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ENVIRONMENT AGENCY

Fish Tracking Technology Development

Phases 1 and 2, Project Definition Desk Study and Equipment Evaluation

R&D Technical Report W102

RESEARCH AND DEVELOPMENT TECHNICAL REPORT

Fish Tracking Technology Development

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Fish Tracking Technology Development

Phases 1 and 2,
Project Definition Desk Study and Equipment Evaluation

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R&D Technical Report W102

This report is the result of work jointly funded by the Environment Agency and the Ministry of Agriculture, Fisheries and Food.

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Statement of use
This report details the results of a review of the current status of fish tracking technology and the evaluation of tracking equipment considered to merit further investigation. However, it will also be used as a reference of currently available fish tracking equipment and its suitability for use by the Agency.

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CEFAS's Project Leader for R&D Project W2/i579 was:
Mr E C E Potter.

Agency Project Leader
Agency's Project Leader for R&D Project W2/i579 was:
Mr William Purvis - Environment Agency Wales

*** Note: In April 1997 DFR, Lowestoft became The Centre for Environment, Fisheries & Aquaculture Sciences (CEFAS), Lowestoft Laboratory an Executive Agency of the Ministry of Agriculture, Fisheries and Food.**

CONTENTS

EXECUTIVE SUMMARY

The document reports on the major findings from a definition study to appraise the options to develop fish tracking equipment, in particular tags and data logging systems, in order to improve the effeciency of the Agency tracking studies and to obtain a greater understanding of fish biology. The definition study was in two parts. The first, Phase 1, collated and evaluated all the known tracking systems that may be suitable for studies of fish which are either produced commercially or have been constructed for specific in-house studies. Phase 2 was an evaluation of all the tracking equipment considered to merit further investigation in Phase 1.

The tracking equipment was evaluated under the headings of: radio transmitters; radio receivers and automatic logging systems; acoustic transmitters; acoustic receivers and automatic logging systems; high resolution positioning fixing; and data storage and archival tags. In addition, other equipment that was considered of relevance to the Agency's requirements but was not evaluated is listed under the headings of telemetry and sensors; miniaturisation; satellite tracking; and other potential fish tracking systems.

The evaluation of the equipment is categorised into laboratory tests, field tests and biological evaluation. The evaluations are conducted from a user's view-point, considering mainly the effectiveness with which the equipment would fulfil the Agency's requirements in the field and the biological effects of the tags on the fish.

The deficiencies between existing and required technologies to improve the efficiency of Agency's tracking studies and to obtain a greater understanding of fish biology are also identified.

Key words: Fish; tracking; telemetry; radio; acoustic; transmitters; data logging systems; archival tags; position fixing; miniaturisation.

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1. INTRODUCTION

1.1 Background and terms of reference

This R&D Technical Report is a synthesis of the major findings of Phases 1 and 2 of the project entitled "Fish Tracking Developments". The overall project objective is stated in the terms of reference of the study thus:-

> " To undertake a definition study to appraise the options to develop fish tracking equipment, in particular tags and data logging systems, in order to improve the efficiency of Environment Agency (the Agency) tracking studies and to obtain a greater understanding of fish biology".

Phase 1, was a project definition study to review the availability of fish tracking technologies, and Phase 2 was an evaluation of the tracking equipment considered to merit further investigation during Phase1.

The specific task required by Phase 2 is stated in the terms of reference thus:-

- To carry out field and laboratory trials (including overseas site visits to assess on-going projects) to empirically evaluate specific items of equipment identified as meriting further investigations within the recommendations of the scoping study (Phase 1, desk review of commercially available equipment).
- Produce an R&D Technical Report to include the findings of the desk study and the evaluation of the equipment identified as meriting further investigations.
- Produce an R&D Project Record to include the findings of the desk and field studies, the identification of deficiencies between existing and required technologies and an appraisal of the feasibility, effectiveness, timescales and costs of options to make good these deficiencies (including the "do-nothing" option). In addition, the Project Record should include cost-benefit analysis for levels of precision different to and including those specified above.

