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APPLICATION OF ACOUSTIC AND ARCHIVAL TAGS TO ASSESS ESTUARINE, NEARSHORE, AND OFFSHORE HABITAT UTILIZATION AND MOVEMENT BY SALMONIDS

Proceedings of a workshop held 10-11 September, 1996
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Application of acoustic and archival tags to assess estuarine, nearshore, and offshore habitat utilization and movement by salmonids

Executive Summary

Salmonid stocks on the west coast are in trouble and concerns have been expressed by scientific, environmental, and fishing communities. Causes of population declines are complex; variations in freshwater flow, dams, habitat degradation, hatchery practices, climate variability, and ocean conditions may all play a role. The contribution of the estuary and ocean to variations in salmonid survival remains poorly known. Understanding this role and how it varies with changing environmental conditions will require improved knowledge of movements and habitat utilization during different life history stages. This volume is the report of a workshop organized in Seattle in September, 1996 to examine the means by which new tagging technologies, principally acoustic and archival tags, can contribute to our understanding of these questions.

Tag technology is a relatively fast-moving field and application to salmonids may require modified designs; thus, it was timely to convene this workshop to promote communication among scientists interested in salmon and the technologists and engineers developing tags. The general goal of the workshop was to address the potential application of acoustic and data logging tags to describe the utilization of estuarine and ocean environments by salmon during different life-history stages to better understand the role of environmental factors in movements and survival.

The workshop report includes papers presented at the meeting, including three introductory papers which lay out perspectives on the important research needs, experience papers describing research work on topics dealing with applications of acoustic or data logging tags and associated research, and technology papers on the status and evaluation of tags, and contributed abstracts on pertinent biology and technology. A written summary of two discussion groups, one on biology, ecology, and oceanography and the second on technology, is augmented by a series of workshop recommendations.

The participants in the workshop developed 17 recommendations. In the biology-related recommendations, a demonstration project using existing tags was given a high priority. Participants strongly supported research to describe movements and habitat utilization of i) young fish immediately after the transition from estuarine to marine waters, ii) young fish within the estuary, and iii) adults moving into the estuary on the return migration. Application of geolocating tags in the open ocean was also given high priority for west coast chinook and coho salmon, sockeye salmon, and steelhead. In the technology-related recommendations, most important was the calibration and verification of tag precision and accuracy and continued miniaturization of tags, the latter reflecting the desire to extend this research to earlier life history stages of salmonids. Also stressed was the need to evaluate effects of these long-term tags on the fish and to improve geolocating algorithms.

New technologies in tagging have the potential to address several key questions that hinder our ability to evaluate the variability in salmon survival. It is our hope that this volume will foster communication and promote the development of technologies specific to address these questions in salmon.

Workshop Report:
Application of acoustic and archival tags to assess estuarine, nearshore, and offshore habitat utilization and movement by salmonids

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Application of acoustic and archival tags to assess estuarine, nearshore, and offshore habitat utilization by salmonids: Introduction and objectives of the workshop

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Introduction

Declining survival of several salmonid stocks on the west coast has raised alarms in the scientific, environmental, and fishing communities. Central California coho salmon have been listed as threatened under the Endangered Species Act, and other stocks in Northern California and Oregon are being considered for listing. The causes of declining stocks are complex, but have been attributed to a variety of factors, including variations in freshwater flow, dams, habitat degradation, hatchery practices, climate variability, and ocean conditions (National Research Council 1996). In March, 1996, a workshop was held in Newport, Oregon, to examine the role of estuarine and ocean survival in the recent declines of west coast salmon stocks (Emmett and Schiewe 1997). This topic had not been addressed in a coordinated fashion since a similar workshop held over a decade earlier (Pearcy 1984), although recent knowledge and important hypotheses have been summarized in a monograph (Pearcy 1992).

Fundamental to understanding variability in survival in the estuary and ocean is improved knowledge of movements and habitat utilization during different life history stages, including the relationship to environmental variability. Most knowledge of ocean habitat utilization comes from experimental net capture data (Pearcy and Fisher 1988), traditional tagging studies (including coded wire tags and other tags; Myers et al. 1996), fisheries data (French and Bakkala 1974; Welch et al. 1995), experimental fishing (Pearcy et al. 1984), acoustic tagging studies (Ogura and Ishida 1995; Quinn et al. 1989) and trophic studies (Welch and Parsons 1993). Although a great deal of research has been done on the habitat preferences of salmonids in freshwater systems, assessment of thermal preferenda, diel variability in depth, and directed movements in response to environmental variability in the ocean are largely inferred from catch and model data (Healey et al. 1990; Thomson et al. 1994; Welch et al. 1995; Beamish et al. 1995), save relatively short-term studies with acoustic tags (summarized in Ogura, this volume).

How salmon utilize their environment on varying scales was a major point of discussion at the Newport workshop that cut across all working groups (Emmett and Schiewe 1997). As examples, the nearshore working group expressed concern about the movement and habitat residence patterns in the first few days after ocean entry; similar studies are underway with Atlantic salmon (see LaCroix, this volume). At broader scales, the offshore group identified as high priority questions the distribution and migration patterns at sea and the manner in which currents and other physical factors influence them. Both early models of fish movement (French and Bakkala 1974) and recent, more sophisticated ones (Thomson et al. 1994; Dat et al. 1995) rely on a variety of assumptions about fish behavior at scales that remain to be studied in sufficient detail to carefully test the predicted movements. Several participants at the Newport workshop identified the need for applications of new tagging technology to address these and other questions dealing with estuarine and ocean survival, and this workshop has been organized to address these questions.

Tagging programs and tag technology

Tagging is a standardized technique in fisheries science (Neilson 1992) and has been an important component of studies with salmon. A variety of salmon databases on tagging exist; the ocean tagging database (Myers et al. 1996) and the coded wire tag program (Johnson 1990) provide good examples of the large scale (and international scope) on which salmon tagging is undertaken. The importance and magnitude of these tagging projects have made salmon the focus of many developments in tag technology, such as the coded wire tag (Bergman et al. 1968), the passive integrated transponder (PIT) tag (Prentice et al. 1990), and visible implant tags (Blankenship and Tipping 1993; Bonneau et al. 1995). Most of these tags have been designed for mass marking and generally address questions dealing with the population level (fish movement, return rates, or stock integrity). Longer range tracking, including satellite-linked systems, have been used in freshwater with radio telemetry (Eiler 1995), but this system will not operate in saline waters of estuarine and marine systems.

Acoustic tags can be applied to far fewer fish, are labor intensive to apply and monitor, but provide detailed information. In the marine environment, acoustic tags have been extensively applied to large fish, including tunas, billfishes, sharks, and deep-sea grenadiers (Carey and Robison 1981; Holland et al. 1990; Cayre 1991; Klimley et al. 1988; Priede et al. 1990). Acoustic tags have the capability to measure a wide variety of parameters, including depth, swimming speed, tailbeat frequency, and internal body temperature. Given that most studies with acoustic tags involve vessels following individual fish, additional parameters (geographic location, bottom depth, ocean currents, thermal profiles, salinity) can be taken in the general vicinity. Acoustic tags have been applied to salmon (Stasko et al. 1973; Quinn et al. 1989; Ogura and Ishida 1992, 1995; LaCroix, this volume). Although these tags have provided important insights into the ecology and habitat utilization of the salmon studied, they have generally required that individual fish be followed, resulting in small numbers of observations and typically short records from each tag. Unfortunately, these short records create concerns about whether observed behavior is normal. With moderate to large tunas and tag placement outside the body, Holland et al. (1990) found no differences in behavior between early in the record and after 6 days, when the fish was relocated. Contrary to this result, however, was the variation in behavior observed in chum salmon shortly after tagging in a long data record (see Ogura, this volume, Figure 9). Miniaturization and newly developed technologies in tagging may allow following multiple fish as well as recording data and dumping it via an acoustic link to a tracking vessel or to a remote listening station (see Voegeli, this volume), possibly through an array of moored buoys (see Lacroix, this volume. This type of development may help with duration of the record and the numbers of tags that can be deployed.

The newest technology is data logging (archival) tags. The most important issues in the dynamics of tuna movements were addressed by Hunter et al. (1986), who identified application of data logging tags as a high priority to determine the horizontal and vertical movements of tuna over long periods. A principal problem has been the need to recover the tagged animal to retrieve the tag and its contained data; thus, most studies concentrate on fish where tag return rates are high. Generally, data logging tag development has been gradual and marked by continually improved technology and decreasing size. Early tags were large and had a reduced parameter set. Long duration applications of data recording tags to marine mammals, providing time, depth, and temperature data, revealed previously unknown information about foraging, dive depths, and dive duration, with tagging periods up to 145 days (Delong and Stewart 1991; Bovent et al. 1996). It should be noted, however, that data logging tags record only the environment which the fish experienced or selected, which is important information in itself; missing are data on the environmental conditions that the fish avoided. Although this may be inferred from climatological ocean records in the region, nearby moored buoys, remote sensing, or ocean models, higher resolution of this information may require simultaneous monitoring of the physical environment.

The first application of data logging tags on salmon recorded time and depth over a period of some 23 days on chum salmon and provided intriguing results. Although short term behavior may be affected by the trauma of tagging, data from later in the record demonstrated a well-defined pattern of diel movement (see Ogura, this volume, Figure 9). Time-depth recording tags have also been applied to returning adult Atlantic salmon and sea trout in Iceland (Sturlaugsson 1995; Sturlaugsson and Gudbjornsson, this volume). Geolocating tags, which typically add light as a measured parameter and then use an algorithm based on time and daylength (measuring sunrise and sunset), are also under development and obviously highly desirable for measuring migrations. At present, the geolocating tags have been applied principally to tunas (Gunn et al. 1994; Ekstrom, this volume) and preliminary results have provided intriguing insights to the migration pattern of southern bluefin tuna (J. Gunn, CSIRO, personal communication), as suggested by Hunter et al. (1986). Although most geolocating tags are at present too large for application to salmon, sizes are continually being reduced. It is also possible to estimate locations through measurement and simulation of ocean thermal conditions, similar to the approach for plaice movements in the North Sea (Metcalfe and Arnold, this volume); the accuracy of the location information, however, may be questionable in an ocean environment that varies interannually.

Two concerns must be taken into account for application of data logging tags. First is the accuracy and precision of the measured parameters and the consistency between tags. Miniaturized sensors may be subject to drift over time, so careful evaluation of the tags is highly important. Second is the capability of the fish to carry the tags. For short-term acoustic tagging of durations less than 5 days, histopathological effects may not be an overriding concern, although tag effects on behavior (from capture, handling, hydrodynamic drag, or other trauma) obviously are. For longer tagging durations, however, it is critical to minimize the effects of tagging, which can affect fish health, swimming ability, or vulnerability to predation. Tag shedding or extrusion must also be evaluated. In traditional tagging programs, significant effort has gone into evaluating tag effects (Roberts et al. 1973; Neilson 1992; Blankenship and Tipping 1993) and tag loss (Wetherall 1982). With acoustic tags, Quinn et al. (1989) demonstrated that returns and travel rate of sockeye salmon did not differ from those tagged with disk tags alone. Other experiments with salmonids have shown effects on behavior (Mellas and Haynes 1985) and dramatic, size-dependent effects of ultrasonic tags on growth (Greenstreet and Morgan 1989). Data logging tags have several characteristics that mandate careful evaluation of their effects before a serious tagging program is undertaken. The tags are relatively large, will likely be on the fish for long periods, and are expensive; preliminary testing of intramuscular implantation in tunas has been promising (see Brill et al., this volume). Because the probability of tag return may be low, it is important to assure the best match of the tag to the fish to maximize chances of recovery (see Siri, this volume).

Objectives of the workshop

New tagging technology has the potential to reveal important information on salmonid movement and habitat utilization. Both short-term acoustic tags and recording, or archival tags may be beneficially applied to address specific topics of interest. Tag technology is a relatively fast-moving field and several salmonid biologists are interested in applying these technologies; thus, it was timely to convene this workshop to promote communication among scientists interested in salmon and the technologists and engineers developing tags. The general goal of the workshop was to address the potential application of acoustic and data logging tags to describe the utilization of estuarine and ocean environments by salmon during different life-history stages to better understand the role of environmental factors in movements and survival.

The workshop took place 10-11 September, 1996, at the NOAA Pacific Marine Environmental Laboratory in Seattle. Before the meeting, participants were provided with a series of questions to stimulate thought on the focus of the workshop, including the following:

Biology, Ecology, and Oceanography

- What is known about the movements of salmon in estuarine, nearshore, and open ocean habitats at varying scales?
- How can we best measure the role of environmental and habitat factors in salmon habitat utilization and movements?
- What are the most important species, life history stages, habitats, and geographic scales to address these questions and what can be gained from the application of acoustic and data logging tags?
- What priority order should be given these research issues?
- What are current or planned research activities associated with application of tags?

Technology

- What is the current state of acoustic and data logging tag development as it relates to application in salmonids?
- What specific developmental engineering work should be undertaken to make these tags more suitable for application to different salmonid life history stages?
- What is the capacity of salmonids to carry these tags?
- What are the priorities for tag development?

Organization of the workshop report

The workshop report generally follows the agenda of the meeting. Three introductory papers were presented to lay out perspectives on the important research needs in estuarine, nearshore, and oceanic environments. "Experience" papers describe research work by participants at the workshop on topics dealing with applications of acoustic or data logging tags and associated research. "Technology" papers were presented on the status and evaluation of tags. The abstracts of these presented papers are followed by a written summary of two discussion groups, one on biology, ecology, and oceanography and the second on technology, held sequentially so that all participants could contribute. The discussion groups addressed the questions outlined above plus other topics that arose during presentation of the papers. Arising from the discussion groups were a series of recommendations; these were circulated after the meeting for further discussion and elaboration, and finally voted on to assign priority order. Finally, three appendices include i) contributed abstracts (pertinent abstracts on biology and technology not presented at the meeting), ii) the meeting agenda, and iii) the list of participants at the meeting.

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Introductory Papers

The following three abstracts reflect three papers presented to provide a perspective to the workshop on the three principal habitats where research using acoustic and data logging tags is deemed useful and to describe the kinds of data that are most important to understanding salmonid utilization of these habitats.

Estuarine Life History of Salmonids: Potential Insights From Tagging Studies

Robert Emmett and Earl Dawley, National Marine Fisheries Service Northwest Fisheries Science Center, Coastal Zone and Estuarine Studies Division.

Studies by Reimers (1973), Simenstad et al. (1982) and others have shown that estuarine rearing plays an important role in salmonid life histories and can affect the ocean survival of ocean-type chinook (*Oncorhynchus tshawytscha*), pink (*O. gorbuscha*) and chum (*O. keta*) salmon. In contrast, with the exception of sea-run cutthroat trout (*O. clarki*), smolts which migrate as yearlings and older [e.g., sockeye *(O. nerka*), steelhead (*O. mykiss*), and (stream type) chinook salmon] generally do not utilize estuaries extensively. Despite these general migration and timing behaviors, actual estuarine use varies by species or stock and appears to be mediated by water temperature, river flow, food availability, and other factors.

Although archival, acoustic, and radio tags may answer many scientific questions related to the estuarine and early ocean life history of salmonids, their large size relative to the size of migrating salmon smolts limits their potential (Table 1). Small subyearling smolts are presently effectively tagged by small coded wire tags (CWT) and passive integrated transponders (PIT) tags.

Table 1. Juvenile salmonid size, timing, peak migration period, and individual residence in West Coast estuaries. Critical size is the minimum length required to survive ocean entry. Question marks indicate unknown or uncertain information.

Species	Size during migration (fork length - mm)	Timing of migration	Peak migration period	Individual residence (days)
Pink salmon	30-80 critical size 45-55?	Early Feb- Jun	Late Mar- Early May	~2-60+
Chum salmon	30-100	Early Feb-Jul	Late Mar- mid May	4-32+
Chinook salmon spring/summer	100-175	Jan-Jul Nov-Apr (Calif)	Apr-May Jan-Feb (Calif)	? limited?
Chinook salmon fall	30-130 critical size 80-90?	Jan-Dec	Jun-Oct	10-60+
Chinook salmon late fall	30-?	Apr-Oct	?	?
Chinook salmon winter	30-?	Jun-Dec	Aug-Sept.	?
Coho salmon	100-200	Mar-Jul	May	6-40
Sockeye salmon	40-120	Apr-Jul	May-Jun	some rearing?
Steelhead	150-300	Apr-Jul	May	limited
Cutthroat trout	130-300	Feb-Oct	Apr-Jul	1-150?

Past smolt tagging studies with CWT and PIT tags have provided valuable salmonid life history information. For example, Dawley et al. (1986) estimated smolt migration rates through the Columbia River and defined timing of ocean entry based on extensive sampling of smolts tagged with CWTs. They also discovered that salmonids released farthest upriver migrated the fastest, while those released closest to the estuary migrated the slowest. Furthermore, they found that subyearling chinook migrated the slowest (<4 km/day), and yearling and older smolts migrating much faster (>10 km/day). They also found that some salmonid stocks, such as ocean-type chinook salmon, actually slowed their migration when they entered the estuary.

Recovery of CWT and non-tagged smolts in the Columbia River estuary by the National Marine Fisheries Service (NMFS) during the Columbia River Data Development Program found that, in general, yearling salmonid smolts migrate in the main estuarine channels and do not considerably slow their migrations. However, at present little information is available that reveals how long individual fish actually reside in different estuarine habitats.

Coded wire tag- and PIT-tag studies in the Columbia River and other Pacific Northwest rivers have also provided valuable information on variability in ocean survival rates for salmonid smolts which migrate at different times and sizes. For example, Matthews et al. (1992) found that late migrating spring/summer chinook salmon in 1990 returned as adults in significantly higher numbers than earlier migrants (Table 2). Evidently, ocean and estuarine environmental conditions were favorable for salmonid survival during that period, however, no data were collected to monitor those environmental conditions. We do know that timing of favorable ocean and estuarine conditions are not always consistent from year to year.

