Living Resources Committee

ICES CM 1998/G:17

REPORT OF THE

STUDY GROUP ON OCEAN SALMON TAGGING EXPERIMENTS WITH DATA LOGGING TAGS

By Correspondence

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1 INTRODUCTION

1.1 Main Tasks

The Study Group on Ocean Salmon Tagging Experiments with Data Logging Tags will continue it's work under the co-chairmanship of Mr D. G. Reddin (Canada) and Mr J. Sturlaugsson (Iceland) and will work by correspondence in 1998 to:

a) consider any new information that would aid in designing experiments to tag salmon with data logging tags;

b) provide detailed proposal(s) for possible small scale pilot studies that would provide the essential background information for a new tagging study, i.e., could include studies on tag reliability, tag attachment, recovery techniques, etc; and,

c) provide a detailed proposal for a possible collaborative international project to study the distribution, movements and/or behaviour of salmon in the sea using data storage tags with best estimates of time scale, costing and participation.

The Study Group will report on progress at the 1998 Annual Science Conference.

1.2 Participants

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A full address list for the participants is provided in Appendix 1.

This report is considered partly as an update to the 1997 Report of the Study Group on Ocean Salmon Tagging Experiments with Data Logging Tags (ICES CM 1997/M:3) and consequently, this report and the 1997 report should be considered jointly.

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 solely on DSTs.

2.2 Purpose of Experiments

In recent years, many Atlantic salmon stocks have experienced significant declines in returns and return rates which is all the more puzzling as ocean exploitation rates have also been declining. These declines have raised concerns in both scientific and fishing communities and learning the cause of at sea mortality is very important. Although the causes of declining stocks are undoubtedly varied and complex; causative factors could include habitat degradation in freshwater and in the sea, climate variability, and variable ocean conditions. As recommended in last years report (ICES 1997/M:3), internationally co-ordinated DST experiments on salmon at sea could provide answers to questions on long-term declines. In order for these at sea experiments to be completely successful, DST studies using geolocation sensors should be linked with earth observation satellite data to discern habitat selection by salmon.

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 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 N 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 & 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 temp might provide position)
Geomagnetic heading
Position (interpreted from 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 sea surface temperature (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 shows the potential importance of DSTs in studies on salmon in the sea (Sturlaugsson 1995a and b; Karlsson *et al.* 1996; Sturlaugsson and Thorisson 1997). 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 recovered.

Mills (1989) separates Atlantic salmon after they have left freshwater as smolts into 3 main groups: postsmolt, 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). Postsmolt 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. Postsmolts have been caught in sufficient numbers at several locations in the Northwest (Reddin and Short 1991) and 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 NEW INFORMATION ON DATA STORAGE TAGS

4.1 Manufacturers of DSTs

This section contains information available up to mid-1998 on Data Storage or Archival tags developed and/or produced by the following manufacturers and research groups (Table 4.1.1)

4.2 Types and Functions of DSTs

In order to compare the advantages and characteristics of the data logging tags, DSTs are listed separately for each manufacturer. Each manufacturer's tags and their use in studies on animals is followed up with tables in which the basic details of each type are explained. Included in the tables is information related to the available tags and the tags already in development that will be released in the time interval 1999–2001. Little information has been obtained from commercial manufacturers on the price of DSTs. However, the prices obtained from two manufacturers given an indication of the range. For an order of 100–400 tags, the price per tag is 1100–1200 $ for available DSTs from Wildlife Computers and 200–300 $ for available DSTs from Star Oddi. Star Oddi have also indicated that the tags that they are currently developing will cost 150–300 $ for DSTs and will be released in 2000–2001 by Star Oddi.

4.2.1 Alec Electronics Co., Ltd. - DSTs

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. The recorders have been used externally as DSTs to study the movements of turtles and yellowtail tuna. These DSTs are relatively large and may not be suitable on smaller fish (Table 4.2.1).

4.2.2 University of Birmingham, England - DSTs

A range of implantable data logging systems for heart rate and body temperature have 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 physiology and energetics of seals, penguins and albatross, and in the high Arctic they have been used on barnacle geese and eider ducks. They have also been used in laboratory work to study the relationship between oxygen consumption and heart rate in birds and fur seals.

A new data storage tag has now been deployed that is even smaller, despite having a depth sensor in addition to multiple temperature sensors and heart rate sampling (Table 4.2.2). These DSTs are not commercial and non of them have so far been used on fish.

4.2.3 CEFAS/Lotek - DSTs

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 models are marketed by Lotek as the LTD_100 and LTD_20 Data storage tag with sensors for temperature, depth and ambient light. The light level measurement enables geolocation by processing the light intensity data. The LTD_100 tag has been used on plaice and cod. The features of the LTD series tag available now and also the next LTD generation are suitable for salmon tagging (Table 4.2.3).

4.2.4 Driesen + Kern GmbH - DSTs

Driesen + Kern GmbH has developed a wide range of miniature data loggers for zoological and biological applications. Some of the products are to big for the Atlantic salmon such as the quite advanced Tracking Recorder DK 600.

The data storage tags from Driesen + Kern that can be used on Atlantic salmon are of two types. The first is the Pillbox-Logger that has been used to record temperature inside the stomach of various animals like penguins and cormorants.

The other DST type comes from the Animal-Trackers DK 550 series but this tag has been developed for aquatic and animals. It can record temperature, pressure (depth or height), light (geolocation) and the animals activity (pitch and roll) altogether (Table 4.2.4).

4.2.5 National Institute of Polar Research - DSTs

National Institute of Polar Research has developed a micro-data loggers to obtain information about behaviour, ecology and physiology of animals under natural condition. These DSTs has successfully obtained data on swim depth, temperature (core and ambient), swim velocity and heart rates from marine mammals, diving birds, reptiles and fishes. The tags are not commercial but the size of these tags enables them to be used on Atlantic salmon (Table 4.2.5).

4.2.6 Northwest Marine Technology Inc. - DSTs

The NMT Archival tag has been developed principally as a position-fixing tag for large marine animals that are migrating over long distances. The tag records internal and external temperature, depth and light intensity. The light intensity is used to extract the times of sunrise and sunset on a daily basis and to calculate the longitude value from that information. Parallel navigational information from external temperature measurements at standard depths are used to calculate latitude. The tag has been used in studies on tuna and then it was implanted either in the body cavity or in muscle.

The tag has a series of different data recording methods and primary data processing for position fixing in the tag itself to allow better use to be made of data memory (Table 8.2.6). This allows it to keep a separate compact log of daily position which will be returned complete for a mission of any length, no matter what other recording choices are made.

Next generation of NMT Archival tag is considerably smaller, allowing the possibility of tagging smaller salmon than the previous version enables (Table 4.2.6).

4.2.7 Onset Computer Corporation - DSTs

Onset Computer Corporation has developed loggers primarily to measure water temperature. These loggers has also been used as DSTs in studies on animals, i.e., alligators, turtles, snakes and ground squirrels. The size of the smallest logger the Stow Away TidbiT enables to use it on salmon (Table 4.2.7).

4.2.8 Star Oddi - DSTs

Star Oddi data storage tags were the first DSTs used on salmon (free ranging fish) to study their sea migration (May-July 1993/DST-Prototype and May-August 1994/DST100). Star Oddi has two small data storage tags (DST200 and DST300), for use on marine animals. The larger tag (DST200) records temperature, pressure and salinity in relation to time. The smaller tag (DST300) records temperature, depth and tilt in relation to time.

The Star Oddi tags have been used successfully in external and internal applications to record the changes in temperature, pressure and salinity experienced by Atlantic salmon, sea trout (*Salmo trutta* L.), and anadromous arctic charr (*Salvelinus alpinus* L.) moving through coastal waters, estuaries, in rivers and lakes and by cod and plaice (*Pleuronectes Platessa*) 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. In addition to this these tag types have been used on green turtle (*Chelonia mydas*) and successful recaptures of DST tagged spider crab (*Maja squinado*) in Spanish coastal waters and DST tagged Puffin (*Fratercula arctica*) have also given very interesting results.

The Star Oddi DSTs are unique in relation to their smallness. This enables a researcher to tag fish species/sizes not possible to tag in reasonable way with the other (bigger) tag types and at the same time includes wide range of different parameter sensors (Table 4.2.8).

4.2.9 Vemco - DSTs

The Vemco Minilog TDR and TDX data loggers has been developed to record time, depth and temperature. Also available from the Minilog series are loggers that solely measure temperature (TR, TX and 12T). Loggers from the Minilog series have been used on Atlantic salmon (Table 4.2.9).

A CHAT tag is now in development by Vemco that is miniature of the CHAT tag now available for sharks/large fish. This interesting tag is combination of data storage tags and acoustic reprogramming and downloading of data.

4.2.10 Wildlife Computers - DSTs

Wildlife Computers Timed Data Recorders (TDRs) and Satellite-linked Timed Data Recorders (SDRs) have been designed specifically for marine wildlife research. Depending upon the model chosen, data on depth, water temperature, heart rate, swimming velocity and light intensity may be recorded.

The SDRs tags are still much too large to be used on Atlantic salmon. These tags have interesting features that in the long run may be suitable for migration studies on relatively small fishes. The pop-up technique enables the release of the SDR from the fish, allowing the tag to float on the sea surface. The tag transmits data to the Service Argos satellite system. These data contain summarised depth, temperature and light level readings. The received data are processed to provide depth and temperature profiles, as well as a track of the migration of the fish (using geolocation techniques). This technique has successfully introduced a new data receiving method into the research field of fishes, as studies on tuna has shown.

The TDRs and SDRs have been used successfully in studies of phocids and otariids, cetaceans, penguins, sea turtles and sharks. The new TDR model Mk7 series tags is also suitable for use on many relatively small fish, such as on Atlantic salmon (Table 4.2.10), because of their size. The Mk7 have successfully been deployed in bluefin tuna.