This R&D Technical Report is a synthesis of the major findings of the R&D Project Record and as such does not include much of the technical data and specifications of the equipment detailed in the R&D Project Record.

1.2 Sources of information and scope of this report

Phase 1 of the project, reviewed all the tracking equipment known to the contractors that might be used in fishery studies undertaken or commissioned by the Agency. Phase 2 of project, provided an evaluation of the tracking equipment considered to merit further investigation in Phase 1.

There are two principal sources of tracking equipment; commercial manufacturers, who produce and design equipment for general sale; and individuals/research organisations, who develop tracking equipment for their own studies. Phase 1 of this review attempted to include both and to highlight where equipment is commercially available, or where it may be in limited supply or unavailable, to outside organisations. There is no single manufacturer who produces telemetry equipment in sufficient quantity or variety to support all the Agency's requirements. Each specialises in one or more particular area, be it general radio or acoustic wildlife telemetry or more specialised applications such as satellite or geographic position fixing.

The general approach of this study has been to attempt to obtain information and specifications on all tracking equipment and, where available, comments and assessments from individuals and research organisations who have used the equipment to track fish in the field. The review has been based upon the information provided by commercial manufacturers (Annexes 1 and 2) in the form of product information sheets and descriptions of equipment from published papers.

In Phase 1, the evaluation of the available tracking equipment for use by the Agency has been based on a number of criteria:

- the equipment appears to meet the specifications outlined in the terms of reference;
- the equipment is commercially available or is likely to be available in sufficient quantity for the Agency's requirements;
- there is adequate technical and after-sales support from the manufacturer; and
- assessments by users of the equipment are favourable.

The equipment considered to merit further investigation was evaluated in two principal ways. Firstly, some items were purchased hired or borrowed from suppliers and evaluated in laboratory tests at the Lowestoft Laboratory and in field trials at a number of sites in England. Secondlt, items that it was not considered cost-effective to purchase and which could not be hired, were evaluated during overseas visits to the manufactures or to sites where the equipment was being operated as part of a scientific study. As a result of this approach, it was not always possible to directly compare different manufacturer's equipment under the same conditions or at the same time. In addition, the laboratory tests that were carried out at the Lowestoft Laboratory, could not generally be duplicated during overseas visits.

Not all the manufacturers that were approached were willing or able to provide equipment for evaluation. Most notable was Lotek Inc. (Canada) who were unwilling to make the required modifications to tags in order to supply a small order on the required frequency. Thus although these items were considered to merit further evaluation, they have not been tested and included in Phase 2 of this study. The Zelcon Archival Tag was also not provided for evaluation within the timescale of the present study. It is now understood that the tag is being redesigned, but at the time of going to press it is still not known when it will become available.

The general approach of Phase 2 was to examine the tracking equipment for its suitability for use in the Agency's research programmes. The evaluations have been carried out from a potential user's point of view, based on the authors' extensive experience of the conditions under which fish tracking studies are likely to be carried out. However, it is probable that future Agency research programmes will include specific and unique conditions for fish tracking, and an assessment of the most the appropriate equipment will need to be conducted at the time.

In the fields of tracking and tag technology, equipment is being continually up-dated and developed by the commercial manufacturers. During the production and publication of this Report, there have been a number of significant advances in many areas covered but in particular in relation to archival tags and acoustic receivers In order to provide access to the most up to date sources of information, details of manufacturers' Web sites have been included in Annex 1. Access to these Pages will allow interested parties to obtain information on the most recent products and developments

2. RADIO TELEMETRY

2.1 Introduction

The majority of fish tracking studies undertaken in freshwater use radio telemetry. This approach is suitable for a range of Agency studies of factors affecting such as the river flows required to support migrations and the habitat requirements of coarse fish.

Radio tags emit electromagnetic energy within the VHF band at frequencies between 30-200 MHz. In the UK, radio frequencies from 173.7 - 174.0 MHz are reserved for medical and biological telemetry. All tags that are used in the UK for tracking studies must operate within these approved Department of Trade and Industry (DTI) frequencies and must also be type-approved by the DTI. In addition, they must be certified to comply with the Electromagnetic Compatibility (EMC) regulations, which now apply to all electronic equipment emitting radiated power.