Development of very small archival or acoustic tags that could record environmental data (salinity, temperature, and depth) would be valuable in identifying 1) how long individual juvenile salmonids reside in particular estuarine habitats, and 2) what environmental factors influence their distribution. The recent development of a surface trawl PIT tag detector by NMFS promises to be a valuable tool for assessing movements and survival of migrating juvenile salmonids (Richard Ledgerwood, National Marine Fisheries Service, Hammond, OR, Pers. comm., Sept. 1996). A recent study by Oregon State University investigators using radio-tagged migrating juvenile spring/summer chinook salmon in the lower Columbia River, highlights the value of tagging studies. They found that 90% of their study fish survived from Bonneville Dam [river kilometer (Rkm) 200] to the head of the estuary (Rkm 75) but about 30% of these fish were lost in the estuary. They were able to find most of the lost tags in nesting tern and cormorant colonies (Larry Davis, Oregon State University, Fish and Wildlife Dept., Corvallis, OR, Pers. comm, Sept. 1996). Although this study appears to identify the intensity of bird predation on estuarine smolts, research needs to be conducted to confirm that radio-tagged juvenile salmonids are exhibiting normal migratory behavior and are not unusually susceptible to avian predation.

In conclusion, archival, acoustic, and radio tags offer a wide range of effective methods for identifying individual movements and behaviors relative to estuarine and coastal environmental conditions, and perhaps identify sources of mortality. However, these tags will probably not provide answers to questions concerning factors that limit estuarine and ocean juvenile salmon survival for most populations. Studies should be conducted that identify the physical and biological conditions in estuarine and nearshore coastal environments that facilitate high ocean survival. These studies can effectively be conducted using serial releases of CWT- or PIT-tagged groups of smolts with concurrent measurements of physical and biological conditions in estuarine and nearshore marine environments. Data collected could be used to ensure that hatchery fish are released at times that are optimal for estuarine and ocean survival.

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Table 2. Adult returns to Lower Granite Dam of spring/summer chinook salmon (Oncorhynchus tshawytscha) smolts marked and transported from the dam in 1990. Data taken from Matthews et al. 1992.

Dates marked	Number of smolts marked	Total adult return estimates N	%
13-18 Apr	5,938 Hatchery	23	0.40
	1,062 Wild	5	0.05
18-21 Apr	6,218 Hatchery	18	0.30
	782 Wild	5	0.60
21-25 Apr	6,256 Hatchery	25	0.40
	744 Wild	18	2.40
25 Apr-2 May	6,039 Hatchery	30	0.50
	961 Wild	5	0.50
2-14 May	6,203 Hatchery	30	0.50
	797 Wild	23	2.90
14-29 May	4,857 Hatchery	85	1.80
	2,143 Wild	58	2.70
29 May-8 Jun	1,177 Hatchery	25	2.10
	1,531 Wild	63	4.10
Totals	36,688 Hatchery	235	0.60
	8,020 Wild	175	2.20
Grand Total	44,708	410	0.90

Habitat Utilization and Movements of Salmonids in Coastal Waters

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Introduction

All anadromous salmonids inhabit coastal waters where they reside during a portion of their early life history. Many coho and chinook stocks never leave nearshore waters and spend their entire ocean life there. Other species, such as pink, chum and sockeye salmon and steelhead, leave coastal waters and migrate into the oceanic zone of the subarctic Pacific, where they feed and mature, and then return to coastal seas on their spawning migrations.

Early marine life of salmonids is thought to be a critical period in the life history, when survival rates are high and variable and when recruitment to fisheries is determined. Most fisheries are for mixed stocks of salmon in coastal waters. These are two major reasons for learning more about the coastal movements and habitat utilization of salmonids.

General Questions

Five sets of questions need to answered in order to understand ocean factors that influence the growth, survival, movements and habitat utilization of salmonids:

1. What are the patterns of distribution and migration of stocks in the ocean? Are they genetically controlled or determined by the environment?

2. How are these patterns influenced by ocean conditions, by physical processes such as fronts, eddies, upwelling and currents, and by biological factors such as food availability, competition and predation?

3. How are patterns of distribution and movements related to subsequent growth and survival rates? Is mortality highest in specific habitats?

4. What are the major causes of mortality? How dependent are predation rates on the availability of other forage species?

5. What are the effects of interactions among stocks on growth and survival--between stocks that inhabit the same ocean habitat or between hatchery and wild stocks in a common ocean region?

What Have We Learned from Past Research?

From the millions of tags (coded-wire, disk, Floy, thermal, etc.) much as been learned about the movements, growth, and survival of salmonids between release, usually at a hatchery facility, and recovery at a hatchery or in a fishery. Examples were (1) the recovery of maturing fish after tagging juvenile fish in their first ocean year (Hartt and Dell 1986); (2) the movements of OPI hatchery smolts during their first summer in the ocean off Oregon and Washington (Pearcy and Fisher 1988); and (3) the latitudinal distribution in the ocean of the coded-wire tagged coho released from hatcheries along the coast of the Northeast Pacific (Weitkamp et. al. 1996).

The advantages of these types of tags is that many smolts can be marked before they enter the ocean. Hence the number of returns are large enough for statistical analyses. Often smolts can be marked over a short period of time, and automated procedures can be now used. The disadvantages are that only data on release and recapture locations and times are provided, and no intervening data. Little information is given on short-term movements or habitat selection, and nothing on vertical excursions.

Ultrasonic tagging, on the other hand, has been used to track a single fish over a period of hours or days, and can provide data on vertical movements and temperature selection (see for example Quinn and terHart 1987; Quinn, this workshop). However, tracking with vessels in the ocean is very expensive, and usually only one fish can be tracked at a time, usually over relatively short distances.

Needed are tags that can be tracked or record information on movements in three dimensions over weeks or months. Ideally, smolts or post-smolts should be tagged so that the origin of the fish is known and the movements of specific stocks can be studied in the coastal ocean during their juvenile life history and during the coastal fisheries for maturing fish. This would facilitate recovery of tags either in a specific fishery or hatchery.

Studies that provide detailed information on movements of salmonid using smart tags should obtain or utilize concurrent data on ocean conditions so that movements can be related to ocean currents, frontal structure, temperature patterns, etc. Although smart tags may monitor temperature, temperature fields available over a broad area are needed to determine habitat preference.

Specific Recommendations

For ultrasonic tags, manufacture a size that can be inserted into the stomach of smolts, 100-200 mm FL. Increase the range of tags so they can be detected up to 1000 m. Study the feasibility of tracking smolts in the coastal zone using a series of moored receivers that either store data or relay data by radio to a shore station or to satellite.

For archival tags, we need tags that can be used on or in maturing fish that monitor latitude, longitude, and depth. External temperature or internal temperature could also be monitored. Internal temperature may increase, as it does in bluefin tuna, and provide information on feeding periodicity and rates. Data from archival tags could be recovered after capture of the fish in a fishery, hatchery or homestream. However, determination of the stock origin may be difficult for fish caught at sea. Desirable features of archival tags include sensors to measure compass heading and swimming speed or tailbeat frequency so that currents in the swimming field can be determined.

Since mortality and predation are major ecological concerns, and affect recovery of tags, sensors should be developed to determine when and where a fish dies. Monitoring tail beat or muscular contractions during swimming, or changes in pH, have been suggested as a way to obtain this information.

For all types of tags, the accuracy of parameter estimates and the effects of the tags on the behavior and physiology of the fish should be carefully evaluated.

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Ocean Studies Using "Smart" & Hydroacoustic Tags

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To date, open ocean salmon tagging has been restricted to the use of uniquely numbered spaghetti or disk tags. Tags are cheap, but application in the ocean is expensive because of the need for an ocean-going vessel capable of remaining out at sea for up to a month. In the eastern north Pacific (Gulf of Alaska) about 10% of all tags applied to salmon in the 1960s were recovered. Even if the recovery position and date is accurately recorded by the fisherman, then the maximum information that can be obtained is the straight line distance between the two points, and the ***minimum*** swimming speed needed to transit directly between the two points.

Tagging programs using the technology of the 1950s and 60s greatly improved our knowledge of the relative distribution of different stocks and species in the open ocean. However, these programs gave us only glimpses of the environmental constraints that have shaped the evolutionary biology of salmon and, by implication, the environmental factors affecting their productivity. I think that there are 3 prominent applications for new tagging technology in the open ocean ecosystem:

(1) How do salmon navigate on the High Seas?

(2) How do salmon use the environment of the High Seas?

(3) How are bioenergetics of salmon on the High Seas determined?

Answers to these questions depend on knowing on a day-by-day or even finer scale basis what salmon are doing in the ocean, where they go, what environmental conditions they avoid or are attracted to, and how salmon migrate through frequently complex and heterogeneous ocean conditions. In essence, we are asking what evolutionary factors have shaped their oceanic life histories. Smart tag technology is now sufficiently accurate to allow us to address most of these questions in the ocean. This talk detailed a short list of questions I view as the next logical steps for us to investigate, and discuss the next generation of tags on which we should focus our development effort.

Experience Papers

The following paper and six abstracts describe selected studies pertinent to the application of acoustic or data logging tags to salmonids. The first paper describes a variety of studies with these tags that have been conducted in Japan, the remainder in the U.S. or Canada. In the contributed abstracts, note that five additional studies are described; two involve research on salmonids, three are on other species.

Acoustic and archival tagging work on salmonids in Japan

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Abstract

I reviewed 12 acoustic and 5 archival tagging studies on salmonids that have been conducted in Japan since the 1970's. Acoustic tags have been used from the mid 1970's for salmonid research and archival tags were introduced to salmonid research in the 1990's. In the 1970's and 1980's Japanese acoustic tagging systems were used in Japan but from the 1980's the VEMCO system became increasingly popular. Eight of 12 acoustic tagging studies were conducted in coastal waters, three studies were done in offshore waters and high seas, and one in a lake. In one of five archival tag studies, fish were released from offshore waters, but other works were conducted in coastal waters and rivers. Chum salmon were used for most of Japanese studies and recently masu salmon were also studied. The purposes of the research using smart tags have been to investigate fish behavior in relation to fishing gear and to investigate salmon orientation and homing mechanisms. The principal motivation, especially for the early studies, was to learn how salmon move at sea. To facilitate communication with North American scientists, I put together a list of Japanese scientists using smart tags for studying salmonids.

Introduction

Salmonids were frequently used as subjects during the development of ultrasonic telemetry systems in Japan because they are popular fish species, have interesting behavior such as homing, and are easy to handle for experiments. When considering the application of archival tags, homing is a very good characteristic because it facilitates recovery of the tag. Though there were some preliminary studies conducted in 1960's and early 1970's, in this report I reviewed successful studies on salmonids with acoustic and archival tags in Japan since the 1970's. Some of the most recent studies are not available on documents and/or papers, and details of some of these studies could not be presented in this report.

Acoustic and archival tagging systems

The National Research Institute of Far Seas Fisheries (NRIFSF, formerly Far Seas Fishery Research Laboratory) and Tokai University were pioneers in developing ultrasonic telemetry in Japan. Their telemetry system had been manufactured by Koden Electronics Co., Ltd. (KODEN) since late 1970's (Figure 1). Japanese studies in late 1970's and 1980's were conducted by using this KODEN system. KODEN may continue to make transmitters but the receiver system has not been improved during the last 20 years. From the late 1980's, most Japanese research groups began to use VEMCO products.

In many studies the transmitter was attached to the base of the anal fin and allowed to trail from the fish (Figure 2). In some recent studies, the transmitter was attached on the back of the fish with two plastic fasteners or vinyl strings (Figure 3). Stomach insertion has seldom been used in Japan. The hydrophone was attached at the bottom of a pole mounted at the side of the research vessel. In most cases, the direction of hydrophone was changed by hand rotation of the pole by an operator, but recently a motor-driven pole was used (Figure 4). Now one group has introduced a towed hydrophone system from VEMCO but it has not been used for tracking salmonids yet.

There are three study groups developing archival tags for biological research; Kyoto University, National Institute of Polar Research (NIPR), and NRIFSF (Fur seal section). Archival tags have been developed for large marine mammals since the 1970's (but not smart <u>memory</u> tags, instead early versions used pen recorders). In the 1990's, tags have been much miniaturized and memory capacity has been increased, and the application to fish study began. Tags developed by Kyoto University are commercially sold through Alec Electronics Co. Ltd. (Alec). NIPR's tags are also available directly.

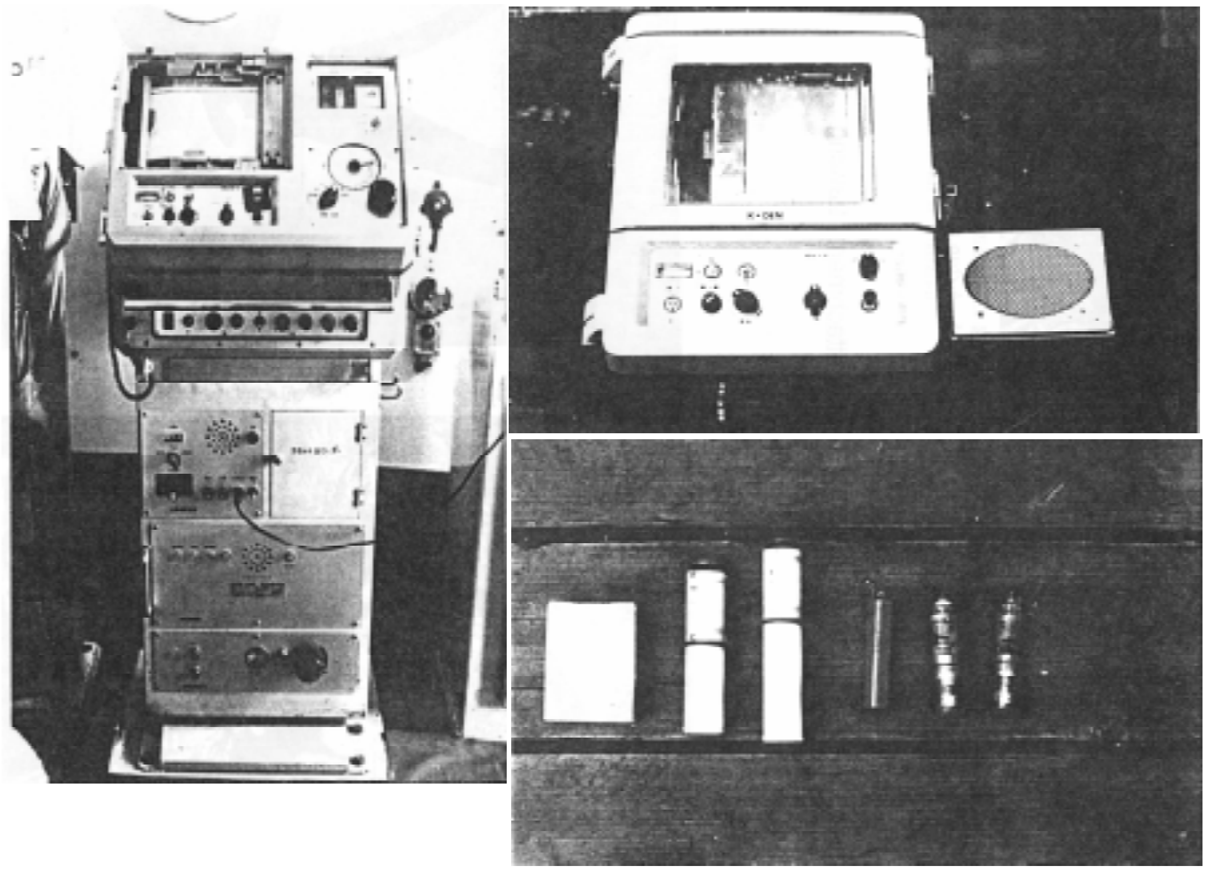


Figure 1. KODEN receiver and transmitters.

The biggest concern of researchers using acoustic tags is the accuracy of horizontal position. Telemetered information, such as depth or temperature, is very accurate (depending on the sensor and transmitter system). Methods of positioning the research vessel have greatly improved. In the past radar or Loran was used but now GPS is used. However, the horizontal position may have a large error. Archival tags would also need to fix the horizontal position accurately.

Acoustic tagging studies

In 1974, NRIFSF and Tokai University conducted a tracking study of maturing chum salmon at off Etorofu Island, Kuril Islands (summary table A, **1**; Ichihara et al., 1975). This was apparently the first successful tracking by Japanese scientists. They tracked the fish over 163.6 km during 37 hours and presented the horizontal tracks and vertical movement in their paper (Figure 5). This shows many circular motions in the fish tracks. In this study the fish's position (= research vessel position) was determined by the radar observation of the vessel and island, and the rotational trajectory was not verified.

Ultrasonic telemetry was used in the environment assessment for examining the effects of heated water from an atomic power plant on fish behavior (Summary table A, **2**). Results of this kind of study were not circulated widely, but Fukushima's report concluded that they did not obtain enough data, especially on horizontal movement, and they stopped using telemetry in their assessment work.

One of the most interesting characteristics of salmonids is their homing ability. Tokai University scientists studied the effects of visual and olfactory ablation on the swimming behavior of chum salmon

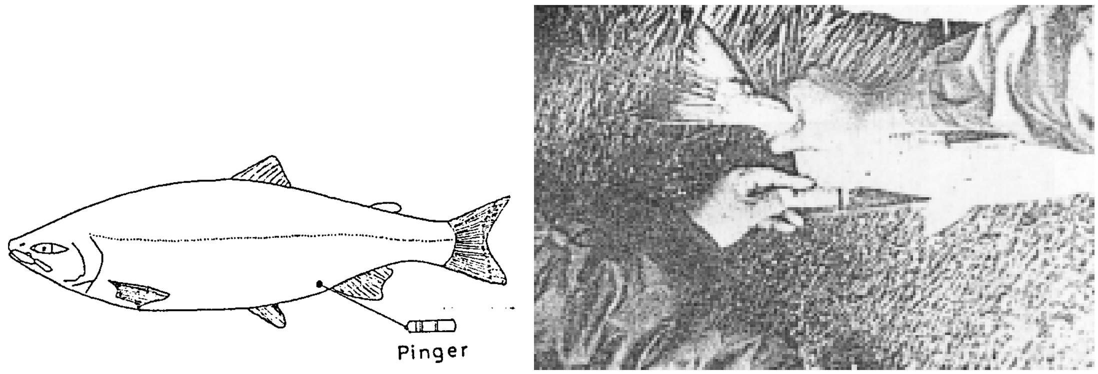


Figure 2. External transmitter attachment: trailing from the fish. On the left is a fish with a pinger and on the right a photo of a chum salmon with trailing type transmitter.