4.3 Size and weight of DSTs

The size (volume) and weight of DSTs is an important factor when planning a tagging programme on salmon of a given life stage/size class/migration stage. In order to simplify comparison between different tag types, their size (different parameters) and weight were plotted for available DSTs (Table 4.3.1) and for DST in development that will be released in 1999–2001 (Table 4.3.2). The tag/fish weight (in air) ratio has been one of the estimates used to check whether tags are within tolerable weight (size) to be used for given fish weight (size). Therefore this ratio is shown for each type of DST in the tables in section 4.2. The Tables show the size of the smallest fish that could be tagged for given tag weight as percentage of fish weight (1%, 2% and 4%). The tag/fish weight ratio can vary considerably between fish species or life stages due to factors such as the shape of the fish and/or its migration pattern or swimming speed.

The effects of transmitting tags on the behaviour and growth of fish have been compared to control groups. These studies have shown that tags weighing 2- 5% of fish weight can be used without effecting the fish (Lawson and Carey 1972; Moore *et al.* 1990). Larger tags (e.g., > 5% of body weight) can sometimes be used without detectable problems if the fish is given longer time to recover after tagging in order to stabilize their bouyancy (Moser *et al.* 1990).

The tag/fish weight ratio in DST tagging of salmonids in Icelandic waters in 1994–1998 have been in the range 0.1–0.8% for salmon, 0.3–3.0% (0.4–1.1% for internal tagging) for sea trout and 0.7–2.3% for sea char. Recapture rates were high for all these fish species and growth rates for the tagged fish (sea trout and char) were normal (Sturlaugsson 1995; Sturlaugssons and Thorisson 1996; Sturlaugsson and Thorisson 1997; Sturlaugsson and Johannsson 1996; Sturlaugsson and Johannson 1998; Sturlaugsson and Johannson 1998; Sturlaugsson *et al.* 1997; Sturlaugsson *et al* 1998. Sturlaugsson unpublished data).

There is tendency for the smallest electronic tags to be more dense (heavier per volume) as a result of the better packaging of the electronics. This must be borne in mind when considering the size of fish that can be tagged. In future work on the suitability of tags for particular fish, additional parameters should be considered in addition to the tag/fish weight relationship. These should include the volume (bouyancy), length and diameter.

4.4 Possible sources of error in DSTs

An example of possible sources of error in DSTs is from solar radiation and in some cases seems to have been overlooked in most of the current commercial DSTs. This is particularly relevant for external attachment of the tag and for fish like salmon that stay close to the surface. Solar heating as a source of error can be eliminated completely by internal attachment of the DST. However, where external DSTs are used, errors of more than 1°C may arise due to solar heating and this will be of particular importance if temperature is also used for positioning.

Solar heating may occur when the electronics are placed in a transparent housing or in a transparent epoxy compound. This allows daylight to impinge on the circuit board where it is absorbed artificially increasing temperature above ambient. The heat conduction to the water may, however, be low, and considerable excess temperature can develop before equilibrium is reached.

Several trials have been made with Star-Oddi and Lotek DSTs both of which demonstrated the effect of solar heating. Errors of the order 1°C were found in both designs even at low sun altitude and with a light cloud cover. The experiments were made with the tags close to the surface, and the effect will evidently decrease with depth. Essentially the heating will be proportional to the total downward irradiance in the visible light range. In clear ocean water, solar heating is will be reduced to 50% of the surface value at approximately 12 m depth and to 10% at 35 m. In relatively clear coastal water, the corresponding depths are 3 and 12 m, respectively (Jerlov 1968). In summary, solar heating should be kept in mind as a possible source of error and can be completely eliminated by internal placement of the DST.

5 SMALL SCALE PILOT PROJECTS

5.1 Introduction

The SGOSTE has been asked (terms of reference - b.) *to provide detailed proposal(s) for possible small scale pilot studies that would provide the essential background information for a new tagging study, i.e., could include studies on tag reliability, tag attachment, recovery techniques,* etc. DSTs are a relatively new technology and have yet to be used extensively on salmonids; although they have been employed in a number of studies of salmon, sea trout, sea char and marine species. A number of small-scale pilot projects will therefore be required to provide background information before larger-scale experiments can be planned.

DSTs have the potential to reveal important information on salmonid movement and habitat utilisation in the sea. However, there are many concerns that must be taken into account for these tagging experiments to succeed. One of the fundamental requirements for determining the numbers of fish to be tagged with DSTs is the recovery rate. There are few data on expected return rates from potential tagging sites, particularly in view of the decline in marine survival and the reduction in fisheries in many areas. As a result, dummy tagging studies will be required as a precursor to the full-scale programme.

It is also important that the most appropriate type of DST is selected to the fit the goals of the study. Tags of the types used must be able to measure the required parameters with the appropriate accuracy and precision and so detailed tests will be needed before deployment. The capability of the fish to carry the tag and how it is attached to the fish will also need to be tested. The effects of the tag and tagging operation on the fish should therefore be evaluated and the appropriate protocols established to minimise mortalities and maximise returns.

5.2 Experimental designs

5.2.1 Recovery rates for various tag attachment techniques

Objective: To determine whether internal or external tag attachment provides a higher rate of recapture for DSTs.

Background: In 1998, in the Northwest Atlantic Ocean, commercial fisheries in Greenland, Labrador and Newfoundland were closed or under moratoria and the fishery in Quebec was subject to a voluntary license buy-out leaving only the small fishery at St. Pierre et Miquelon (ICES 1998/ACFM:15). This decline in ocean fisheries will result in tag recoveries being largely dependent on salmon returning to enumeration facilities, caught as a bycatch in non-salmon ocean fisheries and caught in angling-based recreational fisheries. In Europe, exploitation at sea occurs in Ireland, Scotland, England and Norway and in many rivers by various fisheries and gears. Exploitation overall in Europe has also declined in recent years due to buyouts of licenses, quota reductions and compensation to fishers not to fish (ICES 1998/ACFM:15). Thus, experiments to investigate return rates are essential if the information derived from ocean DST experiments is to be maximised.

Experimental Design: Salmon for tagging are obtained from gillnets or the appropriate gear for the particular site. Salmon randomly selected for tagging with externally and internally placed DSTs. Dummy tags can be used to reduce costs. Return rates from internal vs external are compared.

Location: Labrador Sea/Norwegian Sea to determine what rates of recovery would be or land-based at enumeration facilities could be used to determine mortality rates from tag application and subsequent loss.

Dates: adult salmon for experimentation can be obtained in most months in the Labrador and Norwegian seas. Postsmolts can be readily captured in the summer in the Norwegian Sea and in the Labrador Sea from late summer to early fall.

Number to be tagged: 100 internal and 100 externally attached DST or dummy tags.

Estimated cost (indicative):

Ship time = $ 300 000

Tags = $ 10 000 (if dummy tags used)

Total cost = $ 310 000

Ship time may be an indirect cost as most countries have fisheries research vessels that could be allocated to this project.

5.2.2 Assessment of fisheries independent recoveries

Objective: To assess if the magnitude of recoveries using buoyant tags would be sufficient in number to provide results from ocean DST tagging without the need for recoveries from fisheries.

Background: Reductions in ocean fisheries require that alternate non-fishery based recovery techniques be pursued. One possibility mentioned in last years report was to develop buoyant tags. Buoyant tags should be released from research vessels over as wide a geographic area as possible to assess recovery rates from stranding on beaches. In order to reduce costs, tags that look and behave like actual DSTs, i.e., with a similar shape, configuration and buoyancy but do not carry instrumentation should be used.

Experimental design: Buoyant tags without sensors should be used to reduce costs and piggy-backed on available research vessels to further reduce costs.

Location: Labrador Sea/Norwegian Sea as they are the most likely places for a large-scale DST experiment.

Dates: adult salmon for experimentation can be obtained in most months in the Labrador and Norwegian Seas. Postsmolts can be readily captured in the summer in the Norwegian Sea and Labrador Sea from late summer to early fall. Dates for dummy tag release should be similar to those that would be selected for at sea DST studies.

Number to be tagged: 500 DST dummy tags

Estimated cost (indicative):

Tags = $ 10 000

Total cost = $ 10 000

5.2.3 Benchmark testing DSTs

Background: The accuracy, precision, and reliability of DSTs since most are relatively new products are unknown. This is especially true for geolocation DSTs which have been shown to be very inaccurate (ICES 1997/M:3). In last year's report, it was recommended that all parameters measured by DSTs should be tested for accuracy, precision, and reliability before use. Geolocating tags which typically add light as a measured parameter and then derive location by an algorithm based on time and day length (measuring sunrise and sunset) are the best available option in open ocean for measuring migration and habitat preference of salmon. Due to DST sizes, geolocation based on light recording is the best option in studies on relatively large salmon that can carry such tags but postsmolts (< 40–45 cm in length) and smolts have to depend on DSTs that record temperature and depth.

A. Environmental functions

Objective: To test DSTs for accuracy, precision and reliability of measured functions, i.e. temperature and salinity.

Experimental design: Tags from a single or several manufacturers are attached to test instrumentation on a navigation buoy or some in water structure such as a flume tank or fluvarium where temperature and other parameters can be independently measured. When recovered the data stored on the DST is extracted and compared to known data from the same position. The instrumentation used for comparison must be of known accuracy and precision, i.e., Hugrun for testing of water temperature or the Sea Bird CTD system for temperature and salinity.

Location: Land-based tanks suitable for holding salmon for at least 6 months and up to one year if possible. An example of one such facility is the Fluvarium in St. John's, Newfoundland.

Number to be tagged: 6 tags per manufacturer.