There are a number of advantages in using radio tags for tracking studies. Firstly, it is the highest frequency at which simple crystal oscillators can be used to generate the carrier frequency directly. The most simple crystal-controlled tags can therefore be made with less than ten components and can weigh less than 1 g. Secondly, smaller receiving aerials can be used to detect the signals. Aerial size is directly proportional to wavelength, which is inversely related to frequency. Thus a dipole aerial operating at 200 MHz is 0.75 m high, whereas one for use at 30 MHz is 5 m high. At frequencies between 100 and 200 MHz practical and portable directional aerials can be built with a typical beam width of 8°. Despite this, fish tracking studies in North America have traditionally been carried out using frequencies in the 30, 40 and 50 MHz range. However, recent studies have shown that the use of higher frequencies in the VHF band (150 - 176 MHz) give considerably better results, and many radio tags manufactured by North American companies are now also produced at these higher frequencies.

Radio waves penetrate through freshwater and radiate from the water surface above the tag; they can therefore be picked up by aerials in air. The signal is, however, attenuated by its passage through the water, and the degree of attenuation depends upon the radio frequency and water conductivity. This leads to a reduction in range of detection depending upon the depth of the tag in the water. Radio tags are most useful in shallow rivers where acoustic noise and entrained air bubbles preclude the effective use of acoustic tags. The detection range of radio signals is normally good (up to 1.5 km), although it may vary depending upon a number of factors including the power output of the tags, the aerial and the line of site from tag to receiving aerial. Radio tags cannot usually be used in saltwater due to the very rapid attenuation of the signal, although they have been used in studies of animals such as basking sharks and marine mammals which move near the surface of the sea. In these cases signals may be detected intermittently when the tag is above or very close to the surface of the water. Detection is not possible when the animal is at depth.

At its simplest, radio tracking consists of attaching a radio tag to a fish and then following the animal using a hand-held directional aerial and a receiver (possibly with a set of headphones). The radio tag identifies the individual fish by virtue of its frequency and pulse rate. Bearing is determined by listening for peaks and nulls in the signal level (depending upon aerial design) as the aerial is rotated. Fish location is determined from a series of bearings. More sophisticated automatic systems for logging the movements of fish past fixed locations are also now widely used .

Radio signals are also used in satellite transmitters or platform transmitter terminals (PTTs) where the signals are detected by the US/French Argos system with receivers carried on board the NOAA series of satellites (see section 9).

2.2 Radio transmitters

A wide variety of commercially available radio transmitters have been specifically designed for tracking fish.

All the transmitters commercially available in the UK are DTI type-approved and generally operate at the frequencies approved for medical and biological studies. A number of overseas manufacturers produce transmitters that can operate at the UK frequencies but do not have type-approval for their products. In addition, these transmitters are not certified under EMC regulations. Use of these transmitters in the UK would therefore require that the manufacturer or operator obtain the relevant certification.

It is now widely accepted that before tracking any fish, the effects of the tag together with the method of attachment should be fully assessed. The principle criteria for the selection of a radio tag for use on a fish is that the tag should not effect the behaviour or survival of the animal. The size, shape and weight of the tag therefore needs to be considered. One of the largest and heaviest components in most tags is the battery and so there is a trade-off between power output (i.e. range), operating life and size/weight. The size and shape of the tag will also affect the drag if it is attached externally and the ease with which it may be inserted into the stomach or body cavity. However, there is no hard and fast rule relating the maximum weight of the tag with the size or weight of fish.

The range of a tag is often difficult to assess as it is dependent upon a wide range of interacting factors. These include power output, aerial type, attachment method, orientation, size and type of receiving aerial, line of sight, and depth and characteristics of the water. Comparisons between tags are therefore often misleading. The Effective Radiated Power (ERP) provides a comparable measure but it is rarely quoted by manufacturers. The suitability of a tag for a particular study will thus often necessitate testing the tag in the field.