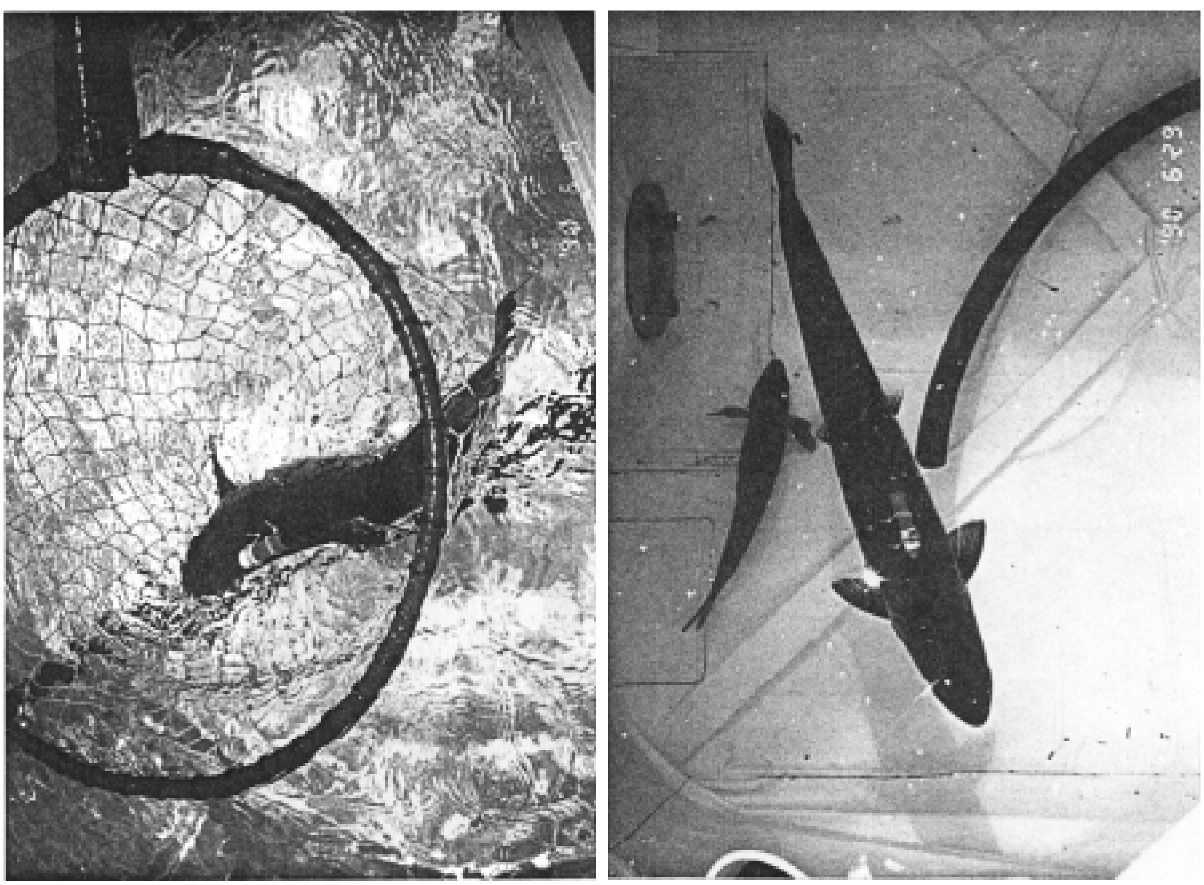


Figure 3. External transmitter attachment: fixed on the back.

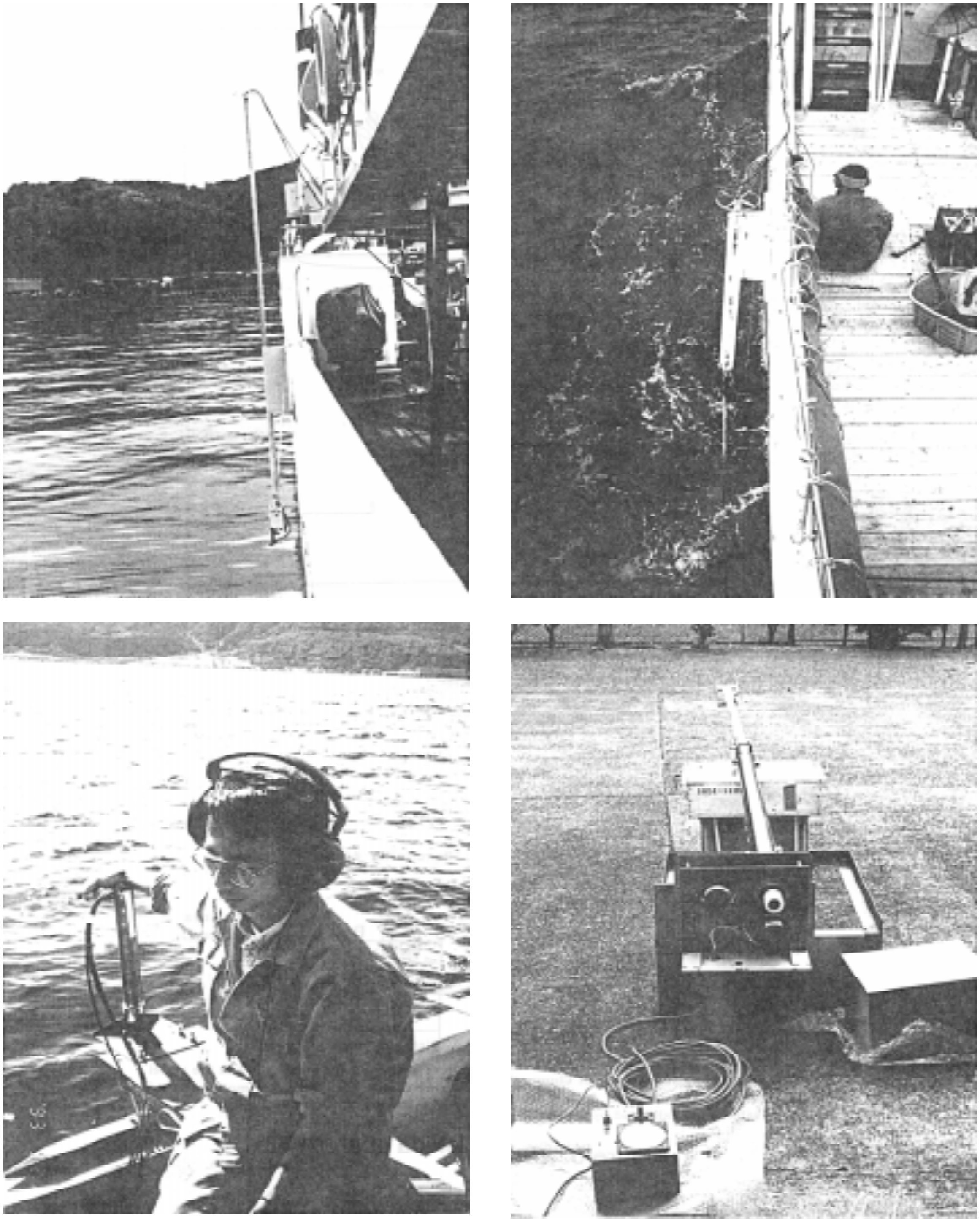


Figure 4. Hydrophone and pole rotating system.

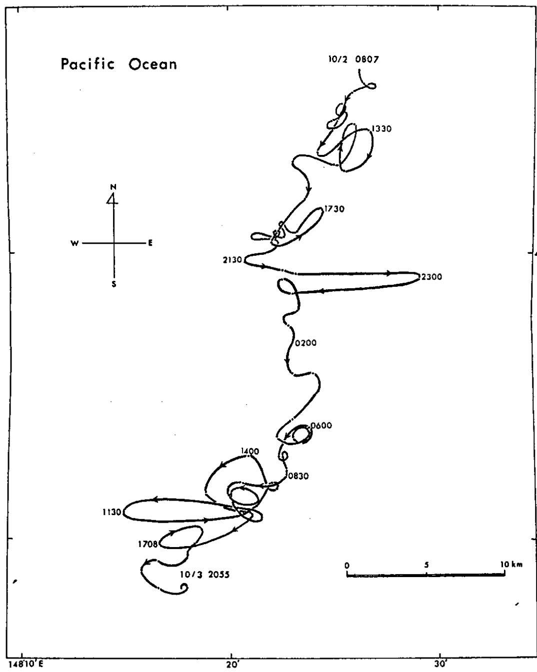


Figure 5. Horizontal movement of a chum salmon (from Ichihara et al. 1975).

with acoustic tags (summary table A, 3; Yano and Nakamura, 1992). Chum salmon caught in the river, 1.5 km upstream from the river mouth, were transported to a release site at sea near the river mouth. Twenty-one fish with acoustic tags were released as controls. Vision was ablated in 6 fish, olfactory ablation was done in 7 fish and both ablations were done in one fish. Intact fish and blind fish returned to the home river, but anosmic fish did not. From observations of the horizontal and vertical movements for each experimental group, the authors concluded that olfaction was necessary for correct choice of the home river (as shown in previous studies) and vision is important for regulating the amplitude of vertical movements.

In 1980's some studies attempted to observe salmon movement in coastal waters in relation to the coastal fishing gears, such as the trap net (summary table A, 4, 5, 6; Yoza et al., 1985; Soeda et al., 1987; Ishida et al., 1988). It is important to know the movements of adult salmon in coastal waters for regulating these fisheries. The path of adult chum salmon before entering the natal river was along the coastline. Authors in Iwate PFES's group showed that there was a relationship between salmon movement and tidal direction. They were also concerned with the low accuracy of horizontal position in this tracking method (Figure 6).

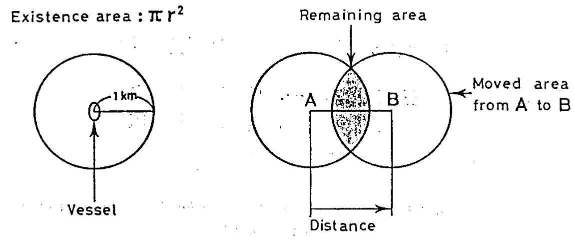


Figure 6. Estimated existence area of chum salmon in relation to the vessel. When the vessel tracked chum salmon from A to B for the distance shorter than 2 km, the moved area of chum salmon are exhibited by the existence area of B less the remaining area. (From Ishida et al. 1988).

In 1989, NRIFSF started a tracking study in the open sea in the area of high seas salmon driftnet fishery ground in order to examine the efficiency of surface gillnets and to study migratory behavior (summary table A, **7**). After preliminary studies with tracking devices, they decided to use the VEMCO system. They continued this work during four years and tracked 23 individuals of 6 salmonid species in the central North Pacific and the Bering Sea (Ogura and Arai, 1992; Ogura and Ishida, 1992; Ogura 1994; Ogura and Ishida, 1995). The authors showed the vertical distribution of each species and discussed the migratory ability of salmonids in the open sea.

Aomori PFES tracked masu salmon movements in coastal waters in relation to the fishing gear (summary table A, **8, 9, 12**). Masu salmon have high commercial value and Japan has had an enhancement project for masu salmon for a long time. Aomori PFES tracked masu salmon at three life history stages: sea run juveniles in an estuary, immature fish in coastal waters, and adult fish in coastal waters. Though the tracking durations of juvenile fish were brief (from one to six hours), and the number of immature and adult fish tracked was also not enough, they provided general descriptions of behavior. The author said that while tracking fish in coastal waters he could not track fish when they fish moved into shallow waters near rocks. Aomori PFES subsequently changed from acoustic tracking to archival tagging.

Hokkaido University and Hokkaido Salmon Hatchery are continuing the tracking study to investigate the mechanism of homing by using kokanee

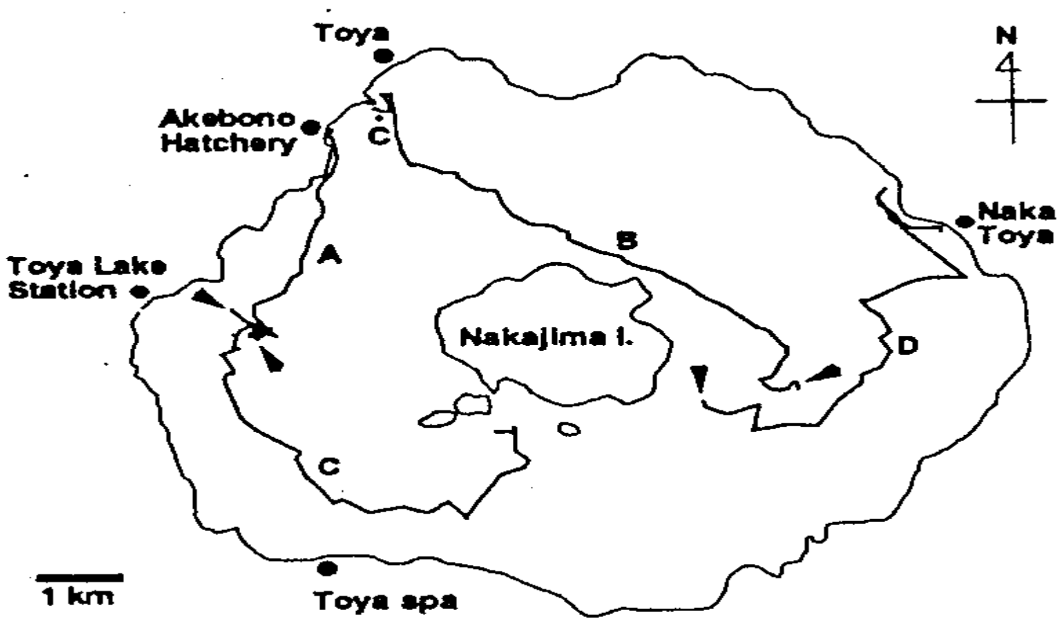


Figure 7. Tracks of four mature male kokanee salmon in Lake Toya during the spawning season. Arrowhead indicates the releasing point of each fish. A, control fish; B, magnetic cue-interfered fish; C, visual cue-interfered fish; D, visual and magnetic cues-interfered fish. (from Ueda et al. 1995).

and masu salmon in Lake Toya (summary table A, **10**; Ueda et al., 1995; Sato et al., 1996). Lake Toya has surface area 70 km^2, average diameter 9.4 km and average depth 116 m (Figure 7). Four mature fish were subjected to one of the following treatments: A) attachment of a brass ring on the head, B) attachment of a NdFe magnet ring on the head, C) injection of a mixture of carbon toner and corn oil into eyeball to detach retinas, D) detached retinas and attachment of magnetic ring. The results demonstrated the direct return of kokanee using visual cues and indicated that kokanee did not primarily use magnetic cues in the selection of the natal area, but it is still likely that fish supplementally use magnetic cues for their orientation. They also conducted biochemical and cytophysiological analyses as well as behavioral study with acoustic tagging.

Chiba University and NRIFSF (and Tohoku National Fisheries Research Institute) developed artificial magnetic field generators consisting of an electromagnetic coil and a drive circuit to investigate the magnetic sense of the ocean migrating maturing salmonids (Figure 8; Yano et al., 1996). In the first several hours, this device was off and the salmon swam under the normal geomagnetic field. Then the magnetic field generator began inducing an alternating magnetic field whose intensity is 6 gauss, with polarity reversed every 11.25 min. during the subsequent 16 hours. This device was used in the field research in 1994 off Kuril Island and 1995 off Hokkaido's Pacific coast. Changes of fish behavior were observed by the acoustic telemetry system (summary table A, **11**; Yano et al., 1995; Yano et al., 1996). In 1994, tracking time was not sufficient to evaluate the difference between behavior under artificial magnetic field and normal conditions. However, one fish with this device returned to a Hokkaido river 20 days after it was released. In 1995, 4 chum salmon were tracked during 67 hours. Most fish showed no remarkable changes of movements after application of the altered magnetic field.

Archival tagging works

To investigate the behavior of maturing chum salmon returning vicinity of their natal river in early stage for spawning (i.e. water temperature in the coastal waters is still high), Iwate PFES released 10 chum salmon attached with two archival tags (temperature and depth) for each fish (summary table B, **13**). Seven fish were recaptured by trap nets in the coastal waters. The data showed that the fish swam in water temperatures

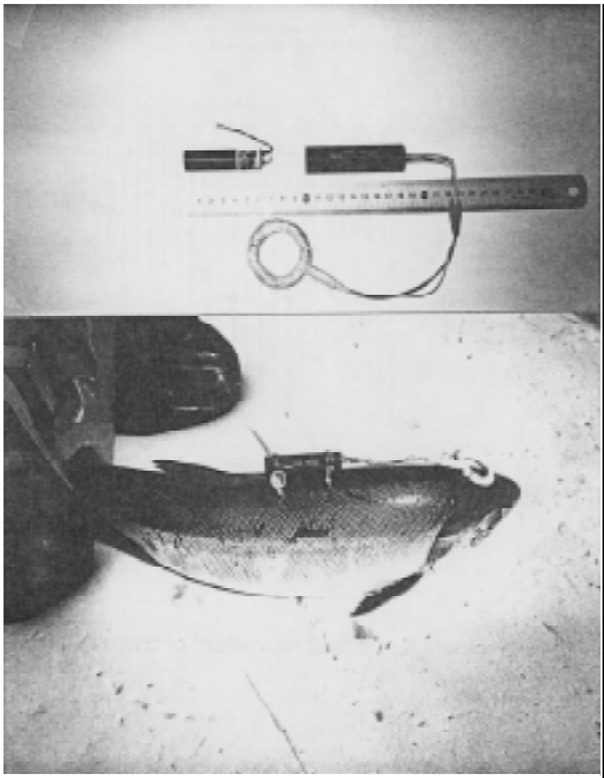


Figure 8. Artificial magnetic field generator attached to a chum salmon.

less than 13˚C at depths of 100-210 m in daytime and occasionally ascended to the surface where water temperatures was more than 18˚C at night. To further investigate how salmon select their ambient temperature, NIPR and Iwate PFES released 27 chum salmon with archival tags (both temperature and depth recording) and obtained 12 recoveries (summary table B, **17**) in 1995 (Tanaka et al., 1996). This research was conducted in October and December, two different water temperature conditions. Results showed that salmon stayed in deep water in October (salmon avoided high temperatures and took refuge in deeper water) whereas they stayed in shallow water and rarely occurred in deeper water in December.