Estimated cost (indicative):

Tags = $ 5 000

Total cost = $ 5 000

B. Geolocation

Objective: To test DSTs for accuracy, precision and reliability of geolocation.

Experimental design: DSTs from a single or several manufacturers are attached to a navigation buoy of known position or a suitable position on a research vessel with GPS (Global Positioning System) so that the ships track is continuously recorded. When recovered the data stored on the DST is extracted, geolocation determined and compared to known position of the ship or buoy. A third method of single position testing would be done at an aquaculture site where tags would be attached to several salmon and then recovered at harvest.

Location: RV Scotia from Marine Lab in Aberdeen or RV Templeman from Department of Fisheries and Oceans, St. John's, Newfoundland or any other deepsea research vessel could be used. Vessels that are wide-ranging should be chosen so that geolocation accuracy can be assessed over as wide a range of latitudes and longitudes as possible.

Number to be tagged: 6 DSTs per manufacturer

Estimated cost (indicative):

Tags = $ 10 000

Total cost = $ 10 000

Ship time not included as experiment can be piggy-backed on any research vessel trip.

5.2.4 Earth observation satellite data linked with DSTs

Objective: To demonstrate that DST information on fish movement and habitat selection can be linked with earth observation satellite data to assess habitat preference by salmon.

Background: The declines in salmon returns have been partially attributed to wide-scale climatic effects. In order to learn more about salmon habitat preference will require information on the choices that salmon make compared to what was available to them. DSTs will inform us about the habitat where salmon are but not about the surrounding habitat. Thus, linking DSTs with satellite and other data will provide answers about the available habitat and what choices were made.

Experimental design: Information on temperature that salmon inhabit determined from DSTs should be linked with earth observation satellite data to discern if fish are actually making a choice. This can be done with information presently available in Iceland or new information from DST experiments as it becomes available.

Location: in Iceland, DSTs have been deployed on salmon in the last few years and would be an ideal data set to begin with.

Number to be tagged: 100 kelts (10 DST with light+temp.+depth)
(90 DST with temp.+depth and/or temp.+depth+salinity)

Estimated cost (indicative):

Tags	= $ 30 000
SST satellite data	= $ 5 000
Total cost	**= $ 35 000**

There may be possibility to access satellite data by other means in order to lower that cost.

6 PROPOSAL FOR INTERNATIONAL DST PROJECT

6.1 Developing an International Proposal

The SGOSTE recognised that developing a full proposal for a collaborative international project would require a major commitment from the participating groups. The nature of such a research proposal would also depend upon the organisations from which funding was to be sought and the skills/interests of the parties involved. The SGOSTE was not therefore in a position to provide the full details suggested in the terms of reference but recommended that those groups most interested in pursuing these studies should collaborate in the continued investigation of experimental options and the development of techniques. Further development of at sea DST studies that are to be internationally funded and developed with several participating countries and institutes will require a meeting. Recognising that experiments of this nature are expensive and difficult to plan will necessitate contributing agencies committing to funding it either 'in kind' by providing research vessels or staff and financially.

The SGOSTE also noted that, in common with most areas of electronics, this is a rapidly developing field of technology and significant innovations may occur at any time that will radically alter the potential for studies of migratory fish. As a result, any proposal must maintain an element of flexibility to make the best use of any such developments.

6.2 Experimental Options

The SGOSTE recognises that the main constraint on the use of DSTs on salmon in the near future will be the size of the tags. Tags that can record temperature, light (for position fixing) and pressure are still too large to attach to smolts but could be used on adult salmon caught in the sea (in the open ocean or returning through coastal waters) or kelts captured in river at enumeration facilities. The data storage tags that have light sensors onboard are feasible to use on salmon within the size interval that can be equipped with those tags. New tests on accuracy of data storage tags using light have shown that the daily position of an animal tagged with such DST can potentially be estimated within average error of ca. 140 km based on the data received (Welch and Eveson, submitted).

Postsmolts if captured at sea when 30 cm or more in length could provide good results on habitat selection over the fall and winter periods of the first sea year. However few manufacturers currently make DSTs small enough for use on such fish. The smallest DST available (DST300 from Star Oddi) is suitable for tagging postsmolts down to ca.30 cm in length, and has already been used on sea trout and sea char of this size (Sturlaugsson unpublished). Some of the other DSTs that are currently available are suitable for tagging salmon down to ca. 40 cm in length. Further DSTs are in development, and should be available during 1999–2001. The smallest of these commercial tags would allow tagging of postsmolts down to ca. 20 cm in length to be tagged and relatively large smolts (Star Oddi tags: DST500, DST anonymous and DST400 respectively). The miniature DST (DST400) will be similar/lesser in size as the smallest ultrasonic telemetry tags that have been used on emigrating smolts in sea. Postsmolts would be much more expensive than kelts and smolts due to the requirement for research vessels.

6.3 Main Considerations for an International Proposal

6.3.1 Objective

The main objective of a programme involving the use of DSTs to obtain information on salmon in the sea would be:

> To 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.

This could be approached in several Phases, dependent upon the development of appropriate technology and methods.

6.3.2 Kelt tagging

The SGOSTE considers that the most promising approach for an initial international study of the movements of adult salmon in the sea using DSTs should be based upon tagging of kelts. We believe that tagging wild or hatchery origin (fish originally released as smolts) kelts would have the following advantages over tagging adult salmon at sea:

- full outward and return tracks might be obtained (although it must be noted that these fish would not necessarily follow the same course as post-smolts on their first marine migration);
- tracks would be obtained for salmon from known rivers/sites in the participating nations;
- tag recovery programmes could be targeted on local fisheries in areas where returns were expected; and,
- recovery rates should be greater than for marine tagging because of their better condition due to ease of capture. Postsmolts would have to be caught at sea in nets which will reduce their chances of survival;

6.3.3 Numbers to tag

It is important that the programme is organised to provide a high probability of obtaining a number of good tracks from free-ranging fish. A large number of factors may affect the chance of obtaining successful tracks including:

- survival of tagged fish;
- tag attachment;
- tag recovery;
- tag return; and,
- tag failure.

Estimates must be obtained for each of these parameters and a simple model should be constructed to estimate the expected number of successful tracks per fish released. The number of fish to be tagged should depend not only on seeking a target number of returns (e.g., 10) but ensuring that the probability of getting inadequate or no returns is very low.

6.3.4 Reconditioning

Wild kelts might be obtained from trapping sites and hatchery origin fish from ranching programmes. In both cases it might be advantageous to recondition the fish under hatchery conditions in order to improve their subsequent survival.

This might also allow tags to be attached to the fish some time before they were released in order to check on the attachment and wound healing.

However, reconditioning in particular is a labour-intensive, expensive and time-consuming process and so the effects on the survival and return rates of the fish should be fully evaluated. The cost of reconditioning should be compared with simply tagging a larger number of untreated kelts. A benefit-cost analysis should be undertaken to determine whether reconditioning would result in a sufficient improvement in return rates (or possibly in the quality of the results) to merit the additional costs.

6.3.5 Tagging locations

A number of sites are available in Europe and North America at which wild or hatchery origin kelts could be obtained in sufficient numbers (> 100) over a period of 1–3 years. It would clearly be desirable to include a number of release sites in the experiment both to spread the risks and, hopefully, to obtain a wider range of data since it is known that different stocks of salmon do not use the same migration routes. However, there are likely to be significant differences in the return rates to different sites depending both upon the nature of the stocks (e.g., the tendency for stocks to produce previous spawners is quite variable) and the experimental facilities available (e.g., traps).

Information is available from some of sites on return rates of conventionally tagged fish and more detailed analysis of these return data might permit the selection of fish for tagging that have a higher chance of survival. Nevertheless, as return rates are still likely to be low (< 10% at some sites), it will still be advisable to tag samples of fish with dummy tags before committing funds to large numbers of DSTs and sites.

6.3.6 Choice of tags

DST technology is continuing to advance rapidly and the project should use the most suitable tags available at the time that the programme is due to start. As a minimum, the tags (single type/combination of types) should sample information on the following parameters:

- Geolocation;
- Water temperature;
- Depth (pressure);

Choice of tags should be based primarily upon their biological suitability (i.e., suitability for attachment, etc), their features and accuracy/reliability. While the cost of individual tags must inevitably be an important consideration it must not be allowed to compromise the project. The best tag type or combination of tag types for the project should be used regardless of cost. If financial resources are a problem it is better to use fewer tags rather than compromising the results with inferior tags. However, if few tracks are obtained the interpretation of the results must be must be treated with great caution in relation to general migration trends.

6.3.7 Attachment method

Preliminary studies are likely to be required on tag attachment methods, although use may be made of experiences in other DST tagging studies (e.g., those in Icelandic waters and in the Baltic) and conventional telemetry studies on salmon. If additional trials are required, the behaviour of 20–30 salmon (> 60 cm in length) should be studied in large freshwater/saltwater flumes. The tags should be attached using 3–4 alternative methods (e.g., external or body cavity insertion), and the behaviour and survival of the fish recorded. The following criteria should be used to assess the impact of tag design and methods of attachment:

- feeding behaviour;
- survival;
- wound healing; and,
- growth and general condition.

Where body cavity insertion occurs, studies should also be conducted on:

- inflammation of internal organs; and
- tag expulsion.

Drag coefficients should be calculated for the different tag attachments over a range of fish swimming speeds. If the tag design includes an umbilical for the light/temperature sensors, careful attention must be given to the stability of the trailing sensors at different swimming speeds. Any tendency for the tag to oscillate and thus cause irritation or damage must be assessed.

6.3.8 Tag recovery

Particular attention must be given to ensuring that tags are identified when tagged fish are recaptured and that the tags are returned. An intensive publicity campaign should be conducted and commercial and rod fisheries should be monitored for returned tags. Consideration should be given to paying a large reward (e.g., in excess of the value of the tag) and possibly supplementing this with a lottery prize. The infrastructure will normally exist at study sites to undertake scanning programmes.

