlandi. (Data storage tags used to study the migratory pattern of homing salmon in coastal areas W-Iceland - in Icelandic). Veidimadurinn., 147: 26–39.

Sturlaugsson, J., and Thorisson, K. 1995b. Post-smolts of ranched Atlantic salmon (*Salmo salar* L.) in Iceland: II. The first days of the sea migration. ICES CM 1995/M:15. 17 pp.

Sturlaugsson, J., and Thorisson, K. 1995c. Post-smolts of ranched Atlantic salmon (*Salmo salar* L.) in Iceland: III. The first food of sea origin. ICES CM 1995/M:16. 18 pp.

Sturlaugsson, J., and Thorisson, K. 1996. Depth movements of homing Atlantic salmon (*Salmo salar* L.) in coastal waters W- Iceland, in relation to environmental factors. Book of abstracts. Fifth European Conference on Wildlife Telemetry. Strasbourg, France, 25–30 August 1996. 1 p.

Sturlaugsson, J., and Johannsson, M. 1996a. Migratory pattern of wild sea trout (*Salmo trutta* L.) in SE-Iceland recorded by data storage tags. ICES CM 1996/M:5. 16 pp.

Sturlaugsson, J., and Gudbjornsson, S. 1997. Tracking of Atlantic salmon (*Salmo salar* L.) and sea trout (*Salmo trutta* L.) with Icelandic data storage tags, pp. 52–54. *In* Application of acoustic tags and archival tags to assess estuarine, nearshore, and offshore habitat utilization and movement by salmonids. Edited by G.W. Boehlert. NOAA Technical Memorandum. NOAA-TM-NMFS-SWFSC-236. 62 pp.

Sturlaugsson, J., and Jóhannsson, M. 1997. Migration study of wild sea trout (*Salmo trutta* L.) in SE-Iceland: Depth movements and water temperatures recorded by data storage tags in freshwater and marine environment. Proceedings of Fifth European Conference on Wildlife Telemetry. Strasbourg, France 25–30 August 1996. In print.

Swain, A. 1980. Tagging of salmon smolts in European rivers with special reference to recaptures off West Greenland in 1972 and earlier years. *In* ICES/ICNAF Joint Investigation on North Atlantic Salmon. Rapp. et Proc. Verb. des Réunions, 176: 93–113.

Tait, J.B. 1948. Hydrography: Scottish Investigations. Ann. Biol., V: 53–56.

Tait, J.B. 1949. Hydrography. Ann. Biol., VJ: 83–87.

Tait, J.B. 1950. Hydrography. Ann. Biol., VII: 69–72.

Tait, J.B. 1951. Hydrography: Northern North Sea and Approaches. Ann. Biol., IIX: 94–98.

Tait, J.B. 1952. Hydrography: Northern North Sea and Approaches. Ann. Biol., IX: 95–99.

Tait, J.B. 1953. Hydrography: Northern North Sea and Approaches. Ann. Biol., X: 82–84.

Tait, J.B. 1954. Hydrography: Northern North Sea and Approaches. Ann. Biol., XI: 33–34.

Tait, J.B. 1955. Hydrography: Northern North Sea and Approaches. Ann. Biol., XII: 58–59.

Tanaka, H., Tkagi, Y., Yokosawa, Y., and Naito, Y. 1996. Vertical movements and behavioural thermoregulation for adult Chum salmon during homing migration in coastal waters. Book of abstracts. Fifth European Conference on Wildlife Telemetry. Strasbourg, France, 25–30 August 1996. 1 p.

Thorsteinsson, V. 1995. Tagging experiment using conventional tags and electronic data storage tags for the observations of migration, homing and habitat choice in the Icelandic spawning stock of cod. ICES CM 1995/B:19. 16 pp.

Thorisson, K., and Sturlaugsson, J. 1995a. Post-smolts of ranched Atlantic salmon (*Salmo salar* L.) in Iceland: I. Environmental condition. ICES CM 1995/M:10. 9 pp.

Thorisson, K., and Sturlaugsson, J. 1995b. Post-smolts of ranched Atlantic salmon (*Salmo salar* L.) in Iceland: IV. Competitors and predators. ICES CM 1995/M:12. 9 pp.

Tomczak, G. 1964. Investigations with drift cards to determine the influence of the wind on surface currents, pp. 129–139. *In* Studies on oceanography. Dedicated to K. Hidaka. Tokyo.

Welch, D.W., Ishida, Y., and Nagasawa, K. 1997. Thermal limits and ocean migrations of Pacific salmon: long-term consequences of global warming. Canadian Journal of Fisheries & Aquatic Sciences.

Welch, D.W., Ishida, Y., and Nagasawa, K. In press. Thermal limits on the ocean distribution of steelhead trout (*Oncorhynchus mykiss*). North Pacific Anadromous Fish Commission Bulletin. 'Assessment and Status of Pacific Rim Salmonid Stocks'.