NRIFSF released 13 chum salmon with depth recording archival tags from off Kuril Islands under the usual tagging program (summary table B, **14**). One fish was recovered in the coast of Hokkaido and 21 days data showed clear daily vertical movement pattern (Figure 9).

As mentioned before, Aomori PFES started the archival tagging for masu salmon instead of the acoustic tagging from 1995 (summary table B, **15**). They released 5 adult masu salmon but no recovery was reported in 1995.

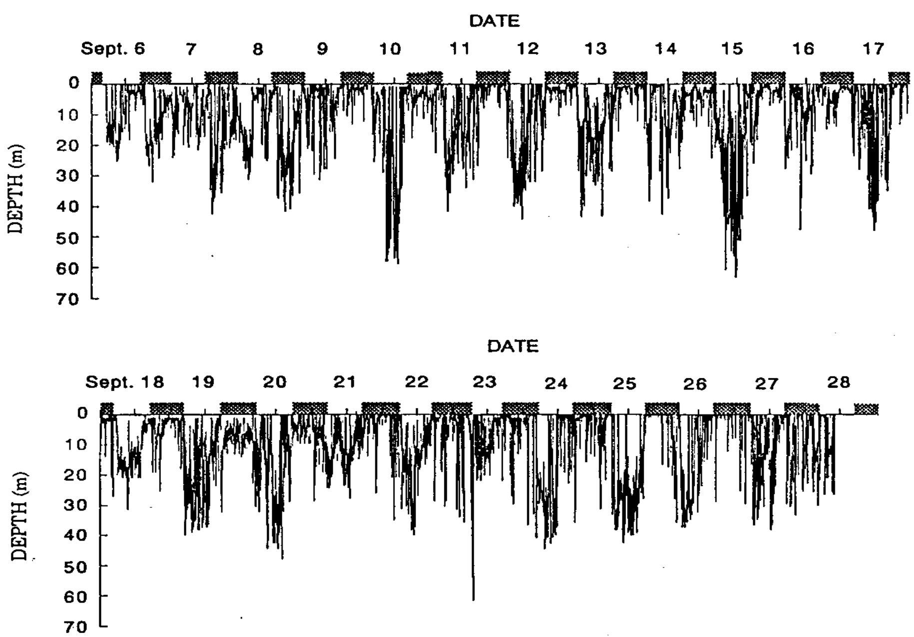


Figure 9a. Vertical movement of chum salmon from September 6 to 28, 1994. Shaded time zones indicate nighttime.

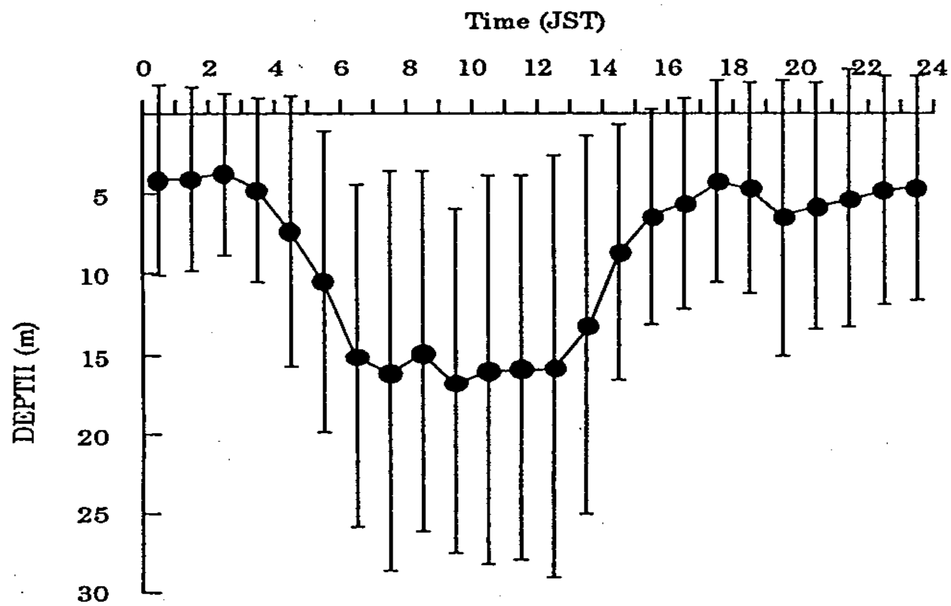
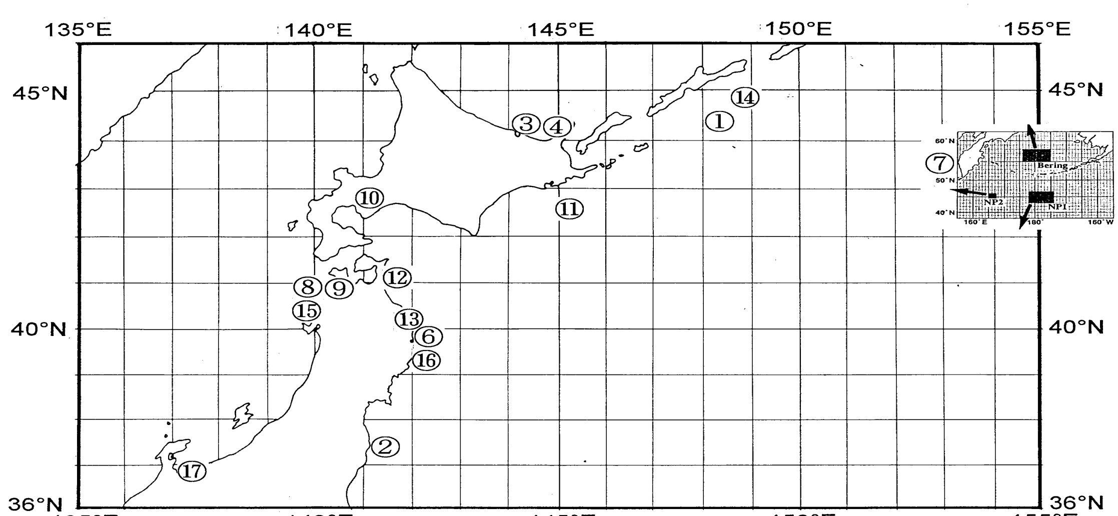


Figure 9b. Average vertical movement of chum salmon. The average depth during 1 hour periods. Values are means and standard deviations. JST, Japan Standard Time.

Kyoto University scientists have investigated the otolith microchemistry to detect the timing of ocean entry and upstream movement of masu salmon. They began the behavioral study using archival tags this year (summary table B, **16**). The purpose of this archival tagging was to learn the duration and the timing of residence in the river mouth and to compare this information with the archival information on the otolith. Next year, researchers are planning to track masu salmon in the river so radio or satellite tracking will be used.



Summary figure. Locations of smart tag studies on salmonids by Japanese scientists. The numerals indicate study numbers in summary tables A and B (located on the following two pages).

Summary table A. Studies with acoustic tags conducted since the 1970's in Japan. Numbers in the left column refer to studies in the text and locations on the summary figure on page 23.

	Organization	Period	Area	System manufacture	Species	Number tracked	Total data (hr)	Purpose of research, Special treatment
1	NRIFSF	1974	Off Kuril Island	Original	Chum	1	37	Swimming behavior
2	Fukushima PFES	1978-1979	Coastal waters Honshu Pacific Coast	KODEN	Chum	6	50	Assessment research of atomic power plant
3	Tokai Univ.	1979-1981	Coastal waters Hokkaido Okhotsk Sea	KODEN	Chum	35	394.5	Natal river finding mechanism, Visual and /or olfactory ablation
4	Nihon Univ.	1982-1996+	Coastal waters, Hokkaido Okhotsk Sea	KODEN	Chum	20+	422+	Swimming behavior in coastal waters in relation to coastal fishing gears
5	Aomori PFES	1983	Coastal waters, Tsugaru Strait	KODEN	Chum	5	?	?
6	Iwate PFES	1984-1985	Coastal waters, Honshu Pacific Coast	KODEN	Chum	6	81	Swimming behavior in coastal waters in relation to coastal fishing gears
7	NRIFSF	1989-1992	High seas, Bering sea and central N. Pacific	VEMCO	6 Salmon Species	23	1138	Migratory behavior
8	Aomori PFES	1992-1993	Coastal waters, Honshu Japan sea coast	VEMCO	juv. Masu Salmon	7	27	Estuary habitat of sea run juvenile
9	Aomori PFES	1992-1993	Coastal waters, Honshu Japan sea coast	VEMCO	Masu salmon	3	79	Swimming behavior in coastal waters in relation to coastal fishing gears
10	HSH, Hokkaido Univ.	1993-1996+	Toya lake	VEMCO	Kokanee Masu salmon	13	?	Natal river finding mechanism Visual ablation, magnet attachment
11	Chiba Univ., NRIFSF	1994-1995	Off Kuril Island, Off Hokkaido	VEMCO	Chum			Homing behavior, Artificial magnet field
12	Aomori PFES	1995	Coastal waters, Honshu Pacific coast	VEMCO	Masu salmon	4	?	Swimming behavior in coastal waters in relation to coastal fishing gears

NRIFSF: National Research Institute of Far Seas Fisheries. KODEN: Koden Electronics Co., Ltd., Shinagawa, Tokyo, Japan
PFES: Prefectural Fishery Experimental Station. HSH: Hokkaido Salmon Hatchery

Summary table B. Studies with smart tags on salmon in Japan. Numbers in the left column refer to studies in the text and locations on the summary figure on page 23.

	Organization	Period	Area	System manufacture	Species	Number of fish recaptured/released	Days of data	Purpose of research, Special treatment
13	Iwate PFES	1993	Coastal waters, Honshu Pacific	Alec	Chum	7/10		Swimming behavior in relation to water temperature
14	NRIFSF	1994	Off Kuril Island	Alec	Chum	1/13	23	Swimming behavior
15	Aomori PFES	1995	Coastal waters, Honshu Japan sea	VEMCO	Masu salmon	-/5	-	Swimming behavior in coastal waters in relation to coastal fishing gears
16	NIPR, Iwate PFES	1995	Coastal waters, Honshu Pacific	Original	Chum	12/27	>10 per individual	Swimming behavior in relation to the environment change
17	Kyoto Univ., Toyama PFES	1996+	River and estuary, Honshu Japan Sea coast	Alec	Masu salmon	?	?	Behavior in the estuary,

NIPR: National Institute of Polar Research Alec : ALEC Electronics Co.,Ltd., Nishi-ku, Kobe, Japan

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Atlantic Salmon Data Requirements and Data-Logging Tags

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The distribution of thermal habitat has emerged as an important correlate to survivorship and sexual maturation processes in Atlantic salmon. The first year of ocean life is critical to defining population abundance and fishery yields of Atlantic salmon populations. As is the case with other salmonids, the ecology of Atlantic salmon during the first year at sea is poorly understood due to a lack of basic data on distribution and behavior. Research catches have yielded some information; but, research cruise effort has been limited and salmon post-smolts have proven difficult to catch in conventional gears. Some success has been achieved recently using small mesh gill nets in the Labrador Sea and surface trawls in the Norwegian Sea; however, a comprehensive description of the thermal preferences and distribution of post-smolts is still lacking. Index stocks in the northeast Atlantic area survive at higher rates when warm waters dominate the North Sea and Norwegian coast during May, the peak smolt migration month. These temperature trends may affect post-smolt growth directly or affect post-smolt migrations. Population abundance of both North American and European two seawinter salmon has been correlated with over-wintering thermal habitat. It has been suggested these temperature distributions guide migrations, which in turn influence sexual maturation. Data-logging tags offer a tools to study both survival and maturation phenomena in Atlantic salmon. Tags are already being applied to adult salmon to study thermal preferences of maturing fish; however, no tags are yet available to record thermal history of post-smolts during the critical first year at sea.

Ultrasonic Tracking of Salmonids: Selected Experiences and Perspectives

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The movements of salmonids in marine waters are of great interest to those studying migratory behavior and to those charged with managing fisheries and conserving fish populations. Fisheries take advantage of migratory patterns, so knowledge of these patterns is essential for sound management. In pursuit of basic knowledge with applications to management, I have been involved in several studies using ultrasonic telemetry. I will briefly review the work on sockeye salmon, steelhead trout and chinook salmon, indicating some of the patterns observed. I will also discuss the drawbacks of "conventional" tracking and present two situations that present excellent opportunities to test archival tags.

New Technologies for Measuring Tag Induced Stress: Determining Competency Over Time

Paul Siri, Bodega Marine Laboratory, Univ. Of California, Davis P.O. Box 247, Bodega, CA 94923

The desirability to create increasingly powerful, intelligent tags that provide insight to stock behavior is tempered by physiological limitations created by host response. Although large and sophisticated tags have been tested successfully in elasmobranchs and large bony fish such as marlin, swordfish and tuna, the ability to tag salmon with smart tags will require evolution to smaller packages and a thorough understanding of host response as measured by conventional cortisone and glucose techniques and newer more sophisticated cellular and molecular assays that are proving to be more reliable and sensitive indicators of stress events. Together, these tools will provide insight to cumulative stress factors that will assist in interpreting the range of environmental conditions that make anadromous fish such a challenge to tag. The ability to sort out multiple stress events will guide the determination of reliable tag size limit and the appropriate tagging environment.

NerkaSim: A micro-computer model of the Northeast Pacific Ocean and Bering Sea for simulating sockeye salmon migrations and growth.

Michael Healey, Fisheries Centre, Westwater Research Centre, Department of Earth and Ocean Sciences, University of British Columbia, Vancouver, BC, Canada.

A spatially explicit, individual-based migration model of the Northeast Pacific Ocean and Bering Sea (NerkaSim) has been constructed to explore hypotheses regarding migration and growth of sockeye salmon. Monthly surface currents (from an empirical model), sea surface temperatures (from COADS data), and prey fields (from available zooplankton data) provide the space-time variability of the biophysical environment from 1950 to the present. Plausible migration behaviours have been parameterized. Fish movement may be random or directed, and swim speed may be proportional to body length or optimum cruising speed (a function of fish weight and temperature). Bioenergetics equations are used to model growth (a function of fish weight, temperature, swim speed, and available food). The model runs under Windows95 or WindowsNT and provides a variety of graphical and statistical outputs.

NerkaSim was used to formalize, test and explore alternatives to an accepted yet untested conceptual model of sockeye migration (French et al. 1976), which has fish migrating twice around the Alaska Gyre during their two-year period of ocean residence. Using minimal assumptions about navigational capability and swimming behaviour, model fish only completed one loop of the gyre; however, these results account just as well for the available empirical data as the "accepted" model. Our most striking result was the degree to which interannual variations in surface currents of the Gulf of Alaska influenced the migration trajectories. These simulations have suggested several hypotheses that could be validated by archival tagging (one versus two loops of the gyre, large differences in migration trajectories between years driven by current variations, greatly different oceanic locations of year classes just prior to return migration).

The flexibility of NerkaSim allows the testing of a very broad range of hypotheses about sockeye migration behaviour and salmon growth. Because sockeye salmon disperse over large areas in the open ocean, the spatial and temporal heterogeneity of the environment experienced by members of the same population can be captured well using this individual-based modelling approach. Prior to undertaking any costly, large-scale archival tagging program, NerkaSim should be considered for developing and refining testable hypotheses. It should also be considered for the quantitative analysis of salmon trajectories obtained from tagging experiments, particularly when the effects of advection and salmon behaviour shouldn't be separated.

Computer Simulations of Sockeye Salmon Return Migrations: Results yielding testable hypotheses of migration behaviour and the effects of the marine environment on migration paths that plead for archival tagging experiments.

Keith A. Thomson, Fisheries Centre and Department of Earth and Ocean Sciences, University of British Columbia, Vancouver, BC, Canada.

Latitude of landfall, coastal migration routes, and timing of sockeye salmon during their return migration are important to Canadian and U.S. fisheries managers, particularly, the latitude of landfall and coastal migration routes of Fraser, Nass and Skeena River sockeye because the year- to-year variation in migration paths affects the proportion of fish accessible to American fishermen. We have used computer models to simulate the effects of gyre-scale and mesoscale currents on sockeye salmon migrations, gaining new insights on how sockeye navigate and how interannual changes in the ocean may affect the return migration paths. The results have been used to develop new indices of ocean variability for predicting stock-specific return times of Fraser River sockeye; however, lingers doubts about the robustness of such forecasts will persist until we obtain a move complete understanding of the underlying processes. The available empirical data are insufficient to verify our migration models - archival tagging experiments are called for.

Simulations of the effects of gyre-scale currents on sockeye return migrations have shown that the interannual variability of northeast Pacific Ocean currents could account for year-to-year differences in return times as high as 2 wk and latitudes of landfall as high as 550 km. The eastward-flowing Subarctic Current assists the homeward migration of sockeye and the northward-flowing Alaska Current deflects migrating fish to the north. A stronger Alaska Gyre circulation would generally result in earlier return times and more northward latitudes of landfall, depending on the pre-migration distribution of the fish. Simulations of the effects of the Sitka eddy on sockeye returning to northern British Columbia were prompted by speculation that this vigorous mesoscale eddy, which is not present every year, would deflect migrating salmon to the south (thereby affecting the proportion of salmon accessible to Alaskan fishermen). Migration paths were simulated using a range of hypothesized direction-finding mechanisms (i.e. compass orientation, navigation with constant swimming speed, and speed-compensated navigation) and rheotactic responses to ambient surface currents. The least complex migration behaviour (i.e. compass orientation with no rheotaxis) was only slightly less efficient in metabolic terms than the dynamic programming solution (which calculated the optimum migration paths by minimizing metabolic cost). It appears that a complex migration behaviour need not be postulated for efficient return migrations. Except for behaviours with positive rheotaxis, the eddy currents provided a homeward "boost" to model fish and reduced migration times. The eddy also effected bifurcations of migration paths around its centre and bimodal distributions of salmon return times at the coast. The Sitka eddy does appear to effect southward deflections of migration paths, and thus more southward latitudes of landfall compared to when the eddy is not present. The largest year-to-year differences in latitudes of landfall, however, were due to interannual variations in the Alaska Current, not the presence or absence of the Sitka eddy.