An important aspect of any DST study is the financial reward paid to the individual returning the DST and advertising for the return of DSTs. The general public and fishers should be informed that the DST experiments are going on, the purpose of the experiments and that a reward is offered for the return of DSTs. SGOSTE suggests that the magnitude of the reward should be commensurate with the cost of the experiment, which can be considerable, if a research vessel is involved. The reward for the return of the DST and recapture information should at least be equal to the cost of the DST.

6.3.9 Data analysis

Data from the recovered tags will be analysed and used to describe the migration patterns of the recaptured salmon in the North Atlantic Ocean. Migratory patterns and distribution of salmon in the sea will be modelled using light data and sea water temperature. Data on light, sea temperature, internal body temperature and depth will be used to determine the position, distribution and behaviour of individual salmon. Additionally extra parameters such as salinity that provide specific and valuable landmarks for the beginning and end of the sea migration (the coastal waters) can be sampled in some instances (e.g., kelts) to get better information on the migration between coastal and oceanic waters. Thus consideration should be given to using some tags which could collect this data in conjunction with the main bulk of the tags collecting geolocation data to plot the ocean distribution of salmon in the sea.

The swimming behaviour of salmon during feeding will be modelled from the data collected by the onboard pressure and temperature sensors. Horizontal movements and diurnal patterns of vertical activity will be related to sea water temperature to describe the feeding behaviour in relation to thermal fronts and areas of productivity. Internal temperature (stomach) which is often elevated during digestion may be used to monitor food intake. Feeding and prey exploitation rates may be modelled from this data, together with growth rates and the energetic requirements for migration calculated.

6.3.10 Costs

With so many details of the study being dependent upon decisions that have not yet been made, it is difficult to determine even approximate costs. The following figures are therefore designed to give only a very rough indication of possible costs for such a study. The study should be run in parallel at 3–4 sites.

Joint cost for all sites:	Preparatory studies	= $ 200,000
	Management and data analysis	= $ 200,000
Cost per site (indicative):	Fish capture/handling	= $ 20,000
	Tags	= $ 250,000
	Tag recovery	= $ 30,000
Total cost (assuming 3 sites)		= $ 1,300.000

6.4 Phase 2 - Ocean DST Experiment

The SGOSTE recommended that repeat spawners should be tagged with DSTs initially as they will provide the least costly alternative to direct ocean tagging. However, repeat spawners may not utilise the same migration tracks or have the same behaviour in the sea as postsmolts and consequently it will be necessary to confirm with postsmolts any relationships between climate and salmon derived from the tagging of repeat spawners. DST technology is changing very quickly and it may be that tags of sufficiently small size will be available to apply to smolts as they depart rivers for the open sea. Presently, due to the current size of DSTs, salmon will have to be caught at the postsmolt stage at sea. It is recommended that tagging salmon in the open ocean (in the Labrador Sea and/or Norwegian Sea) should be used to determine the relationship between salmon and marine climate during the postsmolt 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.

Initial suggestions are that this study could therefore take the following form:

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 Faroes.
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

7 RECOMMENDATIONS FOR OCEAN EXPERIMENTS USING DSTS

It is recommended that the small scale experiments listed in Section 5 be carried out.

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 the technology allows.

It is recommended that tagging salmon in the open ocean (in the Labrador Sea and/or Norwegian Sea) should be used to determine the relationship between salmon and marine climate. Specifically, how migrations are influenced by ocean conditions, by physical processes such as fronts, eddies, upwellings and currents and by biological factors, i.e., food, competition and predation. These should be internationally co-ordinated and jointly funded experiments.

8 REFERENCES

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Table 4.1.1 The manufacturer (firms/institutes) developing and/or producing Data Storage or Archival Tags in relation to nationality and producing process (commercial or not).

Section number	Name of Manufacturer	Nationality	Product process
2.2.1	Alec Electronics Co., Ltd.	Japan	Commercial
2.2.2	Birmingham University	England	Not commercial
2.2.3	CEFAS/LOTEK	UK/Canada	Commercial
2.2.4	Driesen + Kern GmbH	Germany	Commercial
2.2.5	National Institute of Polar Research	Japan	Not commercial
2.2.6	Northwest Marine Technology, Inc.	USA	Commercial
2.2.7	Onset Computer Corporation	USA	Commercial
2.2.8	Star Oddi	Iceland	Commercial
2.2.9	Vemco	Canada	Commercial
2.2.10	Wildlife Computers	USA	Commercial

Table 4.2.1. A Data storage tags that are manufactured or in development by Alec Electronics. Here are listed the DSTs that are small enough to be used on Atlantic salmon of multi-sea winter size or smaller.

Alec Electronics - DSTs	**NB! The data sampled is recorded in relation to time**		
Tag feature	**Tag types (commercial)**		
Parameter	**Available**	**In development**	**Units**
	MDS-Series		
Size - Diameter: length:	18 109		(mm)
Weight (in air / in water)	28.4 / 3.5		(gram)
Case- material and shape /site (holes) for attachment cord (no)	Polyester resin (white) cylender with round ends / none holes for tether (cord) attachment		
Depth max tolerance	500		(meter)
Memory size [a] (total sampling capacity)	32 $\leq$ 32.000.000		(Kbytes) (recordings)
Memory type	RAM memory with battery backup		
Programming Sampling defination:	The sampling (measuring) interval is selected from 4 options (1 sec, 1, 10, 20 minute)		
Interface [b] programming & downloading of data	Hard-wired		
Life time [c] (max sampling duration)			(month)
Year of release (on the market)			(year)
Sensors (sampling/resolution range) [d]: **Temperature** - sampling: - resolution:			(°C)
Sensors (sampling/resolution range) [d]: **Depth** (pressure) - sampling: - resolution:			(meter)
Sensors (sampling/resolution range) [d]: **Light** (intensity) - sampling: - resolution: - wavelength response:			
Fish size: **Fish size minium at T/F** [e] **= 1%**	2840		(gram)
Fish size: **Fish size minium at T/F= 2%**	1420		(gram)
Fish size: **Fish size minium at T/F= 4%**	710		(gram)

[a] Ech recorder has the facility for one sensor (of the 3 available) and therefore measures only one environmental parameter

[b] Data retrieved via Memory interface that require IBM-compatible PC (with an RS232 serial port)

[c] In addition to memory capacity the tot. possible sampling period depends on battery capacity includ. trade off between rate of sampling & tem The data retention time is depending on battery backup of RAM).

[d] **The accuracy:** (information not received)

[e] T/F = tag weight in air/fish weight in air (the ratio is here given as %)

Table 4.2.2. The data storage tags that have been developed or are in development by University of Birmingham. They are used for special research tasks, and are designed for implantation. These tags are not commercially available, but could be produced given sufficient demand.

Birmingham University - DSTs **NB! The data sampled is recorded in relation to time**

Tag feature	Tag types (Not commercial)			
	Already deployed (the two last types)		In development	
Parameter	**BL1.2**	**BL2.0**	**BL3** [a]	**Units**
Size - width x height :	24 x 6.5	17 x 12	10 x 3	(mm)
length:	55	38	15	
Case- material and shape /site (holes) for attachment cord (no)	Cubic shaped, rounded ends / none		Cubic shaped / none	
Weight (in air / in water)	25 /	14 /	<10 /	(gram)
Depth max tolerance	300	300	300	(meter)
Memory size (total sampling capacity)	128.000	4.000	8.000	(Kbytes)
Memory type	non-volatile, EEPROM	non-volatile, FLASH	non-volatile, FLASH	
Programming[b] Start time delay: Sampling defination:	The start delay and rates of sampling of each parameter is defined via hard-wired serial connection to PC & data is retrieved by same means			
Interface programming & downloading of data	Hard-wired	Hard-wired	Hard-wired	
Life time [c] (max sampling duration)				(month)
Year of release	1990	1998	1999-2000	(year)
Sensors (sampling/resolution range) [d]: **Temperature** - sampling: (≤ 4 channels)	x	0 - 50	X = sensor included in tag	(°C)
- resolution:		~0.3		
Depth (pressure) - sampling:		0 - 300	X	(meter)
- resolution:		1.2		
ECG [e] - sampling:	0 - 1000	0 - 600	X	(beats/min)
- resolution:	1 - 4	0.1		
Bioactivity (switch) - sampling:			X	
- resolution:				
		Interface for intelligent sensors (1 channel, IIC)		
Fish size: **Fish size minium at T/F** [f] **= 1%**	2500	1400	< 1000	(gram)
Fish size minium at T/F= 2%	1250	700	< 500	(gram)
Fish size minium at T/F= 4%	625	350	< 250	(gram)

[a] Functionally it will be as type BL2 except there will only be 1 temperature channel.