Tags can be constructed with a whip (trailing) or a coiled (internal) aerial to transmit the signal to the receiver. Whip aerials, in general, have higher power output, and therefore greater range, and are less directional. However, when the tags are attached externally, whip aerials can increase the risk of entanglement within the aquatic environment or may be broken by continuous flexing in the current. Tags that are inserted into the stomach or surgically implanted into the body cavity require that the aerial is led to the outside of the fish. Normally during stomach insertion the aerial is threaded through the last gill arch opening and allowed to trail alongside the fish. When the tag is implanted into the body cavity a needle is pushed through the flank of the fish and the aerial threaded through to the outside. This technique may increases the risk of irritation and infection associated with implantation.

Tags with coiled or loop aerials generally have lower power output and are more directional, however they are less awkward to use. Standard whip aerials may be coiled and encapsulated into the tag by the manufacturers, but this may result in a reduction in power output of 25 dB, which will significantly reduce the range. (A reduction in power of 3 dB will effectively halve the original range of the tag.) The efficiency of internal coiled aerials can, however, be improved by tuning them. In North America, whip aerials have generally been used to maximise the range of the tags during tracking studies in extensive river systems. In UK, range has not been such an important consideration and coiled internal aerials have been favoured under most situations.

For the majority of freshwater fish tracking studies in the UK, the requirement has therefore been for radio tags with internal aerials that can be implanted into the stomach or body cavity of the fish. It is now widely accepted that the most suitable method of attachment of tags in feeding fish is within the body cavity. However, in spawning fish and where an external environmental parameter is to be telemetered, alternative methods of attachment may be necessary.

There are two basic types of radio tags that are used to track fish. These are pinger and coded tags.

Radio pinger transmitters

Pinger radio tags emit pulses at predetermined rates (20-120 pulses per minute, ppm). A combination of the pulse rate and frequency of the tag is normally used to identify individual fish. Thus using 10 different pulse rates on each of 10 radio frequencies allows 100 fish to be uniquely identified. Most radio tags manufactured for fish tracking are of this type. They are currently used by the Agency and other organisations for many tracking studies in the UK and would be appropriate for many of the Agency's requirements in the future.

Coded radio transmitters

The maximum number of fish that can be confidently identified with pinger tags depends upon the number of separable pulse rates and frequency bands. It is commonly around 100 but may be up to about 400. An alternative method to increase the number of fish that may be tracked simultaneously is to use tags with their own unique identifiable codes. Coded tags make better use of limited frequency space and reduce sampling time required to obtain data on each animal. Coded radio tags could permit more fish to be uniquely identifiable than is possible with pinger tags. This would simplify tracking programmes and allow fish marked in separate experiments to be distinguished. This is not an urgent requirement for Agency tracking programmes but would have some advantages.

2.2.1 Evaluation of radio transmitters

The radio transmitters considered suitable in Phase 1 and evaluated in Phase 2 of the study were:

Advanced Telemetry Systems (USA)	Model 10: Model 393: Model 357: Model 379.
Telonics (USA)	Model IMP-100-L: Model IMP-200-L
MAFF (UK)	Model SAL3: Model SAL4
Biotrack (UK)	Model SS-2-Ag317: Model SS-2-Hg312; Model TW-4-Ag357: Model TW-4 Ag392

The performance of the radio tags was evaluated during both laboratory and field trials. Laboratory evaluations included the measurement of the polar output plots of each tag and their frequency and pulse rate stabilities under a range of environmental temperatures and pressures (depth). The field trials compared the signal range of the tags in water bodies of differing conductivity, depth and flow. The tags were also considered from a biological viewpoint in terms of the size of fish to which they may be attached and the most appropriate method of attachment.

2.2.2 Laboratory tests

Polar output plots

Polar output plots provide a measurement of the radiation pattern from a tag's aerial and are usually measured in decibels @ 1 metre (dBm). The ideal tag would produce an omnidirectional signal of equal strength in all planes. However, in most tags the circuitry and aerial are such that there are blind spots or nulls in the radiation pattern transmitting from the tag. This means that when the tags are at a particular angle with respect to the receiving antenna, there is a relative loss in the signal and in extreme cases the tag is not detectable. The polar plots do not give a complete picture of the radiation pattern from a tag, but indicate the extent of the variation in signal strength in different directions. A reduction of 3 dBm in signal strength is equivalent to a 50% power loss, which in turn will reduce the range of a tag by approximately half. However, in many Agency research programmes, the radio tagged fish are likely to be moving relative to fixed monitoring sites, and so in practice limited null areas and blind spots will only result in transient loss of signal. An exception to this situation is where radio tags are being used as part of a High Resolution Position Fixing System to monitor the movements of fish close to an obstacle such as a weir. Under these circumstances the radiation pattern of the tags will become more important.