These results comprise a set of testable hypotheses which should be considered for study with archival tagging experiments.

Auke Bay Laboratory's Ocean Carrying Capacity Research Program

John H. Helle, Auke Bay Laboratory, Alaska Fisheries Science Center, National Marine Fisheries Service, Juneau, Alaska

A major marine climate regime shift occurred in the North Pacific Ocean during 1976-77. Survival of salmon at sea increased greatly after this shift. However, body size of chum salmon decreased and age-at-maturity increased in both North America and Asia. Most of the other species of Pacific salmon have also decreased in size. These changes have coincided with record numbers of salmon returning to spawn, which may indicate that the ocean carrying capacity for salmonids may be limited under certain conditions.

The North Pacific Anadromous Fish Commission (NPAFC) at their 1993 annual meeting identified two critical issues for research by the member parties: 1) factors affecting current trends in ocean productivity in the North Pacific Ocean and their impacts on salmonid carrying capacity, and 2) factors affecting changes in biological characteristics (growth, size and age at maturity, oceanic distribution, survival, and abundance) of Pacific salmon.

The Ocean Carrying Capacity Research Program (OCC) was initiated in 1995 at the Auke Bay Laboratory to respond to these concerns. This Program has four components: 1) research on juvenile salmon in coastal waters, 2) research on immature and maturing salmon in coastal and offshore waters, 3) monitoring of oceanographic conditions along the coastal waters, and 4) retrospective research on growth using scales, otoliths et al.

Various aspects of this research were described, in particular, the successful 42 day cruise of the chartered FV Great Pacific during July and August 1996. A surface trawl was towed at 5 knots and proved very effective in capturing juvenile and immature salmon. This gear was fished from shore to the continental shelf from Dixon Entrance to beyond Amchitka Island in the Aleutian chain. More than 9000 juvenile and immature salmon were captured and samples were retained for genetic stock identification, examination of heat-marked otoliths, and research on growth, energetics, and food studies.

Technology Papers

The following six abstracts describe selected studies on current acoustic or data logging tag technology and evaluation. Two abstracts represent evaluation or benchmark studies of tag accuracy and the need for further evaluation, one the current development of a data logging tag, and the remaining three describe products from different manufacturers. In the contributed abstracts, note that products from four additional manufacturers are described.

Benchmark Tests of Accuracy of Two Archival Tags

A. Peter Klimley, Bodega Marine Laboratory, Univ. of Calif., Davis, P.O. Box 247, Bodega Bay, CA 94923

Charles Holloway, Joint Institute of Marine and Atmospheric Research, University of Hawaii, 1000 Pope Rd., Honolulu, HI 96822

Geolocating archival tags obtain records of the daily geographic positions of tagged fish. Longitude is determined using a method similar to that used by ancient sailors to navigate the oceans. They found their longitude from the difference between the time when the sun was at its highest point at their present location and the expected time at a reference location (e.g., Greenwhich, England). This time differential was measured with a chronometer. The archival tag has an accurate internal clock which can be initialized to GMT. However, the tag can not find noon directly from the position of the sun, but does so indirectly by sensing the rapid changes in the level of light under water when the sun rises and sets below the horizon each day. Apparent noon can be estimated as midway between points on a curve of daytime light curve. Daylength is additionally an indicator of latitude. The accuracy of the latitudinal coordinate is dependent both on latitude (highest near the poles, lowest near the equator) and time of year (highest during the solstices, lowest during the equinoxes).

We tested the accuracy of two archival tags (Northwest Marine Technology [NMT], Wildlife Computers [WC]) at a depth of 10 m on a Fish Aggregation Device (FAD) located 9 km northwest of Oahu, Hawaii (21o 27.50' N., 158o 16.90' W). The mean longitude determined over a period of 26 days by the NMT tag was 16.6 km west of the FAD and the coordinate varied ±57.0 km along a meridian. The mean longitude of the WC tag varied from 8.5 km east to 75.8 km west of the FAD based upon the sampling interval (2, 4, and 6 min). These positions varied ±46.7-88.1 km. The mean latitude of the WC tag over 15 days ranged from 16.8 km north to 41.7 km south of the FAD with positions varying ±133.4-183.4 km. We will briefly describe tests on a prototype magnetic field sensor capable of increasing the accuracy of the tag's latitude coordinate. This sensor would estimate latitude using (1) an estimate of the tag's longitude based upon light changes, (2) a measurement of local total field intensity, (3) a file of known intensities for the same longitude corresponding to different latitudes, and (4) the one-dimensional root- finding Newton-Raphson method.

Progress on Geoposition Estimation and Assessing Archival Tag Accuracy

David Welch, High Seas Salmon Research, Ocean Sciences and Productivity Division, Pacific Biological Station, Dept. of Fisheries and Oceans, Nanaimo, B.C. V9R 5K6

We began evaluating the capabilities of archival tags for use in ocean studies of salmon migration and bioenergetics starting last fall (1995). This experience has led me over a circuitous course. The first major message I have is that designing a ***proper*** experiment to calibrate and evaluate geoposition of any potential tag is far from trivial. As a result, the preformance of most tags on the market have not been sufficiently “ground-truthed”, simply because it is extremely difficult to do so. As a result, the true capabilities of most tags on the market are unknown, and the practical benefits of various technical differences touted by the manufacturers is impossible to evaluate. The bottom line is that independent evaluation of the capability of various tags after the tags are commercially available is crucial, and must be built into the costs of conducting a tagging program. **It is unacceptable in my view to rely on manufacturer’s stated claims of accuracy before a very serious effort is put into validating accuracy. This is the responsibility of the scientific community.**

The second (and primary) message of this presentation is that archival tags show great promise for opening up major avenues of research which to date have been blocked by the lack of appropriate technology. In my own research, I have focussed on developing a modified strategy for estimating geoposition from dawn and dusk, and developed specialized filters that can be designed to pass the geoposition signal while excluding much of the variability due to electronic noise, variations in sea state, cloud cover, and fish orientation. The latter are very substantial! I believe these technical advances will allow us to significantly improve the estimation of daily geoposition from light data over what was previously possible, and perhaps allow us to estimate the daily mean position of a tagged animal to within perhaps ±20 kms-- much closer than was previously possible. More importantly, the positional accuracy is likely now as small or smaller than the amount of movement a tagged salmon might make each day, and below the spatial resolution of physical oceanographic models of the current and temperature fields in the ocean. ***My second message is that the time is now ripe for starting a major ocean tagging program. By its nature, this means that the program should be a single focussed international effort, including all of the Pacific Rim salmon producing countries***.

Development of a Small Format Temperature Logging Tag

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The Northeast Fisheries Center, in cooperation with researchers at the University of Rhode Island and private sector industry, is developing a data-logging tag that can be applied to small fish. The approach has been to concentrate on one measured parameter, temperature, and package the tag as small and cost effectively as possible. To achieve this design goal, the tag will be based on a monolithic integrated circuit that performs all the functions of a programmable temperate data-logger. The thermal sensor is implemented as a simple pn-junction. Pn-junction voltages will be converted to digital data with an 8-bit A/D converter, which will more than exceed accuracy goals of 0.5˚C. Timing will be kept onboard the chip by using a ring oscillator circuit, thus, eliminating the need for an external crystal oscillator and reducing fabrication and engineering costs. However, this design feature is not without its limitations, timing accuracy is compromised and power consumption is accelerated reducing the longevity of the tag. Serial communication on the device will allow delayed arming and flexible programming of sampling intervals. The feasibility of bonding the chip directly to a battery power supply housing is being investigated. This tag system provides the basis to develop a family of data logging tags utilizing the space and cost advantages of silicon integrated circuits.

Tagging Technology from VEMCO Limited

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Ultrasonic tracking techniques are fast changing to allow a wide range of automated data gathering experiments with fish released after tagging with electronic tags. The increased pace of developments has been enabled by the availability of miniature low power microprocessors to perform data gathering and communication functions.

The archival or storage tag can gather a Megabyte or more of data but requires that the animal be recaptured to retreive the data. To retreive the data without recapture of the fish we combine data storage with ultrasonic data communication. The first implementation of a "Communicating Histogram Acoustic Transponder" (CHAT) tag was tested this summer in a package size suitable for sea mammals and sharks. The tag size although excessive for salmon (32mm Diameter x 120mm Length) can be miniaturized in the future for work on adult salmon. The limitation placed on the amount of data which can be transmitted in the low acoustic bandwidth (typically 6000 readings) demands that some data processing be done on the tag to reduce the amount of data. Data reduction algorithms can be designed for a particular animal type or study. The prototype system provides a user selectable interval over which Min, Max and Average depths are recorded along with temperatures at each depth.

Ultrasonic receiver and tracking system developments have also been evolving rapidly. The receiving system for the CHAT tag is suitable for large vessel tracking at sea with four hydrophone arrays and a personal computer interface which points the helmsman directly to the tag showing range and bearing. This allows the tracking vessel to maintain contact with a tag until the data has been downloaded. Automated monitoring stations for simple identification tags will be modified to gather data from CHAT tags. The data gathering system which will be described allows the tag to break off communication at any point and resume communication at the same or any other monitor.

We have also put significant effort into tag development for salmon smolt studies. In the last two years we have been involved in a collaboration between the Atlantic Salmon Federation and Fisheries and Oceans Canada to develop a tag which will allow tracking of wild smolt as they move out of the rivers. A new single chip crystal controlled transmitter has been successfully implanted in wild smolt of 150mm length. The transmitter size is 8mm diameter by 26mm length and gives up to 400 meters range in salt water for one month. Smaller tags with longer life can be built with the same single chip circuit if detection range can be sacrificed.

Automated detection sites have proved valuable for monitoring the passage of smolts out of an estuary. Submersible monitors can identify multiple tags on each frequency. A description of plans for further development of automated receivers and miniature ultrasonic tags will be presented at the workshop.

Archival Tag Technology from Northwest Marine Technology, Inc.

Phil Ekstrom, Northwest Marine Technology, Inc., P.O. Box 427, Shaw Island, WA 98286

The NMT archival tag was developed for geolocation in tuna, and has demonstrated longitude accuracy of better than one degree in that service. Errors appear to be dominantly random and unbiased, and an average over a long run of successive positions is ordinarily good to a few tenths degree. Its latitude accuracy from solar data is less good, with systematic errors of perhaps two degrees at mid-latitudes, plus random errors, but that is expected to improve. Latitude may also be obtained from sea temperature, but its accuracy difficult to evaluate. The tag can return daily positions for a mission of at least seven years. Time series logging of internal and external temperature, depth, and light intensity is also provided for a more limited duration. Size is 16 mm diameter by 100 mm long, weight 52 grams. Surface materials are stainless steel, silicone, and fluorocarbon plastic. The tag is designed to be implanted, with a 2mm diameter measurement stalk protruding through the skin of the animal. Tuna tolerate it well, showing none of the irritation or infection common with other percutaneous tags at the site of skin penetration. Implantation in salmon has not been tried.

A new version now under development will be smaller and lighter with larger memory and longer life. A possible version of the tag adapted specifically to the shorter life span of salmon could be smaller and lighter yet.

Lotek Marine Technologies Inc.--Salmonid Acoustic and Archival Tags; Current Products and Emerging Technologies

Keith Stoodley. Lotek Marine Technologies, Inc., 114 Cabot Street, St. John's, NF, A1C 1Z8 Canada

Lotek Marine Technologies is a full service biotelemetry company which specializes in the design, manufacturing and servicing of innovative products and systems for tracking and monitoring in the ocean environment.

Lotek Marine builds upon nearly two decades of aquatic telemetry expertise at its sister company, Lotek Engineering; including its role in a multi-agency effort to examine factors influencing the migration of Chinook (Oncorhynchus tshawytscha) and stealhead (O. mykiss) on the Columbia and Snake rivers. Lotek's acoustic expertise and product line was enhanced by the recent signing of a licensing agreement with the Ministry of Agriculture, Fisheries and Food (MAFF) of the United Kingdom. For the past 30 years, MAFF's Directorate of Fisheries Research, has provided innovative and reliable telemetry systems for application to environmental issues in the estuarine and marine environment. Yet another significant Lotek collaboration, is its five year partnership with the Institute of Biotelemetry at the University of Waterloo and the Natural Sciences and Engineering Research Council (NSERC). In recognition of the need for improved tools and technologies to understand and predict the behavior and response of fish to natural and anthropogenic perturbations, this initiative includes studies ranging from fundamental muscle physiology to studies of fish energetics, nutrition and condition indices.

Recent developments have brought microprocessor based transmitters to the forefront. Our 'field-proven' digitally encoded telemetry system dramatically improves your ability to keep track of large numbers of tagged fish. The ability to tag multiple fish on the same frequency optimizes the use of available bandwidth, decreases scan time and hence decreases the probability of missing fish while increasing the tags operational life. Lotek Marine also supply a variety of non-coded specialty transmitters for use of micropingers on small fish such as smolt, and in special sensor applications. The electromyogram (EMG) transmitter for example, is designed to obtain, transmit and record the electromyograms produced in the muscle of free swimming fish as quantitative indicators of overall fish activity in the laboratory or field.

Lotek's Combined Acoustic Radio Transmitter (CART) is the fusion of acoustic and radio frequency transmitters into a single device. Through a conductivity sensor, the CART device senses it's operational environment, saline vs fresh water, and dynamically switches to the optimal mode of transmission, acoustic vs radio. CART enables researchers to monitor the migration of anadromous species such as Pacific salmon from ocean through to spawning site with a single transmitter. These same researchers are quick to appreciate the ability to switch between ultrasonic and radio monitoring; an inherent system attribute of Lotek's SRX_400 receiver. The SRX_400 is a rugged 4 MHz telemetry receiver/datalogger, which provides the basis for cost effective yet comprehensive systems for unmanned, remote data acquisition for coded or uncoded transmitters. These field proven systems bring to the manager and researcher multi-tasking capabilities for such diverse functions as manual tracking, automatic data logging and direction finding. Lotek Engineers are currently developing an innovative receiver technology that will be able to discern sonic signals at a lower signal-to-noise ratio than possible with existing technology.

As open ocean studies are extremely challenging, many research groups have moved to Archival or Data Storage Tag research programs. Lotek's archival tag utilizes a light sensor to measure ambient light levels to obtain navigational information and is supplemented with sensors that measure pressure and temperature. The data transfer mechanism is an infrared optical link and it has 1 Mbyte of flash memory.

Discussion Groups and Workshop Recommendations

Following the presented papers at the workshop, two discussion groups were convened on the topics of "biology, ecology, and oceanography" and "technology" as applied to the application of acoustic and data logging tags to salmonids. The discussion groups were held sequentially so that all participants could contribute. From the discussion groups came a series of workshop recommendations, which are included in this section.

Group Discussion: Salmonid Biology, Ecology, and Oceanography; What can be learned from acoustic and data logging tags?

Discussion Leader: **Kate Myers**

This group discussion was initiated with a series of non-exclusionary questions posed in the agenda, as follows:

- What do we need to know about the movements of salmon in estuarine, nearshore, and the open ocean at varying scales that is not available from current sources?
- How can we best measure the role of environmental and habitat factors in salmon habitat utilization and movements?
- What are the most important life history stages, habitats, and geographic scales to address these questions and what can be gained from the application of smart tags?
- What priority order should be given these research issues?

As background, several topics were discussed. First, the magnitude of the problems suggests a critical need for a collaborative effort. Salmon stocks are often mixed at sea. Different national fisheries may take returning fish (with problems of interceptions). Pooling limited funding and scientific resources will be required. There is also an important need to show the relevance of recommended research to either fisheries management or to questions dealing with the Endangered Species Act (ESA) in the US.

Participants also noted that we should focus on the most important issues but must be realists in determining what can be reasonably accomplished. The group agreed to initially focus the discussion on what can be done with existing technology and then move toward broader objectives to give the engineers and tag technologists information that can help with future design requirements.

Estuarine and Early Offshore: Residence and Movements

Many important questions exist about estuarine residence and movement into the nearshore environment. Generally, participants agreed that the most important problems were associated with juvenile salmon; adult movements up-estuary are rapid and may not be an issue in survival (with the possible exception of longer-term residence in locations like Puget Sound). For juveniles in estuaries, the fundamental question of interest is the role of estuarine residence in survival. Do different groups of fish (hatchery vs. non-hatchery, early versus late season fish) show different residence behavior? Are there survival differences between fish that move immediately to the ocean as opposed to those that remain in nearshore areas? Acoustic or recording tags may not be the appropriate tool to address these questions.

Some participants felt that estuarine residence is not a period in the life history that contributes significantly to variability in survival; instead, the period during and immediately after ocean entry may be more important. As an example, tagging studies in the Columbia River have shown that juvenile salmon move rapidly through the estuary and directly to sea water.

Two kinds of studies were described to address these issues. First, double tagging studies (with conventional tags) and estimation of numbers can help determine relative survival. Second, transplant experiments (e.g. different release points, such as barging fish offshore) allow one to examine differences in survival among groups of returning fish. The results of these experiments have been equivocal. Campbell River studies suggest that estuarine residence is important to subsequent survival, but in Scandinavia, results were the opposite. Well-designed conventional tagging experiments are needed for this kind of research because large numbers of fish can be tagged at a reasonable cost, but experiments with acoustic tags would provide scientific information critical to understanding mechanisms of movement and habitat utilization in estuarine and nearshore waters.

Current technology in acoustic tags can be used to address the problem of how larger juveniles move through the estuary, but the large size of the data logging tags currently available limits their utility for use in small juveniles. Acoustic tags that identify individual fish with moored recorders (detection ranges of 100 to 250 m) can give spatial and temporal locations of fish which can be used to calculate movement rates within the estuary and nearshore area, as has been done with Atlantic salmon (Lacroix, in press). It was suggested that this could be done in the more exposed west coast nearshore regions as well, but that some kind of longline arrangement of the recording detectors would be required, and the logistics would obviously require a significant investment in hardware. Such research is continuing on Atlantic salmon. It was suggested that the Columbia River is not the right place to do the initial research because of its size and the weather constraints. At least for a demonstration project, justification for working in a smaller system is appropriate; locations could include Willapa Bay or Tillamook Bay, but in these systems the role of predation may be very high, decreasing the return of tags. There was also considerable discussion of concern about tag loss to predation and about tracking predators after tagged fish were ingested.