[b] Options of BL2 (similar for BL3). All the 7 channel can have individual sampling rates from 1 sec to 18 hours.
Up to 4 separate programs can be used consecutively, each in either of the following 2 modes:
Delay mode: Delay = 1 hour to 2730 days (resolution 1 hour) Log = 1 to 256 days (or until memory is full)
Sample mode: Sample on = 1 hour to 256 hours, Sample off = as delay, Program duration = 1 - 256 cycles

[c] As long channel sampling periods are possible, the total possible sampling period depends on battery capacity.
The data retention time from this non-volatile EEPROM and FLASH memory tags is ≥20 years

[d] **The accuracy of measurements:** Temperature = 0.2°C (Bl2 type); Depth = 1 m (with 0-300 m sensor)

[e] Heart rate is calculated from the mean period averaged over the ECG (electrocardiogram) channel sampling interval & stored as floating point val
An integral radio transmitter emits a short pulse whenever a valid ECG is detected by hardware or software (ECG trace can also be recorded)

[f] T/F = tag weight in air/fish weight in air (the ratio is here given as %)

Table 4.2.3. The data storage tags that are manufactured or in development by CEFAS/Lotek

CEFAS/Lotek - DSTs		**NB! The data sampled is recorded in relation to time**			
Tag feature		**Tag types (commercial)**			
Parameter		**Available**		**In development**	**Units**
		LTD_100	**LTD_20**	**LTD_(anonymus)**	
Size -	Diameter: / length:	18 / 57	18 / 57	<18 / <57	(mm)
Weight	(in air / in water)	16 / < 1	16 / < 1		(gram)
Case- material and shape	/site (holes) for attachment cord (no)	Transparent cylender with round front end / 1 at rear end (depth sensor end)			
Depth max tolerance		1.000	1.000	3.000	(meter)
Memory size	(total sampling capacity)[a)]	1.000 / 198.000[b)] 500.000[c)]	1.000 / 198.000[b)] 500.000[c)]		(Kbytes) / (recordings)
Memory type		non-volatile	non-volatile	non-volatile	
Programming[d)]	Start time delay: / Sampling defination:	The start and rates of sampling of each parameter is defined using TAGTALK reader and software (Windows™-based program) and data is retrieved/manipulated by same means			
Interface[e)]	programming & downloading of data	Infrared LED	Infrared LED	Infrared LED	
Life time[f)]	(max sampling duration)	≥ 132 (11 years)	132		(month)
Year of release	(on the market)			1999-2000	(year)
Sensors (sampling/resolution range)[g)]	**Temperature** - sampling: / - resolution:	+2 - +25 (subzero min value option) / 0.03	+2 - +25 (subzero option) / 0.03	External sensor option (combined light/temp. probe)	(°C)
	Depth (pressure) - sampling: / - resolution:	0 - 100 / 0.04	0 - 20 / 0.04	External sensor option (combined light/temp. probe)	(meter)
	Light[h)] (intensity) - sampling: / - resolution:			x	
	Tilt - sampling: / - resolution:			x	
	Compass (inertia) - sampling: / - resolution:			x	
	Bioactivity (e.g. EMG) - sampling: / - resolution:			x	
Fish size	**Fish size minium at T/F**[i)]**= 1%**	1600	1600		(gram)
	Fish size minium at T/F= 2%	800	800		(gram)
	Fish size minium at T/F= 4%	400	400		(gram)

a) Optional addition of 33 % memory increase (0.5 Mbyte)

b) According to measuring of light & depth every 4 minutes and of temperature once daily (total sampling time 18 months)

c) According to measuring only depth and temperature every 15 minutes (total sampling time > 7 years)

d) Sampling defined via the interface TAGTALK (timer programming is from 1 sec to 99 days, but the start delay can be up to 1 year) Sampling protocols are programmed seperately for each parameter, but if light is sampled depth are commonly sampled parallely because it serve as light intensity level control (enables to detect variations in light levels derived from variations in depth)

e) The interface box require IBM-compatible PC (with an RS232 serial port) and the data is read from the DSTs using an infrared optical link

f) In addition to memory capacity the tot. possible sampling period depends on battery capacity includ. trade off between rate of sampling & temperat
The data retention time from this non-volatile FLASH memory tags is ≥20 years

g) **The accuracy:** Temp. = 0.06°C ;Depth = 0.1 - 0.5 m (LTD_20 - 100); Light intensity/Geolocation (information not received)
In addition to the sensors that are in development for future tag, that tag is also planned to be integrated with temperature corrected real-time cloc

h) The light data (level in relation to time) is used for geolocation using recordings from sunrise and sunset

i) T/F = tag weight in air/fish weight in air (the ratio is here given as %)

Table 4.2.4. A Data storage tags that are manufactured or in development by Driesen + Kern GmbH. Here are listed the DSTs that are small enough to be used on Atlantic salmon of multi-sea winter size or smaller.

Driesen + Kern GmbH - DSTs		**NB! The data sampled is recorded in relation to time**		
Tag feature	**Tag types (commercial)**			
	Available		**In Development**	
Parameter	**Phillbox logger**	**DK550 - Series**		**Units**
Size - Diameter or width* x height*:	15	25 x 30		(mm)
*(max dimension) length:	100	110		
Weight (in air / in water)	18-22 / 11	/ 25-35		(gram)
Case- material and shape	Titanium cylender	Hydrodynamic shape		
/site (holes) for attachment cord (no)	/ none holes for tether	/		
Depth max tolerance				(meter)
Memory size (total sampling capacity)	130 130.000	256 256.000		(Kbytes) (recordings)
Memory type	non-volatile	non-volatile		
Programming [a)] Sampling defination:	Preset sampling interval: 8,16,32,64.128,256 or 512 sec (8 seconds - 8 minutes)	User-selectable sampling interval: 2 seconds to 24 hours		
Interface[b)] programming & downloading of data	Hard-wired	Optic		
Life time[c)] (max sampling duration)	24 (2 years)			(month)
Year of release (on the market)				(year)
Sensors (sampling/resolution range) [d)] **Temperature** - sampling:	0 - +50 (other ranges available)	0 - + (other ranges available)		(°C)
- resolution:	0.	0.003		
Depth (pressure) - sampling:		0 - 100		(meter)
- resolution:		0.003		
Light [e)] (intensity) - sampling:				
- resolution:				
Bioactivity (pitch &roll) - sampling:				
-resolution:				
Fish size **Fish size minium at T/F** [f)]**= 1%**	1800 or 2200			(gram)
Fish size minium at T/F= 2%	900 or 1100			(gram)
Fish size minium at T/F= 4%	450 or 550			(gram)

[a-b)] The interface module require IBM-compatible PC (with an RS232 serial port). Analysis-software is available.

[c)] In addition to memory capacity the tot. possible sampling period depends on battery capacity includ. trade off between rate of sampling & tempera
The data retention time from this non-volatile memory tags is $\geq$20 years

[d)] **The accuracy:** (Information not received)

[e)] The light data (level in relation to time) can be used for geolocation

[f)] T/F = tag weight in air/fish weight in air (the ratio is here given as %)

Table 4.2.5. A Data storage tags that are manufactured or in development by National Institute of Polar Research Here are listed the DSTs that are small enough to be used on Atlantic salmon of multi-sea winter size or smaller.

National Inst. of Polar Research - DSTs

NB! The data sampled is recorded in relation to time

Tag feature		Tag types (Not commercial)			
Parameter		Already deployed		In development	Units
		Anonymous.1	Anonymous.2		
Size -	Diameter:	19	14		(mm)
	length:	75	75		
Weight (in air / in water)		30 /	20 /		(gram)
Case- material and shape		Cylindral with rounded ends			
/site (holes) for attachment cord (no)		/			
Depth max tolerance					(meter)
Memory size (total sampling capacity)		512 (within 12 channels)	394 (within 4 channels)		(Kbytes) (recordings)
Memory type		non- volatile	non- volatile		
Programming[a]	Sampling defination:	The start and rates of sampling of each parameter is defined prior to enclosing housing			
Interface	programming & downloading of data	Hard-wired	Hard-wired		
Life time[b] (max sampling duration)					(month)
Year of release (first deployed)					(year)
Sensors (sampling/resolution range)[c]	**Temperature** (External stalk sensor option) - sampling:				(°C)
	- resolution:				
	Depth (pressure) - sampling:				(meter)
	- resolution:				
	Swim velocity - sampling:				
	- resolution:				
	ECG - sampling:				(beats/min)
	- resolution:				
Fish size	**Fish size minium at T/F**[d] **= 1%**	3000	2000		(gram)
	Fish size minium at T/F= 2%	1500	1000		(gram)
	Fish size minium at T/F= 4%	750	500		(gram)

[a] Sampling recording schedule designed in relation to research task.

[b] In addition to memory capacity the tot. possible sampling period depends on battery capacity includ. trade off between rate of sampling & temp.

[c] **The accuracy:** (information not received)

[d] T/F = tag weight in air/fish weight in air (the ratio is here given as %)

Table 4.2.6. The data storage tags manufactured or in development by Northwest Marine Technology (NMT)

NMT - DSTs	**NB! The data sampled is recorded in relation to time**		
Tag feature	**Tag types (commercial)**		
Parameter	**Available**	**In development**	**Units**
	"Archival tag"	**Anonymus**	
Size - Diameter:	16	16	(mm)
length:	100	65	
Weight (in air / in water)	52 /		(gram)
Case- material and shape	Stainless steel cylender with round ends (+silicon rubber collar at stalk end)		
/site (holes) for attachment cord (no)	/ none holes for tether (cord) attachment		
/external devices	/ Flexible stalk (probe) sensor with teflon surface for external temp. and light. Size of stalk 2 mm diameter and 20 cm standard length (other length options)		
Depth max tolerance	≥ 700		(meter)
Memory size (total sampling capacity)	256		(Kbytes)/ (recordings)
Memory used for 3 sampling duties			
a) Summary of total data (in histograms)	9		
b) Daily primary position (compact data)	30		
c) Time series data	215		
Memory type	RAM memory with battery backup	RAM memory with backup	
Programming d) Sampling defination:	The measurement interval is constant (128 sec) = 675 measurements/day. Routine sampling **a)** and **b)** with some adjustable options (e.g. depth levels where temp. measured in addition to the surface level). Then there is time series samplings c) that the user specifies for data storage by selecting multiples of the measuring intervals.		
Interface d) programming & downloading of data	Hard-wired	Hard-wired	
Life time e) (max sampling duration)	≥ 84 (>7 years)	≥ 120 (≥10 years)	(month)
Year of release (on the market)			(year)
Sensors f) (sampl./resolution range) — **Temperature (2 sensors)** internal &external sensor			
- sampling:	-40 - +85	x	(°C)
- full accuracy sampling:	- 5 - +35		
- resolution:	0.2		
Depth - sampling:	0 - 510 (in time series)		
	0 - 700 (in histogram)	x	(meter)
(pressure) - resolution:	1.0 - 3.0 (1 down to 126 m & then 3 resol.)		
Light g) - sampling:	5.5 decades down from noon sun		
(intensity) - resolution:	17% (15 points/decade)	x	
- wavelength response:	450nm +/- 50nm		
Fish size — **Fish size minium at T/F** h) **= 1%**	5200		(gram)
Fish size minium at T/F= 2%	2600		(gram)
Fish size minium at T/F= 4%	1300		(gram)

a) Set of histograms that summarize all data (data distribution) but are of fixed size after intelligent data processing (as the day logs).

b) Day log containing basic position fixing data (times of sunrise/sunset; temperatures at surface/ 61 m /122 m; noon light, clarity; diagnostic data)

c-d) Sampling defined and data retrieved via NMT ADAPTER that require IBM-compatible PC (with an RS232 serial port)

e) In addition to memory capacity the tot. possible sampl. period depends on battery capacity includ. trade off between rate of sampl. & temp. The data retention time is based on when battery backup of RAM finish

f) **The accuracy:** (information not received)

g) Light intensity enables geolocation: record. from sunrise & sunset determine longitude & sea temp. at standard depths determine latitude.

h T/F = tag weight in air/fish weight in air (the ratio is here given as %)

Table 4.2.7. A Data storage tags that are manufactured/in development by Onset Computer Corporation. Here are listed the DSTs that are small enough to be used on Atlantic salmon of multi-sea winter size or smaller.

Onset computer - DSTs	**NB! The data sampled is recorded in relation to time**		
Tag feature	**Tag types (commercial)**		
Parameter	**Available**	**In development**	**Units**
	StowAway - TidbiT		
Size - width x height: length:	30 x 17 41		(mm)
Weight (in air / in water)	22.7 / .		(gram)
Case- material and shape /site (holes) for attachment cord (no)	Pie shaped + expansion due to attachment ear (rounded edges) / 1 ear(hole) for tether (cord) attachment		
Depth max tolerance	305		(meter)
Memory size (total sampling capacity)	32.5 32.520.000		(Kbytes) (recordings)
Memory type	non-volatile EEPROM		
Programming [a)] Sampling defination:	User-selectable sampling interval: 0.5 seconds to 9 hours. Programmable start time/date started with coupler or magnet. Multiple sampling option with min, max or averaging. Memory modes stop when full or wrap-around when full.		
Interface [a)] programming & downloading of data	Optic		
Life time [b)] (max sampling duration)			(month)
Year of release (on the market)			(year)
Sensors (sampling/resolution range) [c)] — **Temperature** (2 options) - sampling: - resolution:	* -5 - +37 ** -20 - +70 * 0.15 and ** 0.3		(°C)
Fish size — **Fish size minium at T/F** [d)] **= 1%**	2270		(gram)
Fish size minium at T/F= 2%	1135		(gram)
Fish size minium at T/F= 4%	568		(gram)

[a)] An starter kit starter is required to the TibiT DST (start & rate of sampling and retrieval of data). These starter kits are both available for I compatible PC (Optic BoxCar Pro) & for Mac (Optic LogBook) & includes software, Optic base station, Tidbit Coupler & computer interface ca

[b)] In addition to memory capacity the tot. possible sampling period depends on battery capacity includ. trade off between rate of sampling & tem

The data retention time from this non-volatile EEPROM memory tag is ≥20 years

Taken as example of total sampling/logging time then 4 minutes intervals of sampling gives that the total sampling time = months

[c)] **The accuracy:** Temperature = 0.4 °C (+/- 0.2°C) at -5 to +35°C and 0.8 °C (+/- 0.4°C) at -20 to +70°C ; Time= 2 minutes/week = +/- 1 m

[d)] T/F = tag weight in air/fish weight in air (the ratio is here given as %)

Table. 4.2.8. The data storage tags that are manufactured or in development by Star-Oddi

Star Oddi - DSTs	**NB! The data sampled are recorded in relation to time**					
Tag feature	**Tag types (commercial)**					
	Available		**In development**			
Parameter	**DST200**	**DST300**	**DST400**	**DST500**	**Anonymus**	**Units**
Size - Diameter: / length:	18 / 48	13 / 46	<10 / <25	13 / < 35	13 / < 35	(mm)
Weight (in air / in water)	12/1	8/2 & 7.5/1.5[a]	3-4/ca. 1	5-6/ ca. 1	< 6/ ca. 1	(gram)
Case- material and shape /site (hole/ear) for attachment cord (no)	Transparent cylender with round front end / 2 (at both ends)		Cylinder of material not stated with round front end / 2 (at both ends)			
Depth max tolerance (sensor dependent)	600	1.000	4.000	2.000-3.000	2.000-4.000	(meter)
Memory size (tot sampling capacity)	8.1[b] / 8.100	8.1[b] / 8.100	32 / 32.000	32 or 128 / 32.000 or 128.000	32 or 128 / 32.000 or 128.000	(Kbytes) / (recordings)
Memory type	non-volatile	non-volatile	non-volatile	non-volatile	non-volatile	
Programming [c] Start time delay: / Sampling defination:	Defined time interval (2 sec-1 year) from activation by removal of magnet - first measurement. Defined either as 1 constant sampling rate or as 2 different sampl. rates where each sampling rate are operating for given N of sampling (cyclus that switches sampling rate after given N)					
Interface [d] programming & downloading of data	hard-wired	hard-wired	RF (radio frequency)	RF (radio frequency)	RF (radio frequency)	
Life time[e] (max sampling duration)	≥12 (1 year)	≥10	≥12	ca. 24	≥12	(month)
Year of release (on the market)	1996	1997	2000-2001	2002	2000-2001	(year)
Sensors (sampling/resolution range) [f]						
Temperature - sampling: / - resolution:	-25 - +50 / 0,05 - 0,1	-25 - +50 / 0,05 - 0,1	-25 - +50 / < 0,02	-25 - +50 / < 0,02	-25 - +50 / < 0,02	(°C)
Depth[g] (pressure) - sampling: / - resolution:	0 - 600 / 0.3 - 2.4	0 - 800 / 0.3 - 3.2	0 - 4.000 / 0.1 - 1.0	0 - 3.000 / 0.1 - 0.8	0 - 4.000 / 0.1 - 1.0	(meter)
Salinity (conductivity) - sampling: / - resolution:	3 - 37 / 0.1			X (Integrated option that enables up to 8 different sensors to be used at same time)		(psu = ‰)
Tilt angle (inclination) - sampling: / - resolution:		(- 45) - (+ 45) / < 2°				(°)
Tilt angle (3-D) - sampling: / - resolution:			X	X		(°)
Geoposition - sampling: / - resolution:					not stated / 5	(km)
3 other sensors (in develop. types not stated)				X	X	
Fish size						
Fish size minium at T/F [h] = 1%	1200	800 & 750	300 - 400	500 - 600	<600	(gram)
Fish size minium at T/F= 2%	600	400 & 375	150 - 200	250 - 300	<300	(gram)
Fish size minium at T/F= 4%	300	200 & 188	75 - 100	125 - 150	<150	(gram)

[a] The lower weight is according to use without tilt sensor

[b] Increased to approx. 32.000 in late 1998

[c] Timer programming from 2 sec to 1 year

[d] The data retrieval and sampling programming is via interface box and require IBM-compatible PC (with an RS232 serial port), but no ext. power

[e] In addition to memory capacity, the tot. possible sampling period depends on battery capacity including trade off between rate of sampling & temp. The data retention time from this non-volatile (EPROM memory) tags is ≥20 years

[f] The customer specifies the intervals measured within (e.g. 0-500 m; 0-20°C; 5-35 psu) & parallely partly the resolution

The accuracy: Temp. = 0.1 - 0.2°C ; Depth = 0.6-4.8m (DST200) and 0.6-6.4m (DST300) ; Salinity = 0.2 - 2 psu (at 5 - 35 psu)

[g] Depth range/resolution within the total range are adjusted according to customer specification

[h] T/F = tag weight in air/fish weight in air (the ratio is here given as %)

Table 4.2.9. The data storage tags that are manufactured or in development by Vemco