Pending outcome of the issues noted above, knowledge of habitat utilization in the estuary may or may not be a universally important problem. The numbers and body size of fish that can be tagged with acoustic tags is limiting, but this type of experiment would be quite useful for examining differences between groups of one species or between species. Application of acoustic tags to assess habitat utilization may appropriately address questions of specific importance to endangered or threatened species, particularly in urbanized estuaries subject to anthropogenic impacts. Little is known about depth, salinity, and physical habitat preferences and how they change (for example on a diel basis and with increasing residence time). In San Francisco Bay, for example, most research effort is devoted to examination of what happens as fish enter the mixing zone. Concerns exist about whether fish are diverted from the system, which runs are most greatly affected, and for those not diverted, whether they are moved into areas suboptimal for growth and survival. An additional concern is to evaluate the impacts of habitat alteration on these species. Application of acoustic tags may be difficult, however, because chinook in the San Francisco Bay estuary are only 80-85 mm in length and average 6.5 gm in weight.

Application of acoustic tags to juvenile fish is a general concern. Experiments to determine the tag carrying capacity of fish of different size, tag-induced mortality, and variations in behavior of the fish caused by the tag are all important. What are the appropriate tagging sites? Should the tag be internally planted or perhaps put into the dorsal musculature? What are tag rejection rates? Research on applications of new biomedical technology could seek better ways to promote tag acceptance and subsequent competence of the fish (see abstract by Kynard and Kieffer). Finally, biologists need to give specific information to technologists with respect to features of the tag important to the fish (dimensions, materials, shape, etc.).

Coastal, Maturing, and Returning Salmon

In the open ocean, the larger size of fish leads to a wider range of technology available to address important problems. While traditional tagging can provide information on population movement patterns and survival, acoustic and recording tags afford the ability to fill in important details (habitat utilization, relationship of distribution and movement to oceanographic factors on different time and space scales, etc.). This information is deemed of high value. Two general points about using acoustic or recording tags were discussed. First, although the costs of these tags may be high, the relative costs of the tags are not that high when amortized over the total cost of the project. The use of conventional tags (for example in the high seas tagging program) requires expenditures for ship time, scientists (salary, benefits, and overhead), and collection and analysis of tagging results. The large amount of data that can be retrieved from relatively few recording tags makes the results of high value (although with current pricing it is obviously best to tag those species and life history stages where survival and tag recovery rates are highest). The second point was the importance of the "eureka" principal. Although recording tags on salmonids can answer well-defined hypotheses about movement and habitat use, we may also discover surprising new facts that will alter the way we view the fishes' interaction with its environment and lead to new approaches to research.

With respect to large scale movements of salmon, a broad goal is to understand when and where they first move offshore and how and when they return as adults. Given the reality of current technology, fish size, and the likelihood of tag return, most discussion focused on tagging on the high seas to learn more about the return migration. Many of these research priorities were discussed in light of the major management issues in British Columbia salmon fisheries, which are also important issues for most northern stocks. These issues are: i) the numbers of returning salmon, ii) the timing of their return, and iii) the route taken for return. From a management perspective, the run timing is probably most important, followed by the numbers returning, and the route taken on the return migration. Numbers of salmon returning is perhaps the most difficult problem, but for the purposes of this workshop is not one amenable to solution by recording or acoustic tags and was thus not discussed further.

Annual variability in the timing of salmonid returns is likely associated with the last six months of ocean life. Geographic location, timing of initial migratory movements, oceanographic conditions, and the route taken are all important features that may affect run timing, and currently available archival tags have the potential to provide this information. Migration routes of salmon (which are important because they affect interception of fish) are probably affected by ocean dynamics in the coastal environment.

There was considerable discussion of the type of tag to use and of the best species to tag. Although acoustic tags have been used to answer several questions about behavior and habitat utilization by salmonids, there was concern expressed about aberrant behavior in the first several days after tagging. Short term tracks may suffer from a variety of artifacts in behavior; research will be required to document this. A good example is shown by the disruption of normal diel patterns in depth during the first four days of a chum salmon track as compared to later in the track (see figure 9 in Ogura, this volume). Pasting together short tracks from several fish to develop a composite picture of behavior may be also present a drawback, because of aberrant behavior, differences between fish, and temporal and spatial differences in environmental conditions. For these reasons, long-term recording tags are deemed preferable. While temperature and depth recording tags in appropriate sizes are presently available, participants agreed that geolocating tags are preferable if available (see Technology Discussion, following).

The appropriate species to tag is an open question. Sockeye salmon are good candidates for open ocean tagging because they are large, commercially important, and a strong database on conventional tag data exists. Recent model predictions of behavior are also available (see Healey and Thomson abstracts). It was suggested that relatively few archival tag recoveries from Fraser River sockeye salmon could be used to examine the hypothesis on how migratory pattern relates to ocean currents. Bristol Bay sockeye salmon have an advantage because of their rapid return from the open ocean, consistent timing from year to year, and an excellent historical record of tag data. Maturing pink salmon would also be an ideal species to tag because recent high seas tagging in the Gulf of Alaska has resulted in tag recovery rates of pink salmon up to 25%. Although adult pink salmon are small (and thus potentially less able to carry a tag), this high recovery rate may enhance the likelihood of a returned tag, which is deemed important for a demonstration project on salmon.

Tagging on the high seas involves a mixed pool of fish, and there was considerable discussion about the likelihood of being able to identify the stock of origin of tagged fish. Non-intrusive approaches to stock identification cannot identify the origins of individual fish. This provided further support for an international high seas tagging study, because fish tagged in the Gulf of Alaska could return to either the US or Canada. Finally, it was suggested that steelhead is a good choice for an initial experiment because spawning females could be tagged after their first return and released to record data on the migration pattern in both directions.

Movement patterns on small to intermediate scales are important to interception and fisheries interactions and can be investigated with acoustic and recording tags. It is important to resolve questions of whose fish (e.g. Canada vs US) are whose and how oceanographic factors effect movement patterns that result in interception-related conflicts. A related problem is the difference in movement between species and stocks that can lead to management decisions on gear types, fishing times and areas. The example was provided of steelhead being captured in fixed gear. Assessment of swimming depths of steelhead using acoustic tags revealed that they swam much shallower than sockeye, the target species in the fishery. This allowed modifications to the gear and consequently continued fishing. A similar analogy and approach could conceivably be attempted to address questions of threatened or endangered stocks by better identification of the movement patterns. New recording tags, even lacking geolocation (i.e. only time/depth/temp data loggers), could provide some of this information at better cost effectiveness. Finally, it was noted that migration models are often used to make fishery management decisions for salmon. These tags have the potential to either validate or falsify the models and thus improve management.

The majority of the discussion up to this point centered on the highly abundant species for which large scale research programs have been conducted. Research issues for coho and chinook salmon are somewhat different and involve the fundamental difference between questions strictly related to fisheries management and those associated with threatened and endangered species (although it was noted that securing permits for acoustic tagging studies on endangered species might be difficult). Scientific and management questions about run timing are important for these species. Broad research questions concern the distance of their migrations and their spatial and temporal use of the ocean environment. Outer- and inner-coast populations may have different coastal migratory patterns. Understanding variability in survival may require improved understanding of the specific ocean habitats utilized. Migration patterns of southern stocks are poorly known. Are their migrations restricted to coastal areas or do they move far offshore? Several participants believe that variability in survival occurs in the coastal zone, when fish are young.

Participants also expressed an interest in examining metabolic costs and bioenergetics of fish at sea, both in light of movement models (to better understand the energetics and the food requirements during migration; see abstracts by Helle, Healey and Thomson) and with respect to growth and size at return. Electromyogram (EMG) tags, presently available in relatively short term acoustic versions, can provide proxy metabolic information to examine growth. EMG capability is not presently available, however, in recording tags. Combining recording tag data, however, with information on the broader environment (prey abundance, temperature, currents) and comparing it with location would be highly valuable; the last 6 months of life at sea are very important. Physiologists have developed a theory that growth at sea may be set in spring each year. This may be related to local environmental conditions affecting the fish at that time, and location from tags could answer the question. Ocean location at different times determines the growth or scope for growth, and growth rates can change dramatically over 100-200 km; some ocean zones to do not support much growth.

Finally, research on the mechanisms through which salmon orient to their environments was discussed in some detail. Acoustic and recording tags (in some cases with further refinements) have the potential to support further understanding of olfactory mechanisms in movements, compass or magnetic orientation, and responses to oceanic stimuli. A question was raised as to whether the level of variability observed in the field will be sufficient to allow progress to be made. Complicated experiments have been done on birds (where the experimental logistics are much easier) but controversy still rages over the roles of different orientation mechanisms. Because this research area is a more basic one and does not really address management issues, it was generally given a lower priority by the participants.

Concluding comments

Participants agreed that many of the research projects discussed have great potential to answer important questions dealing with both fishery management and protected species issues. The group strongly recommended that experiments go forth with existing, tested technology. The results of the experiments can be used immediately. Future research, with improved technology, will benefit from the results of experiments started immediately.

Group Discussion: Current and Needed Technology for application of acoustic and recording tags to salmonids

Discussion Leader: **Kevin Friedland**

This group was tasked with discussing the current state of acoustic and recording tags, the technological problems which exist for applications to salmonids, and the highest priorities for development of new tags.

Salmonid tag carrying capacity and associated problems

The initial discussion centered on what issues must be resolved to improve our understanding of the limitations of salmon for carrying tags. Different species and life stages will have different tag carrying abilities (see Table 1, Emmett and Dawley abstract, for size information on young fish). Miniaturization can only proceed to some finite point, and it may never be possible to get a wide range of parameters on the earlier life stages of salmonids.

Physiological assessment of tagging effects

It was pointed out that many studies use mortality as the endpoint of evaluating tagging effects, but that a variety of sublethal effects may reduce fitness (feeding ability, buoyancy effects, swimming performance and stamina) and thereby affect the results from tagging experiments. The approach of looking at heat proteins, cortisol, or other physiological markers (see abstract by Siri) is complex in itself, and some participants suggested that alternative, simpler assays could be developed to address tagging effects. It was recommended that researchers in this area establish care guidelines for handling fish by those tagging in the field.

Choice of tagging site

The location of the tag on the fishes' body can have implications for fish health but also on the ability to detect the tag (e.g. are fishermen going to notice an internal tag, even if it has the light probe sticking out in the case of an archival tag?). Europeans have a preference for externally mounted tags (see contributed abstracts by Metcalfe and Arnold, Sturlaugsson and Gjudbjornsson). It is a high priority for manufacturers to know what development approach to take. While internal tags may be beneficial because of reduced tag loss, scarring, and infection from the attachment points, fish have the ability to extrude internal tags. The time course of extrusion is likely species and tagging-site specific and some new techniques may reduce extrusion rates (see contributed abstract by Kynard and Kieffer). Research on tag shape and form was encouraged.

State of tag development and priorities for future development

Discussion of the current status and future needs was made difficult by the complexity of the question. The biologists were generally interested in new technology to address specific problems, meaning a variety of life history stages, species, sizes, and measurement parameters. Manufacturers and technologists hoped to see the problem narrowed to more definable scope that could lead to a useful product likely to be purchased in reasonable numbers. Specific requests for information included the following:

- the time factor; the required duration of a track is important to determine battery life and/or memory requirements;
- optimal tag size for different fish sizes;
- optimal attachment point (e.g. internal or external)
- parameters to be measured.

Because of the complexity of the problem, the Discussion Leader developed a set of tables to solicit consensus information on the information available now and that is most highly desired for both acoustic and data logging tags.

Acoustic tags (Table 1): Acoustic tags provide relatively short-term tracks but a variety of useful information (see abstracts by Quinn and Ogura). A variety of parameters can currently be measured, and these tags exist in relatively small sizes at the present time. The first three parameters (temperature, geographic position, and salinity) were deemed high priority but are typically not measured on-board the tag because the system recording the data (whether a remote logger or a vessel tracking the fish) can gather the information in separate ways (e.g. XBTs used for periodic temperature profiles). Depth is important for all life history stages to assess habitat utilization. Activity is most important for smolt and mature seawater fish for assessment of bioenergetic parameters.

Compass heading can provide information on behavior and orientation and is likewise of high importance. Finally, "mortality" is particularly high priority for the smaller life stages subject to high predation rates. Several tracking projects have apparently followed predators that have consumed the fish that was the subject of the track; knowing when the tracked fish was consumed or another logical endpoint of the track would be useful to minimize wasted tracking time. Approaches to the latter parameter included tail beat frequency measurements or pH sensors.

	Temperature	Position	Salinity	Depth	Activity	Compass Heading	Mortality
Parr							
Smolt	4*	4*	4*	4	4	4	4
Post-smolt	4*	4*	3*	4	3	4	4
1SW							
MSW	4*	4*	3*	4	4	4	2

Table 1. Identification of the priorities for information required from acoustic tags by life stage. Priorities range from 0 (lowest, not advisable) to 4 (highest priority). An asterisk indicates that the parameter is not directly measured by the tag, but rather by other instrumentation on the tracking platform or elsewhere. 1SW; fish after the first year in the ocean. MSW; mature ocean fish. A blank box indicates that tagging is impractical in these life stages at this time.

Data logging tags: Current capabilities of data logging tags (Table 2A) begin with very few parameters for small fish (smolt and post-smolt) but expand for larger fish to include position, depth, activity (EMG, see abstract by Stoodley), and compass heading. Salinity sensors are available on data logging tags, but only for short durations due to fouling of the sensors.

	Tempera-ture	Position	Salinity	Depth	Activity	Compass Heading
Parr						
Smolt	x					
Post-smolt	x					
1SW	x	x	x*	x	x	x
MSW	x	x	x*	x	x	x

Table 2A. Present sensor capabilities of data logging tags. An "x" in the box indicates that such information is feasible for a given life stage. Blank boxes indicate the lack of a measured parameter. The asterisk for salinity sensors indicates that these are available for relatively short duration records only.

The desirable parameters to be recorded in a data logging tag vary with life history stage. The priorities for these parameters, and for development of different life stages, was evaluated by the group (Table 2B). First, the most important life stage for data logging tag experiments are mature ocean fish, followed in order by post-smolts, smolts, and first-year ocean fish. It was deemed unlikely in the foreseeable future that the technology for data logging tags for parr would be available. Temperature, position, and depth were accorded the highest priorities for parameters to be logged. With the exception of smolts, salinity is relatively unimportant.

	Temperature	Position	Salinity	Depth	Activity	Compass Heading	Life Stage
Parr	4	0	0	0	2	0	0
Smolt	4	0	4	4	3	2	2
Post-smolt	4	4	2	4	3	3	3
1SW	4	4	2	4	3	3	1
MSW	4	4	2	4	3	3	4

Table 2B. Identification of the priorities for information required from data logging tags by life stage. Priorities range from 0 (lowest, not advisable) to 4 (highest priority). Life stage indicates where greatest priority should be placed for development of tags.

Other technological considerations discussed in the session

Tag and sensor evaluation was seen as a high priority. Benchmark tests of existing tags (see abstracts by Klimley and Welch) have shown variability among tags, particularly in the geolocating capability. Stated accuracy was not always met. Static in-situ tests of geolocating archival tags were highly recommended, as were assessments of the accuracy of position estimates as function of wind or sea state. It was also suggested that until algorithms for geolocation are uniformly agreed upon that raw data be recorded so that alternative algorithms can be used after the tags are returned. It was noted that this might require additional data storage requirements, and that this might conflict with development of proprietary algorithms for geolocation.

Cooperation and communication in developing tags. Significant up-front cost exists in developing tags with new applications, and manufacturers are often unable to do the needed developmental work without the likelihood of a reasonable market. The question was addressed whether there should there be some kind of industry/academic/government cooperation to develop tags. This would depend upon funding, and no sources were readily identified. It was clear, however, that in order to assure adequate numbers of tags to be produced that there would have to be some agreement among scientists regarding the type and nature of the tag to be developed.

Participants also noted the importance of keeping up with new technology. Several manufacturers not present at the meeting have products that may be useful for applications to salmonids if some compromises are made. It was also suggested, but not universally supported, that a “smart tag homepage” could be developed for passing on information and continued discussion; an alternative also discussed was a listserver for interested scientists.

Alternative technology and techniques were also suggested. An alternative, easier way to take a proxy measurement for the current EMG sensors but not requiring surgical implantation is desired. Military sonobuoys have the potential be dropped from airplanes to track fish if the fish tags were appropriately designed. Canadian, US military have the capability to air deploy systems to listen to passing signals.

Workshop Recommendations

A total of 17 recommendations was developed after the meeting through a process using the following steps: first, preliminary recommendations were generated through a review of the notes of the two discussion groups. This list was distributed to all participants with a request for comments, including modification of those provided and generation of new recommendations. After editing and the addition of a short description clarifying each recommendation, they were again distributed to the participants for a voting procedure intended to develop a set of priority recommendations. The workshop recommendations, with short clarifying text for each, are provided below, listed in the order of priority given by the participants.

Salmonid Biology, Ecology, and Oceanography; Recommendations

A4. Field a high-seas tagging study using existing data logging tags (e.g. temperature, depth) on adult salmon in the Gulf of Alaska, concentrating on species where survival and tag recovery rates are high.

- Currently available data logging tags that record temperature and depth have been applied successfully to Atlantic salmon. This type of tag could be employed immediately to demonstrate the utility of the technology to Pacific salmon research while other, more complex tags are being developed and evaluated.

A2. Assess the mechanisms of movement and habitat utilization by post-smolt Pacific salmon in nearshore coastal waters using acoustic tags.

- During and shortly after ocean entry, young salmon are subject to high predation rates and a new environment. Several participants believe that this is a period of perhaps highest mortality and a source of interannual variability in mortality. Several approaches, including moored recorders to follow multiple fish, were discussed at the workshop.

A7. Field a tagging study with geolocating data logging tags on west coast adult chinook and coho to determine migratory patterns.

- Research is needed to resolve uncertainty about movement patterns and ocean habitat utilization (e.g. coastal versus open ocean residence) for these species.

A6. Field an international high-seas tagging study using geolocating data logging tags on sockeye salmon.

- This study could address migration patterns, and run timing, and evaluate the hypothesis on how migratory pattern relates to ocean currents and water mass properties.

A3. Assess the mechanisms of movement from nearshore waters into the estuary and habitat utilization in estuarine waters by returning adult salmon using acoustic or data logging tags.