Vemco - DSTs	**NB! The data sampled are recorded in relation to time**					
Tag feature	**Tag types (commercial)**					
Parameter	**Available (Minilog series)**			**In development**		**Units**
	TX[a] &TDX[b]	**TR[c] &TDR[d]**	**12 T**	**x**	**Anon.[e]**	
Size - Diameter:	16	21	21			(mm)
length:	65	100	95			
Weight (in air / in water)	23 / 10	41 / 12	41 / 12			(gram)
Case- material and shape /site (hole) for attachment cord (no)	Opaque epoxy cylender / 1 (at non sensor end)	Opaque PVC cylender / 1 (at non sensor end)				
Depth max tolerance (sensor dependent)	1.000	1.000	1.000			(meter)
Memory size (tot sampling capacity)	8.1[a] & 16.3[b]	8.1[c] & 16.3[d]	10.8 or 43.6			(Kbytes)
	8.064[a] & 16.256[b]	8.064[c] & 16.256[d]	10.836 or 43.604			(recordings)
Memory type	non-volatile	non-volatile	non-volatile			
Programming[f] Start time delay:	Start can be delayed from defination of sampling until initial time of sampling				Acoustic way	
Sampling defination:	Defined via the minilog interface, as the start delay					
Interface[g] programming & downloading of data	Infrared LED	Infrared LED	Infrared LED		Acoustic way	
Life time[h] (max sampling duration)	60 (5 years)	60	60			(month)
Year of release (on the market)				1999		(year)
Sensors (sampling/resolution range)[i] **Temperature[j]** -sampling:	-30 - +40	-40 - +20 or -50 - +35	-30 - +50	Two sensors / tag (int./ext.)	x	(°C)
- resolution:	0,1 - 0,5	0,1 - 0,2	0,015 - 0,05			
Depth[k] (pressure) -sampling:	[b] 0 - 680	[d] 0 - 680			x	(meter)
- resolution:	0.1 - 4.0	0.1 - 4.0				
Salinity (conductivity) - sampling: / -resolution:				x	x	
Swimming speed -sampling: / - resolution:					x	
Fish size Fish size minium at T/F[l]= 1%	2300	4100	4100			(gram)
Fish size minium at T/F= 2%	1150	2050	2050			(gram)
Fish size minium at T/F= 4%	575	1025	1025			(gram)

d) Additional memory can be ordered to increase the memory capacity to 64 kilobytes (total recordings = 64.000)

e) This tag is developed miniature of the CHAT tag now available for sharks/large fish (32mm dia. x 150mm lenght; weight 190 g in air & 75g in water) The current CHAT tag version have the maximum sampling period of 2 years and it have the 3 sensors (depth,temperature &swimming speed) The CHAT tags are combination of data storage tags and acoustic reprogramming and downloading of data (surface/bottom tracking system based on direct tracking or data received by mounted monitors)

f) Sampling defined via the Minilog interface (timer programming is from 1 sec to 6 hours, fixed options for start delay).

g) The interface box require IBM-compatible PC/AT (with an RS232 serial port) and the data is read from the DSTs using an infrared optical link

h) In addition to memory capacity the tot. possible sampling period depends on battery capacity includ. trade off between rate of sampling & temperature The data retention time from this non-volatile EPROM (TR,TX & 12T) and EEPROM (TDR & TDX) memory tags is $\geq$20 years

i) The accuracy: Temp. = 0.2-0.5°C (TR;TX;TDR;TDX) & 0.03-0.1°C (12T) ; Depth = 0.5 - 20 m (for max 17m - max 680m)

j) The temperature resolution is specified using standard scale (types TX, TR & T12 are solely measuring temperature but TDR &TDX also measure depth) Scales for TX, TR TDX &TDR: -4 to 20°C =0.1°C; -5 to 35°C=0.2°C; -30 to 40°C=0.3°C Scales for 12T: -5 to 40°C=0.015°C; -40 to 50°C=0.05°C

k) The customer specifies the depth intervals sampled (prefixed max depth /resolution as follows in m: 17m/0.2; 34m/0.3; 68m/0.7; ....,680m/6.8)

l) T/F = tag weight in air/fish weight in air (the ratio is here given as %)

Table 4.2.10. A Data storage tags that are manufactured by Wildlife Computers. Here are listed the DSTs that are small enough to be used on Atlantic salmon of multi-sea winter size or smaller.

Wildlife Computers - DSTs	**NB! The data sampled is recorded in relation to time**				
Tag feature	**Tag types (commercial)**				
	Available			**In development**	
Parameter	**Mk7**	**Mk7-S**	**Mk7-L**		**Units**
Size - width x height : length:	20 x 12 88	20 x 20 66	25 x 16 99		(mm)
Weight (in air / in water)	27 /	37 /	47 /		(gram)
Case- material and shape /site (holes) for attachment cord	Cubic shaped block of epoxy resin, rounded front end / user may specify attachment aids (e.g. holes)				
Depth max tolerance	1.000	1.000	2.000		(meter)
Memory size [a] (total sampling capacity per deployment)	2000.000	2000.000	2000.000		(Kbytes)
Memory type	Non-volatile (Flash)				
Programming [b] Start time delay: Sampling defination:	The start and rates of sampling of each parameter is defined using a PC and software (Windows95™-based program) and data is retrieved/manipulated by same means				
Interface programming & downloading of data	PC Serial Port				
Life time [c]	24 months maximum sampling duration; 240 months data retention				(month)
Year of release (on the market)					(year)
Sensors (sampling/resolution range) [d]					
Temperature [e] - sampling:	-40 - +60	-40 - +60	-40 - +60		(°C)
- resolution:	0.05	0.05	0.05		(°C)
Depth [f] (pressure) - sampling:	0 - 1000	0 - 1000	0 - 2000		(meter)
- resolution:	0.5	0.5	1.0		(meter)
Light [g] (intensity) - sampling: - resolution:	1 milli - 1 kilo (logarithmic scale; 250 steps)				(lux)
Fish size					
Fish size minium at T/F [g]**= 1%**	3000	4000	3500		(gram)
Fish size minium at T/F= 2%	1500	2000	1750		(gram)
Fish size minium at T/F= 4%	750	1000	875		(gram)

[a] Examples of recording time for comparision (note: battery capacity only allows sampling for 2 years):
Recording of light & depth every 4 minutes and of temperature once daily (721 rec./day), then total sampling time = 92 months
Recording only depth and temperature every 15 minutes (192 rec./day), then total sampling time = 30 years to fill memory

[b] Sampling is highly-controlled by user-specified sampling protocols that are programmed (timer opt: 1 sec-255 min) separetely (diff. rate opt.) for each param. (sensor). User-defined condition of sensor reading, e.g. depth and/or conductivity (in/out of water) determ. wich protocol is invoked

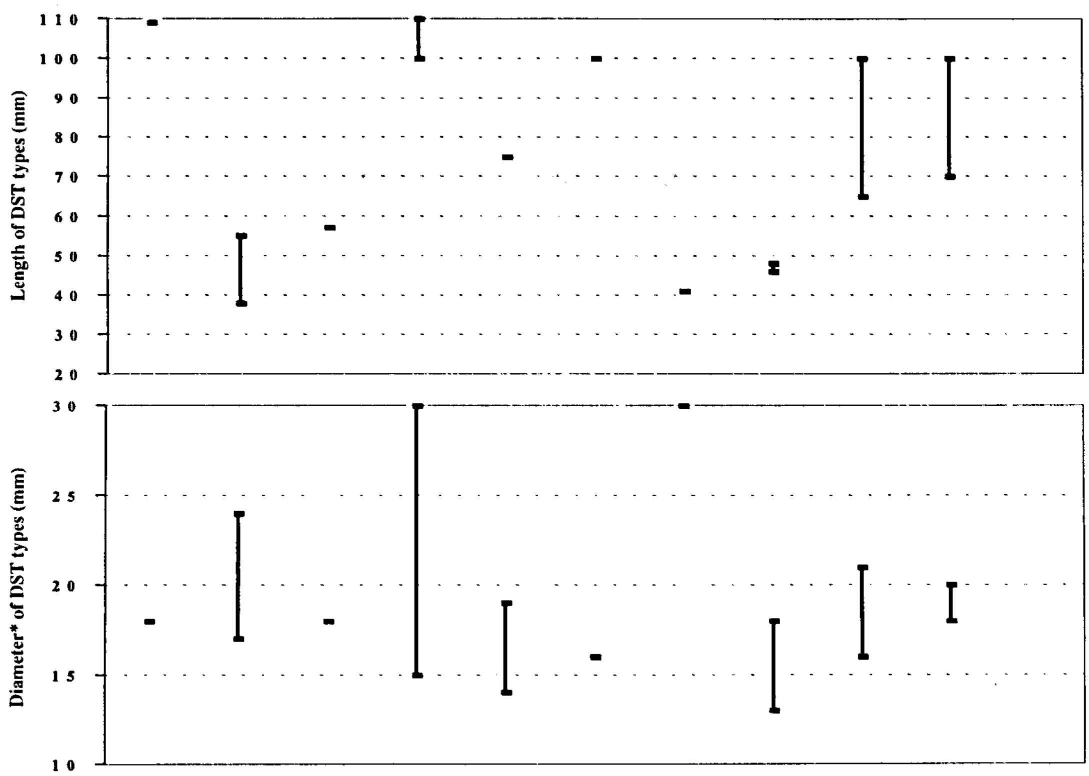
[c] In addition to memory capacity the tot. possible sampling period depends on battery capacity includ. trade off between rate of sampl. & temp.
The data retention time from this tags is 20 years (specification of non-volatile Flash memory)

[d] **The accuracy:** Temp. = 0.1°C ; Depth = 2.5 - 10 m (250-1000); Light intensity = n/a ;Geolocation = +/- 1.0 & +/- 0.5 degrees (lati - & longitude)

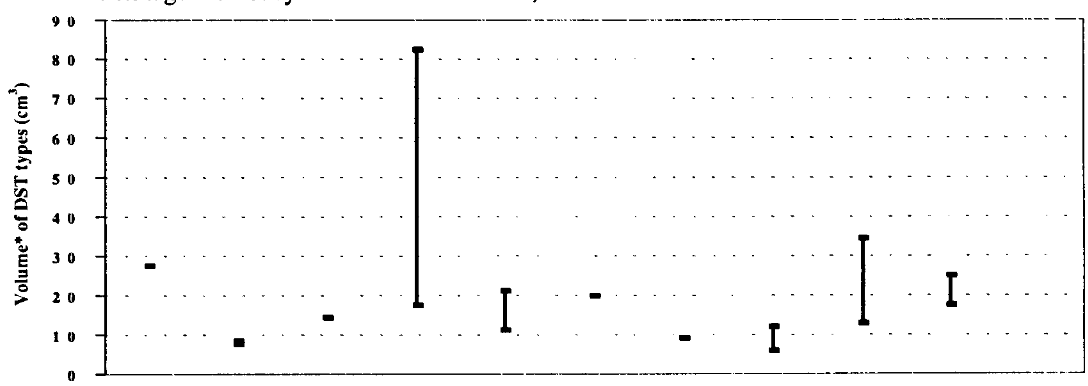
[e] Temperature measurings have option of external sensor that can be used single or parallel with internal sensor

[f] Depth measurings are based on depth range of the sensor (options of max: 500, 1000 or 2000).
Light data (level in relation to time) is used for geolocation using (via software) the timing of local apparent noon to calculate longitude & 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

[g] T/F = tag weight in air/fish weight in air (the ratio is here given as %)



* When tags are not symmetrical in diameter, their diameter values stands for maximum diameter



* Volume is brutto. The volume calculation is based on maximum values for length width or height (diameter) and does not take into account rounding e.g., rounded tag ends.