- How do adults find and enter the estuary? How fast do they move up the estuary and what habitats are used during the passage?

A5. Field a research program tagging adult female steelhead (in freshwater) with geolocating data logging tags to determine the migratory path to and from the high seas.

- Steelhead have the advantage of survival after spawning, so that fish can be tagged in freshwater and held before release. They also have the advantage that data would be recorded for the entire migration track, to and from the high seas, and a reasonable likelihood of tag recovery.

A1. Assess the mechanisms of movement and habitat utilization by juvenile Pacific salmon in estuarine waters using acoustic tags.

- Juvenile salmon moving down the estuary typically move rapidly and also suffer high predation. How they move through the estuary and the preferred habitats during estuarine residence need to be evaluated.

A9. Use acoustic tags to determine how salmon orient to environmental gradients and cues.

- Olfactory mechanisms, compass or magnetic orientation, and responses to oceanic stimuli are all hypothesized to be important in salmon movements. Acoustic tagging experiments can address certain of these questions.

A8. Use acoustic tags with EMG capability on adult sockeye salmon.

- The purpose of this work would be to examine metabolic costs of foraging, migrating, and escaping, on the high seas and in coastal waters. Results would allow a better understanding of growth and biophysical influences on how sockeye lay down their energy reserves for up-river migration and spawning, and would allow testing and improvement of existing models.

Technology Needs for Salmonid Tagging; Recommendations

B1. Calibrate (in laboratory) and verify (in field) the precision and accuracy of acoustic and data logging tags and their sensors. Establish protocols for sensor calibration and evaluation.

- Applications of acoustic or data logging tags on the larger scales discussed at the workshop will be an expensive proposition. Manufacturers need some assurance of a market for products, but scientists proposing research funds to buy tags must demonstrate the important scientific problems being addressed as well as an accurate sensor that will provide reliable data. New developments in tags, modifications to sensors, and changes in algorithms for derived parameters can all affect tag performance. Reliable standards for calibration are required.

B6. Continue miniaturization of acoustic and data logging tags to allow use in early life history stages.

- Tag size continues to be a problem with application of acoustic and data logging tags to salmonids, particularly younger fish. Research and development efforts are required to decrease size of existing tags, and to improve sensors, increase memory capability, and develop new sensors for applications in salmonids.

B8. Evaluate effects of tags on salmon and the capacity to carry tags.

- Tags have impacts on survival, behavior, and growth. There are also concerns about tag rejection and retention, including extrusion of internally planted tags. Questions of optimal tagging location, internal versus external attachment, and other tag effects should be evaluated before undertaking long-term studies with acoustic or data logging tags. Laboratory research with dummy tags evaluating sublethal effects are required.

B2. Develop and verify geolocating algorithms for data logging tags that will minimize problems of horizon on the coast and east-west movement of fish.

- Geolocating algorithms using light level have unknown biases from east-west movement of fish and for variability in the horizon when near the coast. Research should be conducted to evaluate these problems and find solutions.

B7. Develop methodology for tracking fish with acoustic tags for periods of weeks and for tracking more than one fish at a time.

- Longer tracks and multiple fish tagging programs are needed to increase the number of observations and decrease likelihood of aberrant behavior early in the tracks. Some new technology is presently available for this and further improvements are needed.

B4. Develop proxy parameter for metabolic utilization in acoustic and data logging tags.

- EMG tags require surgery and implantation of electrodes. Although they work for fairly short term implantations, the electrodes may not be sufficiently reliable for longer-term recordings. Sensors to record proxy variables, such as swimming speed, may provide similar information with less complex implantation requirements.

B3. Develop sensor and geolocating algorithm using geomagnetic fields.

- Geomagnetic fields represent a potential mechanism for determining geolocation. Development of appropriate sensors in the sizes required for a data logging tag and research on appropriate algorithms are needed.

B5. Develop cooperative program with defense agencies for development of new technologies applicable to fish tagging.

- At the workshop, the example of air-deployed sonobuoys to serve as listening stations for acoustically tagged fish was raised. There may be additional technologies applicable to the problems faced in acoustic and data logging tags and these should be evaluated.

Evaluation of Workshop Recommendations

Voting was conducted to place priorities on the workshop recommendations. All participants were given the opportunity to vote for five recommendations in each of the two categories ("biology, ecology, and oceanography" and "technology"). All but five participants did so. In the interpretation of the priorities that follow, it is useful to note the distribution of expertise at the meeting. Of the 28 participants, only 6 would be classified as technologists or engineers, and the remainder would fall within the category of biologists, oceanographers, or ecologists. Because all of the five non-voting participants were technologists or engineers, the priorities described below do not represent their opinion.

Votes were tallied in two ways. First, five points were assigned to each first place vote, four for the second place votes, and so forth to one point for a fifth place vote; the sum of these scores are referred to as "rank total". We also summed votes independently of the ranks, and these are listed as "vote total." The first seven of the nine recommendations under "biology, ecology, and oceanography" all scored quite highly (Figure 1).

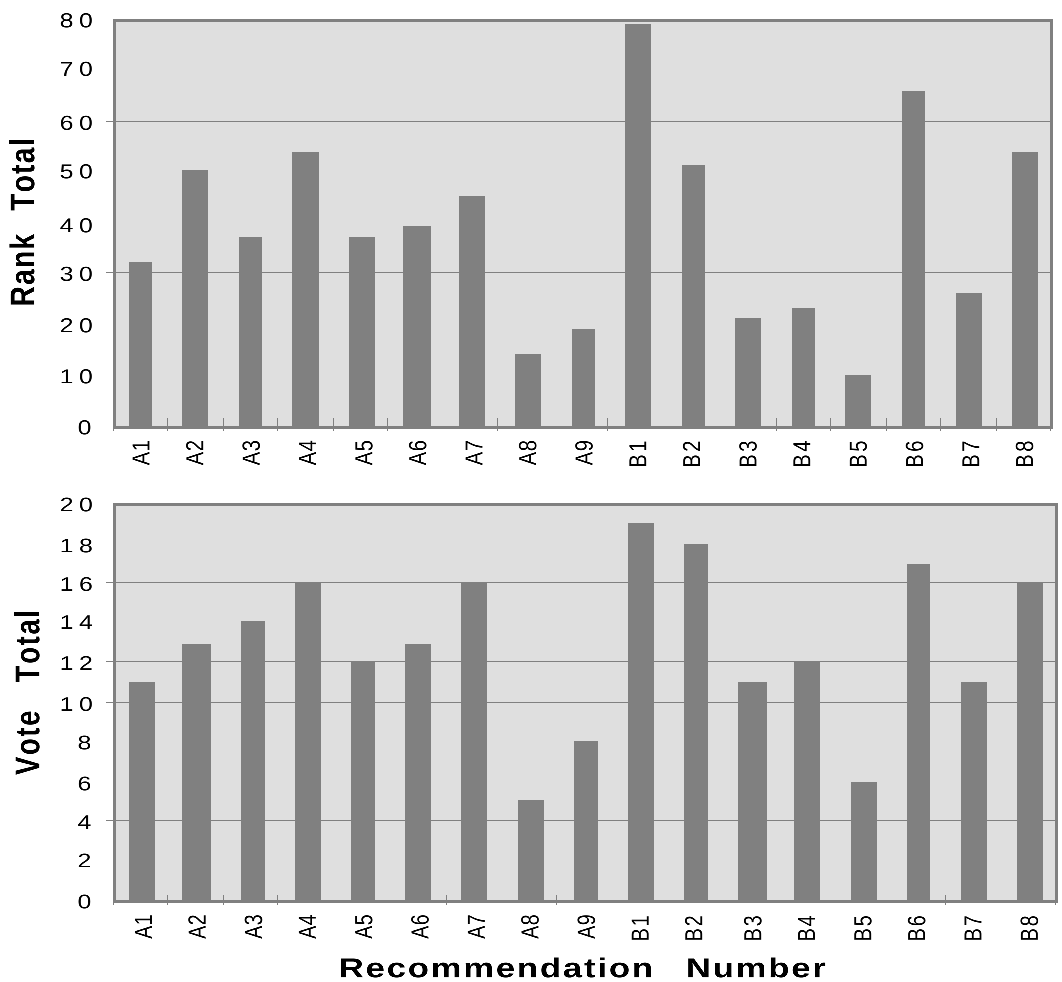

Figure 1. Summary of voting on the workshop recommendations. The upper panel represents the rank total, the lower panel the vote total. Recommendations are listed in the text.

The highest priority recommendation (A4) was to undertake a “demonstration project” to use existing data logging tags as soon as possible. Existing tags would have a lower number of measured parameters than may be desirable, but there is high value in proving the value of data logging tag results to understanding salmon movements and habitat utilization (as has been done for Atlantic salmon -- see Sturlaugsson and Gudbjornsson, this volume). Similarly, strong support for understanding movements of young fish immediately after the transition from estuarine to marine waters (A2) reflects the opinion of many that this may be a point in the life history when survival is highly variable (see Pearcy, this volume). Use of existing acoustic tags, perhaps with an array of moored recorders (see Lacroix, this volume), could help evaluate how these fish move and utilize the nearshore and coastal environments. There was also support, however, for assessing movements of young fish within the estuary (A1) and of adults moving into the estuary on the return migration (A3). Application of geolocating tags in the open ocean was also supported strongly (Figure 1) for west coast chinook and coho salmon (A7), sockeye salmon (A6), and steelhead (A7). Recommendations to use acoustic tags with EMG capability on adult sockeye salmon (A8) or to use acoustic tags to determine how salmon orient to environmental gradients and cues (A9) received relatively few votes; this may be due to the perception that assessment of metabolic activity and orientation mechanisms may have been less pragmatic (and feasible) than research proposed in the other recommendations dealing with habitat utilization and movement patterns.

Distribution of voting for the technology-related recommendations better identified priorities, with four of the eight recommendations receiving the bulk of the votes (Figure 1). The calibration and verification of tag precision and accuracy (B1) was ranked as the highest priority need by participants; this is already the topic of active discussion (see abstracts by Klimley and Holloway, this volume and Welch, this volume) and field tests are underway (D. Welch, personal communication). Discussion of this point at the workshop, however, seemed intent on sending a message to tag manufacturers that this must be a continuing endeavor as new tags are developed. The second priority was placed on continued miniaturization of tags (B6), reflecting the desire to extend the ability to apply tags to earlier life history stages of salmonids while minimizing tagging stress. This goes hand in hand with the need to evaluate tagging effects and conduct research on the ability of different species and life history stages to carry tags (B8), which, along with improvement in geolocating algorithms (B2), was the next highest priority. The remaining four technology recommendations (B3, B4, B5, B7) were less highly supported in this exercise. Again, these four represent longer-range objectives and may thus have been considered less pragmatic by many of the participants.

Appendix 1:

Contributed Abstracts

Several researchers conducting studies pertinent to the workshop and tag manufacturers unable to attend were asked to submit abstracts as a means of increasing the information content of the workshop report and promoting communication among researchers.

Tracking of Atlantic salmon (Salmo salar L.) and sea trout (Salmo trutta L.) with Icelandic data storage tags

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Introduction

The data storage tag (DST) was developed in Iceland by the engineers at Star Oddi Ltd. in co-operation with fish biologists at the Institute of Freshwater Fisheries and the Marine Research Institute in Iceland. These tags record series of measurements from the environment of the fish. They record pressure (depth), temperature and conductivity (salinity). The small size, low weight and cylindrical shape of these data storage tags make it possible to use the tag on relatively small fish.

The Institute of Freshwater Fisheries has used the Icelandic DSTs in Icelandic waters on Atlantic salmon (*Salmo salar* L.) from 1993-1996 and on sea trout (*Salmo trutta* L.) from 1995-1996 (Sturlaugsson 1995; Sturlaugsson and Johannsson 1996, 1997). In addition, the Institute of Freshwater Fisheries has participated in research on Baltic salmon (*Salmo salar* L.), where these tags were used, from 1995-1996 (Karlsson et al. 1996). The salmon were tagged externally, but the sea trout were tagged both externally and internally. A total of 310 salmon and 110 sea trout have now been tagged with DSTs in Icelandic waters.

In the DST tagging experiments in Icelandic waters, the main aim was to study the homing migration of salmon in coastal waters and the sea (feeding) migration pattern of sea trout. These studies were the first instances of DSTs used in research on these species. The Icelandic DSTs are both the smallest and, by far, the least costly data storage tags on the market. Therefore, the Institute of Freshwater Fisheries has been able to tag and recapture high numbers of fish of diverse sizes (39-96 cm). This was done in order to determine, as closely as possible, the common behaviour of these migrants. Different intervals between recordings were used to examine more closely the swimming behaviour (1,5 minute intervals) and diurnal rhythms (DSTs with two different measuring time series, that are repeated). In the case of salmon, different environmental circumstances were used to look at possible effects on the migration pattern. As an example, salmon were released both coastally and off-shore at varying depths. They migrated both against and along the main sea currents over distances ranging from 25-420 km (shortest sea route). Control groups of salmon were tagged with DSTs and kept in net pens in the sea, enabling comparison with the salmon migrating at that time.

The use of DSTs provided new methods of sampling series of data directly from the fish´s environment, and over longer periods of time in the sea than previously possible. For example, we have received a series of vertical movements and corresponding water temperatures, from the sea trout studies, for time periods up to 5 months. These data series were also the first instances of such measurements that included the sea phase throughout the study and the freshwater phase before and after sea migration.

Results of migration studies on homing Atlantic salmon

A high recapture rate of tagged salmon (20-60 %) gave large series of recordings showing that the salmon spent most of their time close to the sea surface, as has been reported. But, the recordings also included much information concerning the poorly documented diving activity that occurs occasionally. This new information included dives made by the salmon down through the thermocline, and dives that were both deeper (down to 153 m) and faster (vertical speed up to 0,73 m/sec) than had been reported previously in coastal waters. The reasons for the diving activity of homing salmon are not always the same. Certain known facts or hypotheses give these reasons for dives while homing: excursions to scan the different environmental parameters as cues for orientation, selective tidal transport, thermoregulation, escape behaviour, and feeding (seldom).

The salmon experienced diversity in the temperature and salinity, and the largest changes in a short time were recorded at the same time as excursions into deep water, estuaries or rivers. Examples of extreme changes in temperature and/or salinity in a very short time are good indicators of the versatility of salmon. The salinity sensor was first used in 1996, and the first results show very interesting behaviour regarding the coastal migration, especially in relation to the estuaries. The water temperature recorded reflects the vertical, estuary or river migration pattern and also gives possibilities for tracking the horizontal location of migrating salmon, in general, close to the sea surface over large areas. By comparing temperature data from a DST to sea surface temperature data from satellite measurements, it is possible to locate the area (temperature zone) to which the fish are migrating.

Because the salmon is frequently in close proximity to the surface, the sea temperature in coastal waters is often correlated to the air temperature in the area. Relatively high temperatures experienced by salmon, combined with their common non-feeding behaviour during spawning migration, resulted in as much weight loss as 10% within 1 month.

Development of new generations of DSTs

The on-going development will result in a release of the new generation DST 300 in November of this year. Reduction of size and weight has been the main object (Table 1).

Table 1. The types of available Icelandic DSTs. Parameters involved are listed with reference to specification of each tag type.

PARAMETER	DST 200	DST 300	Units
Size (diameter/length)	18/48	13/46	[mm]
Weight (in air/in water)	12/0	8/1	[gram]
Memory	8.100*	8.100*	[number]
Maximum depth	>450	>700	[meter]
Temperature range	customer specified from -25 to +50		[˚C]
Depth range	customer specified from 0 to 600		[meter]
Salinity range	customer specified, 5 to 37		
Tilt angle		customer specified, +45 to -45	[˚]
Lifetime	>12**	target 12**	[month]

*Increased to approx. 16.300 in near future **Depending on temperature and number of measurements

The next steps taken in the DSTs´ development in Iceland will involve further reduction of size and weight, expansion of memory, expansion of life time, development of new sensors (5) and specification of complete customer chip solutions.

General conclusions and future perspectives

The data storage tags will be very important research tools in fisheries research in the future. They will open new methods of studying the behaviour and environment of fishes, not the least of which will be the anadromous fish. This is due to the fact that the DSTs enable unique possibilities regarding sampling continuous series of special, behavioural, and environmental information from areas and over time periods where other sampling methods can not be used, or are both too difficult to use and too costly, which often results in limited data. This new dimension in research of fish will therefore add valuable information to our understanding of fish behaviour and their reactions to their environment. Additionally, the results from DSTs tagging can, in some instances, be useful in improving the traditional sampling methods.

In the coming years, the Institute of Freshwater Fisheries will continue to use DSTs in research on salmonids in the sea. In the case of Atlantic salmon, the main activity will be in tagging experiments involving feeding migration in the sea, with a combination of tagging of kelts and large smolts/postsmolts. This will also introduce very interesting ways of comparing growth to sea temperature circumstances.

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Rejection of internal telemetry transmitters by shortnose sturgeon

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From 1988 to 1996 we identified the rejection incidence of internal transmitters placed periodically in a total of 57 adult shortnose sturgeon Acipenser brevirostrum (71 - 112 cm TL) inhabiting two Massachusetts' rivers. Transmitter fate was determined using tracking, double tagging individual fish with internal and external transmitters, and observations of recaptured fish for tag presence and position in the body. Twenty fish were tagged with ultrasonic transmitters in the Merrimack River; 36 fish were tagged with radio transmitters in the Connecticut River. All transmitters were cylindrical, about 115 mm long x 16 mm diameter, with a 2-year battery life. The external surface of the initial nine ultrasonic transmitters was ABS plastic, the remaining 11 tags were coated with Silastic. Radio transmitters were also coated with Silastic, an elastomer from Dow Corning Corporation that is used to coat electronic devices for implantation in humans. Rejection incidence of ultrasonic transmitters was 33 % for uncoated transmitters (3 of 9), and zero for the 11 coated transmitters. Rejection was 21 % for 19 radio transmitters used in 1993 that had short 4-cm-long antennae. Zero transmitters with 2-6 cm long coiled antennae used in 1994-1996 were rejected (n = 17). (Five fish tagged in 1996 that retained tags for six months are included in this total.) Rejection of ultrasonic tags occurred quickly (within 2 weeks); whereas, radio transmitters were rejected within 14 weeks (mean = 7.6 weeks) except for one transmitter rejected at 72 weeks. There was no obvious relationship between fish length and rejection. Our results show that some shortnose sturgeon reject internal transmitters by pushing them through the peritoneum wall and out the anus, and coating commercial transmitters with Silastic can greatly reduce rejection.