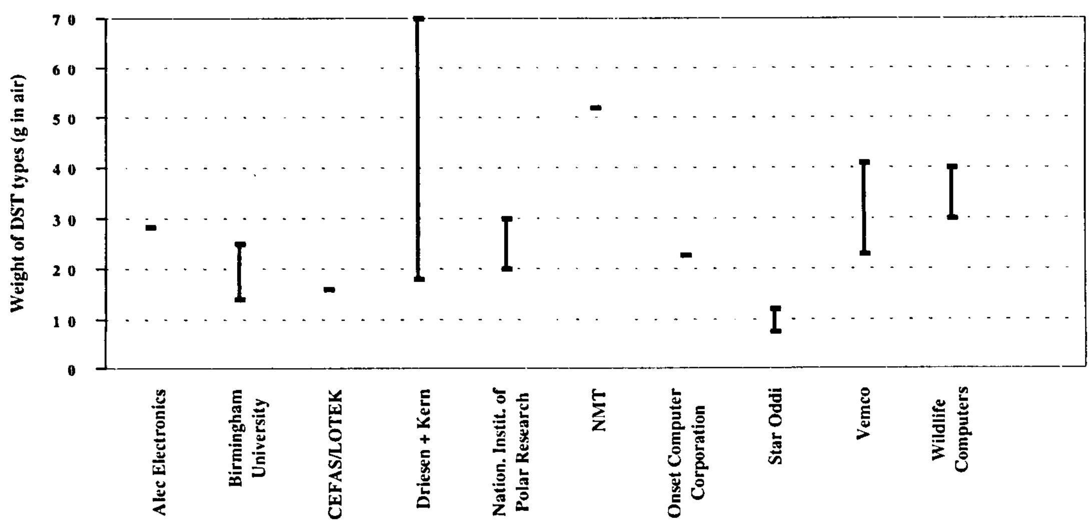
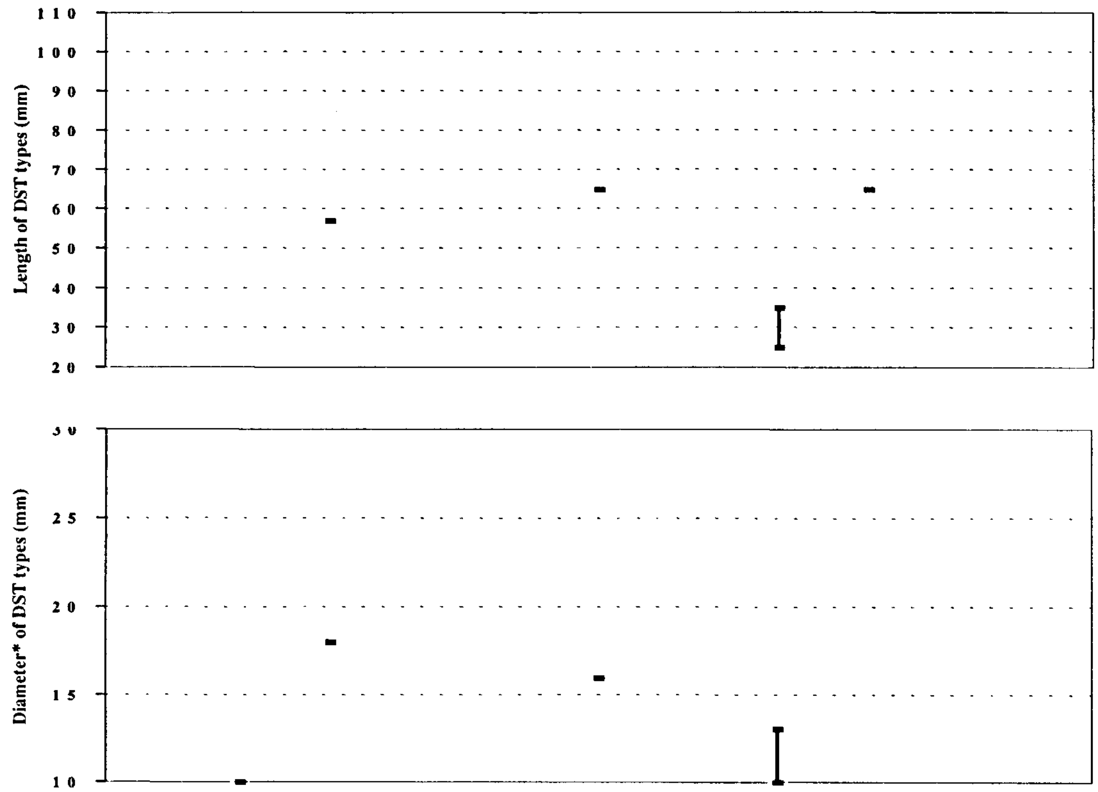
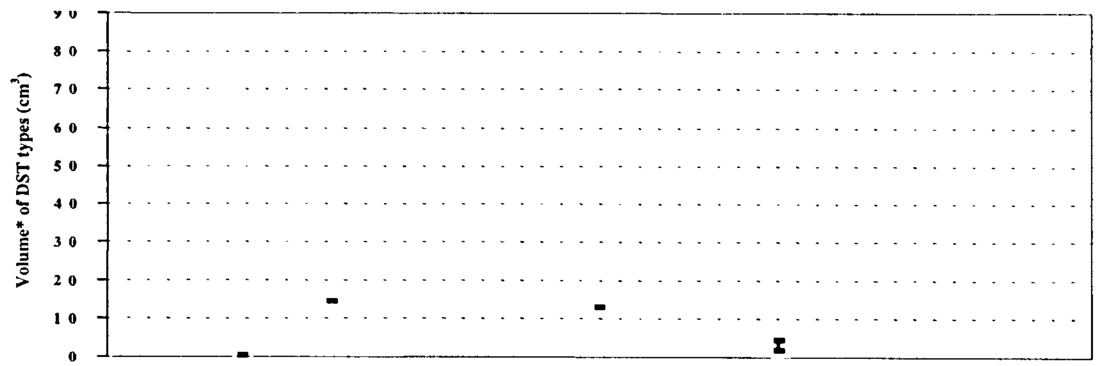


Figure 4.3.1 The smallest available data storage tags or archival tag types or models that can be used on salmon, shown in relation to the firms/institutes manufacturing them. The size of the smallest and largest type/model of tags are shown by plotting their maximum length, diameter, volume (brutto) and weight (in air).



* When tags are not symmetrical in diameter, their diameter values stands for maximum diameter



* Volume is brutto. The volume calculation is based on maximum values for length width or height (diameter) and does not take into account rounding e.g., rounded tag ends.

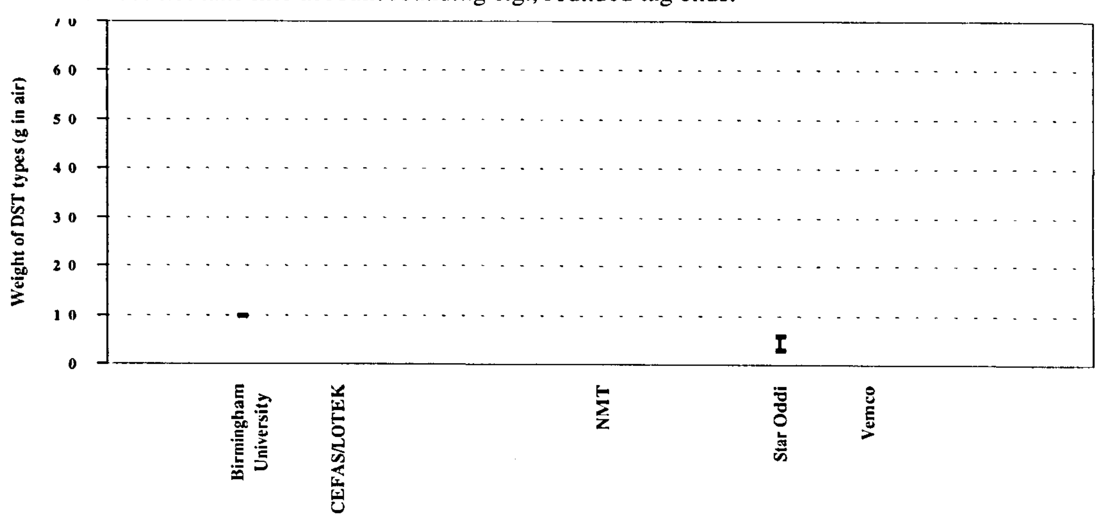


Figure 4.3.2 New data storage tags or archival tag types or models that will be released in the time period 1999–2001 and can be used on salmon, shown in relation to the firms/institutes manufacturing them. The size of the smallest and largest type/model of tags are shown by plotting size limits values that are equal or in most cases higher than planned tag sizes, so most of the tags will in fact be somewhat smaller than these size limits refers to. This maximum in size is given in relation to the following parameters: length, diameter, volume (brutto) and weight (in air).

 O:\Scicom\Lrc\Sgoste\Reports\1998\Rep.Doc

APPENDIX 1

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