Tracking of Post-Smolt Atlantic Salmon into Coastal Areas of the Bay of Fundy

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Several novel studies were conducted in 1995 and 1996 as a result of the collaboration between the Atlantic Salmon Federation and the St. Andrews Biological Station (Fisheries and Oceans Canada) to track the movement of Atlantic salmon during the early stage of their seaward migration in coastal areas of the Bay of Fundy in New Brunswick, Canada. The goal was to examine the hypothesis of increased natural mortality in the marine environment used to explain the recent declines in Atlantic salmon stocks. For this, we needed to obtain direct evidence of the mortality, when and where it occurs, and then to identify the factors responsible. Our recent involvement with VEMCO Ltd. in the research and development of ultrasonic telemetry gear has provided us new tools to do this.

In 1995, pulsed low frequency acoustic pingers (VEMCO V8 Series Expendable "Intelligent" Transmitters) were surgically implanted in the abdomen of 96 hatchery-reared smolts while in freshwater. Hatchery smolts which were considerably larger fish than wild smolts were used because of the limits imposed by the size of pingers (8 mm diameter x 36 mm length) at that time. Groups of 48 smolts with pingers were then released at the head of tide in the St. Croix and Magaguadavic rivers at the time of natural smolt migration in May. The movement of smolts from the rivers into Passamaquoddy Bay was monitored with an underwater receiver (VEMCO VR20-Monitor; an automated submersible pinger detection receiver for remote monitoring) moored underwater at the mouth of each river. Each unit had a radius of detection in excess of 0.25 nautical miles. Movement of post-smolts from Passamaquoddy Bay into the Bay of Fundy was then monitored using a network of 10 automated underwater receivers deployed to cover all outlets from Passamaquoddy Bay. These units were moored at depths of up to 90 m in areas of extreme tidal currents. Each unit could detect individual pingers according to their frequency and pulse period and could store the time of passage of a tagged fish.

The efficiency of the network of underwater receivers at detecting the passage of individual fish was excellent. Post-smolts were usually detected by at least two units when moving out of Passamaquoddy Bay. Searches for fish were also made daily during June by crews on several boats equipped with receivers for pinger location and tracking (VEMCO VR60 Ultrasonic Receiver) equipped with both directional and omnidirectional hydrophones (VEMCO VH32 and V10 Hydrophones). In addition, surveys were made to detect if post-smolts were caught in the many herring weirs along the coast and to determine if post-smolts were attracted to or affected by the presence of numerous marine cage sites for the culture of Atlantic salmon in the Passamaquoddy Bay area.

In 1996, a new single-chip pinger was developed by VEMCO Ltd. over the winter which allowed for size reduction (8 mm diameter x 26 mm length) and use in wild salmon smolts. The new pingers were surgically implanted in the abdomen of 38 wild smolts during May. These were captured in freshwater at the mouth of the Magaguadavic River after they had passed downstream of the power dam in St. George. The surgery on the small wild smolts was successful, and fish were released 24 hours later at the head of tide in the river. The fish were then tracked with hydrophones and receivers aboard boats and their movements from the river estuary into Passamaquoddy Bay and from there into the Bay of Fundy were monitored using automated receivers moored underwater at the same strategic locations used in 1995 to monitor the large hatchery fish. As before, each individual fish tagged could be recognized because each pinger had a different pinging rate.

The performance of the new pingers was excellent. Their range of detection was equal to and often greater than that of the larger pingers used in the past, and the duration of one pinger tested exceeded 3 months. Their smaller size (26 mm long compared to 36 mm in the past) made it possible to successfully implant them in the small wild fish. This is a major breakthrough in telemetry of small fish in sea water, and it greatly opens up the possibilities for research. The duration of the pinger also means that fish can be tracked over long distances in their migration to feeding grounds and overwintering areas.

Both studies were highly successful. The behaviour of smolts upon entry into sea water was examined and their success at leaving river estuaries was determined. The migration routes used by post-smolts after leaving the rivers were then determined from position fixes of fish detected throughout Passamaquoddy Bay and site of detection upon leaving the bay. This was examined in relation to tidal stream and surface currents. The success of post-smolt migration from Passamaquoddy Bay into the Bay of Fundy was then successfully determined using the network of underwater receivers. The sites where post-smolts were lost also allowed us to identify potential areas and sources of mortality.

In summary, the studies successfully followed the movement of hatchery-reared and wild Atlantic salmon at an early stage over relatively long distances in sea water. It effectively sealed off a large coastal area such that all fish surviving and moving through the network of automated underwater receivers could be detected. A comparison of the success, behaviour, and migration routes of wild post-smolts with those of hatchery origin was conducted. The new pingers proved highly successful, and the methodology for implanting them in wild fish was improved. The advances made in ultrasonic telemetry as a result of this work now allow us to address many outstanding questions. The technology should be especially useful to track salmon from the rivers of the inner Bay of Fundy where stocks have severely declined, and to discover their migration routes and the location of their feeding grounds which to date remain unknown.

Feasibility of long term intramuscular implantation of archival tags in large pelagic fishes

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Geographic positions of fish can now be collected using commercially available electronic archival tags that measure and store data on ambient light level, fish depth, and water temperature for up to 12 years. Although the engineering problems have been surmounted, viable long term (years) tag attachment methods remain problematic and in need of careful testing. This is especially true for pelagic species such as tunas (*Thunnus* spp.) and billfishes (Istiophoridae and Xiphiidae) where large individuals are often difficult to handle. Archival tags have been successfully implanted in the peritoneal cavity of southern and northern bluefin tunas (*Thunnus maccoyii* and *T. thynnus*, respectively). However, tags placed in the peritoneal cavity may be lost through trans-intestinal or body wall expulsion and require that fish be removed from the water, restrained and/or anesthetized during placement. An alternative approach is intramuscular implantation. We therefore tested the feasibility of long-term intramuscular implantation using miniature stainless steel scale model archival tags and juvenile yellowfin tuna (*Thunnus albacares*) held in shore side tanks. Because functional archival tags are too large to be implanted in the 1-2 kg fish available for our study, we employed scale model tags approximately 0.6 cm in diameter, 4 cm long, and weighing 3.5 g. The model tags were made of the same 316 grade stainless steel as functional archival tags. They also had a simulated fiber optic light stalk, crafted from nylon monofilament line encased in Teflon, on one end.

Model tags were inserted into the white muscle of fifteen fish, through a small incision in the skin, at the anterior edge of the first dorsal fin. In thirteen fish, the tags were placed with the simulated fiber optic light stalk either pointing anteriorly or perpendicular to the dorsal body surface. In the remaining two fish, the tags were placed with the simulated fiber optic light stalk pointed caudally. Ten of the fifteen fish survived for approximately ten months after tagging and of these, seven had retained their tags. In the fish where the tags were retained for 10 months, the simulated fiber optic stalk pointed anteriorly. More important, in no fish was there any gross evidence of infection or tissue necrosis around the tag insertion site or where the simulated fiber optic light stalk exited the skin. There was also no evidence that any of the seven fish would lose their tags in the near future. Tag bodies were all found to be embedded approximately 5 cm below the dorsal body surface in spite of the fish increasing in size from approximately 1-2 kg to a final body mass of 11$\pm$ 2 kg (mean $\pm$ SD). We also found no evidence of serious chronic inflammation, edema, or major necrosis around the tag body. Instead, only a thin protective layer of connective tissue surrounded both the tag body and the intramuscular portion of the simulated fiber optic light stalk. Our results therefore demonstrate that long-term intramuscular implantation of archival tags is feasible in tunas (and possibly in other pelagic species) and a viable alternative to intraperitoneal placement or external attachment.

The use of acoustic and data storage tags in establishing the role of the tidal streams in plaice migration in the southern North Sea

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During the 1970's and 80's acoustic tracking and mid-water trawling experiments with plaice (*Pleuronectes platessa* L.) in the southern North Sea established that this species migrates between summer feeding grounds and winter spawning grounds by selective tidal stream transport. This behaviour is characterized by a circatidal pattern of vertical movement in phase with the tidal streams. The fish leave the sea bed and move into mid-water at about the time of slack water and swim down tide for the major part of the ensuing north-going or south-going tide. As the tide turns again, the fish return to the sea bed where they remain for the duration of the opposing tide.

Since late 1993, we have been monitoring the movements of plaice in the North Sea with new small electronic data logging tags which record the depth of the fish every ten minutes, and temperature once each day, for periods of up to 8 months. When fish are caught and the tags returned, the patterns of *vertical* movement are used to reconstruct the *geographical* movement of the fish using a computer simulation model of the tidal streams. To date, 140 of these tagged plaice have been released and 20 tags have been returned. From these over 1500 days of data have been retrieved revealing seasonal patterns of vertical and spatial movements.

These data are now yielding detailed information on the behaviour of free-ranging fish over periods of many months which should allow us to recognize what, if any, environmental event stimulates the start of the pre-spawning migration and how this varies between sexes and ages of fish. The information will also indicate how the patterns of vertical movement of individual fish relate to local tidal and diel cycles allowing us to identify which environmental clues and cues are important in controlling vertical movement and, therefore, which sensory systems underlie the complex repertoire of behaviours which result in large scale seasonal migrations.

Further data are needed if we are to understand fully the migrations of plaice in the North Sea, together with the interrelationships between the various stocks and sub-stocks that are thought to exist. We should like also to extend the work to other parts of the continental shelf and to other species, such as cod, about which we already know a little from tracking experiments with sonar and transponding acoustic tags. To this end we need cheaper, smaller electronic tag with a longer recording life, a target that our engineers have recently achieved with a new tag 56 x 18 mm, 16 g in air (1 g in water) and with 12 Mbit memory which can store over 523 000 data samples (light, pressure and temperature) with a 12 bit resolution. In the longer term, too, we would wish to significantly increase the probability of data recovery by developing a pop-up tag whose data could be recovered by airborne radio or satellite, techniques that are probably already practical with large pelagic oceanic species, such as tuna and swordfish. The planned addition of sensors into our electronic tags for detecting compass heading will, likewise, greatly expand our understanding of the environmental clues and sensory mechanisms used to orientate during down-tide swimming, while the addition of a swimming speed sensor will reveal more complete information about the energetics of migration and permit more accurate reconstructions of the geographical tracks.

Temperature and data loggers from Onset Computer Corporation

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Onset Computer Corporation, has designed and manufactured low-power data loggers since 1981. We have over 100,000 loggers in use worldwide and our largest customer base is the natural resources market, including a strong following in the fisheries market. Onset has a company goal of being a market leader in providing high volume, low cost miniature data loggers. Generally, we build and stock standard products although we do accommodate custom product variations of our standard products (i.e., changing temperature ranges, adding external sensors).

Our products are primarily used to measure water temperature, but we have several customers who have used our smallest loggers to measure body temperatures in alligators, turtles, snakes and ground squirrels. Onset manufactures two single-channel, battery-operated temperature loggers which are small. The HOBO Littler (1.5S long x 0.5S wide x 0.5S thick) takes 1800 measurements over two months and weighs 0.15 oz.. The StowAway Tidbit ((1.2S wide x 1.S tall x 0.65S thick) takes 7,944 measurements over two years and weighs 0.8 oz. Both products can be off loaded to a PC or Mac using our Logbook software. Data can be exported to popular spreadsheet programs.

Onset data loggers incorporate 8 bit microprocessors and store data on non-volatile EEPROM memory. This memory ensures that the data is saved in the event that power is lossed. Accuracy and resolution curves are available for all Onset data loggers. More information on Onset single channel data loggers and multi-channel data logger/controller engines are available at www.onsetcomp.com.

Data Archival and Satellite-linked Tags from Wildlife Computers

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Wildlife Computers has been producing data archival tags (TDRs) designed specifically for marine wildlife research since 1986. The customized packaging and sensors of our tags have allowed them to be used for studies of diverse species, including phocids and otariids, cetaceans, penguins, sea turtles and sharks, as well as on long-line and trawl fishing gear. Sensors include depth (ranging from 0-25m tags for Albatross to 0-2000m tags for elephant seals), internal and environmental temperature, light-level, activity, noise level, and heartrate. These instruments are designed to withstand harsh environments, to be small in size, to have a long deployment life and high memory capacity, and to be flexible with a variety of user-programmable parameters.

Our archival tags can be programmed to collect light-level and environmental temperature readings to be used for global positioning (geolocation). In 1990, we developed a system of PC-based programs to process these collected data to calculate daily latitude and longitude positioning with an accuracy of approximately 1°.

Over the years, Wildlife Computers has incorporated advancements in technology to increase the capabilities of our instruments, as well as to reduce the size and power consumption. The newest data archival tag has 2Mbytes of non-volatile memory, weighs approximately 30g, and has a battery life of 10 years.

Wildlife Computers also manufactures satellite-linked time-depth recorders (SDRs) which transmit collected data to the Service Argos satellite system. The first SDRs were deployed in December 1989.

Acoustic tags available from SONOTRONICS

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SONOTRONICS has been a manufacturer of ultrasonic tracking systems for 25 years. These systems offer particular advantages over RF tracking under specific conditions. Ultrasonic (often referred to as just "sonic") systems rely on propagation of sound waves in water, which is fundamentally a mechanical rather than electronic process, and operate at frequencies between 30kHz and 100kHz. As a rule of thumb, sonics are the most suitable tags in water over 5m in depth or when conductivity exceed 400umho /cm.

Sonic systems are comprised of hydrophones, receivers, and tags. Hydrophones are basically sensitive underwater microphones that are tuned to accept sound at these high frequencies, and due to the short wavelengths of ultrasound in water, relatively small hydrophones can offer excellent directivity: beam widths of +/- 6 degrees are typical of units the size of a small tupperware container. Ultrasonic receivers are generally paired with a particular manufacturer's hydrophone in order to achieve optimum performance. Typically, receivers are separated into 2 types: scanning receivers used for unmanned or automatic systems, and manual tracking receivers designed to by used by individuals tracking from shore or on a boat.

Sonic tags are the most variable item of a system, and usually amount for the majority of the cost. Three variables define a tag: size, life, and range, and once 2 of these items are selected, the third becomes fixed. Size in generally determined by the smallest size specimen to be tagged: a general guideline states that the tag weight (measured in water) should not exceed 2% of the body weight (in air) of the fish to be tagged. Currently, the smallest tag manufactured by SONOTRONICS measures 8mm x 28mm, with a water weight of just under 2 grams. Following the above guideline, this tag should be used on fish of no less than 100 grams. These tags, when used with SONOTRONICS' receivers, have a detectable range of 750 to 1000 meters, and consequently have a lifetime of slightly more than 2 weeks. Although it is likely that smaller tags will soon be available (40% smaller), this will result in a shorter useable life (7 - 10 days). On the other hand, tags with a 4 year life are available with detection ranges of 1km, but with dimensions of 18mm x 65mm and a water weight of 8 grams. It should be noted that tags used in studies that will last more than 3 - 6 months should seriously consider surgically implanting tags. A free video is available on request from SONOTRONICS showing a sample surgical procedure.

Identifying individuals with sonic tags can be accomplished a couple of ways: bandwidth in the ultrasonic region is narrow, only 10's of unique frequencies are available, so unique intervals between pings may be used with tags of the same frequency to provide identification. SONOTRONICS also uses a technique of aural coding provide individual recognition.

A code such as 2-4-9 would be detected by a person listening to a receiver as 2 pings, followed by a pause, followed by 4 pings, another pause, then 9 pings and a pause before repeating this sequence over again. This technique allow for literally hundreds of tags to be used in the same area yet be identified as unique. Finally, sonic tags may be used to provide parametric data about the immediate environment where the specimen is located. Depth or temperature may be telemetered back to the receiver by changing the interval between successive pings from a tag, providing realtime information about the habitat.

Zelcon Technic Wildlife Tracking Systems

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Zelcon produces an archival tag known as the "ZT6 Datalogger". This advanced surface mount technology is employed in miniature dataloggers that have been designed for wildlife and environmental studies. The recording schedule can be designed by the user, with sampling rates varying from 1 second to 1 year. The logging life is up to 4 years and the data retention is over 20 years, independent of the battery life. The tag has the following characteristics:

Minimum size: 55x24x12mm
Minimum weight: 25 gram
Memory capacity: 1Mbyte of Flash memory.
Sensors:
- Activity sensor, Travel sensor, In-Water sensor (conductivity), In-Water sensor (ultrasonic)
- Pressure sensor (0-500m, resolution 2m)
- Pressure sensor (metallic package)

*Other pressure sensors, pressure ranges available
- Sensor pad (including external temperature sensor and light sensor)
- Light sensor (on the tag)
- Temperature sensor external/internal (-20°C to +50°C range with 0.15° C resolution standard)
- Tail-beat sensor
- Humidity

Data format: ASCII
Interface requirements: Adaptor to PC serial port, 4,800 minimal baud rate
Software required: Any Terminal Program (eg Windows 3.1 Terminal)plus Data Display/Analysis Software

The assembly is potted in heat cured epoxy to provide environmental protection.

Future developments with this tag include reduction of datalogger's weight and size (down to 60-70% of the current parameters) and options in the memory capacity (512Kbyte, 1 Mbyte, or 2 MByte Non-Volatile memory). Also under development is ZelLINK™, a Pop-Up Satellite transmitting Electronic Datalogger, which will integrate a datalogger (archival tag) and an ARGOS Satellite Transmitter to allow the transmission of data direct to laboratories via the ARGOS System and ensure an 1:1 data recovery rate.

Also under development is the ZELCODE™ Advanced Telemetry System, which allows for transmissions of sets of data on only one frequency for a large number of animals/fish/birds due to unique digital codes associated with the transmitters. The system is suitable for monitoring studies of a large number of individuals. The data -- unique digital code and optionally temperature, activity, travel information and other parameters -- are received and sent via RS-232 interface to an IBM compatible computer. The ZELCODE™ system can be easily adapted to transmit the information via ultrasound. The range, number of tags required, relevant measurements (eg:temperature, pressure etc.) for the application are to be determined in consultation with the end-user.

Appendix 2: Workshop Participants

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