A typical polar output plot of a single radio tag is shown in Figure 1.

Stability of frequency and pulse rate with pressure and temperature

Typical results of the evaluations of the stability of the frequency and pulse rate of a single radio tag with pressure and temperature are shown in Figure 2. Tags were evaluated up to pressures which equated to approximetely 125 m depth, and at temperatures from 2 to 30°C.

2.2.3 Field tests

The field tests were carried out at sites on three inland waters each with a different water conductivity and current speed. The results of the range tests are shown in Table 1 (conductivity and flow), and Table 2 (depth). Generally, the ranges of the tags were less in water of higher conductivity (River Trent - 994 µS) than they were in water of lower conductivity (River Avon - 482 µS). There did not appear to be any relationship between the range of the tags and differences in the current speed at the three sites.

There were very significant decreases in the ranges of all the tags with depth in Rutland Water (Table 2). Only four models of tags (ATS model 357, MAFF SAL3 and all Telonics tags) were detected at a depth of 4 metres, and none of the tags were detected at a depth of 15 m.

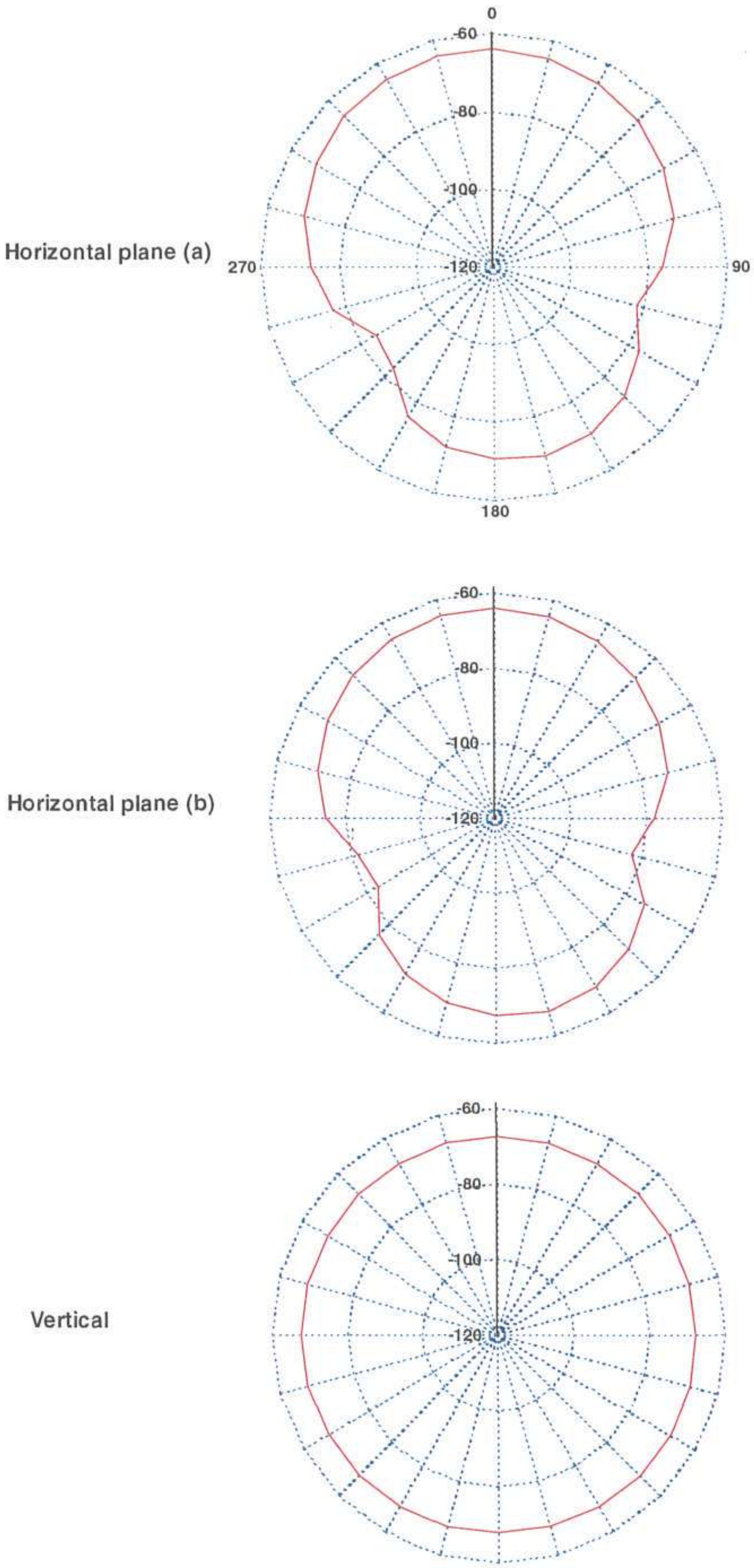
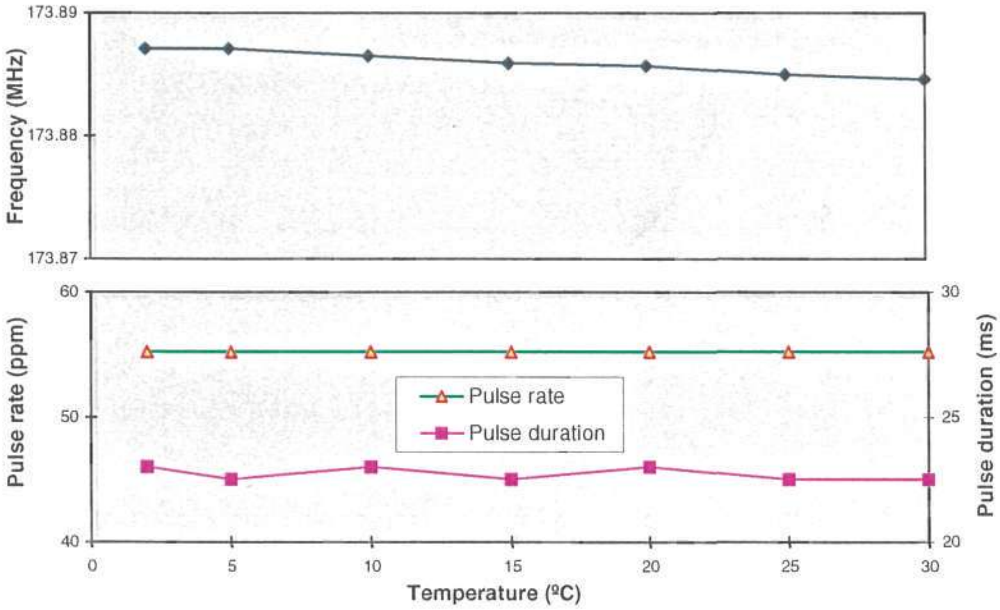


Figure 1. The polar output plot of an ATS Model 10 radio transmitter. The values are decibels @ 1 metre (dBm)

Temperature (ºC)	Frequency (MHz)	Pulse duration (ms)	Pulse rate (ppm)
2	173.8871	23.0	55.2
5	173.8871	22.5	55.2
10	173.8865	23.0	55.2
15	173.8859	22.5	55.2
20	173.8857	23.0	55.2
25	173.8850	22.5	55.2
30	173.8846	22.5	55.2



Pressure (psi)	Frequency (kHz)	Pulse rate (ppm)
14.38	173.8851	55.2
24.38	173.8851	55.2
34.38	173.8851	55.2
39.38	173.8851	55.2
44.38	173.8851	55.2
54.38	173.8851	55.2
64.38	173.8851	55.2
120.00	173.8851	55.2

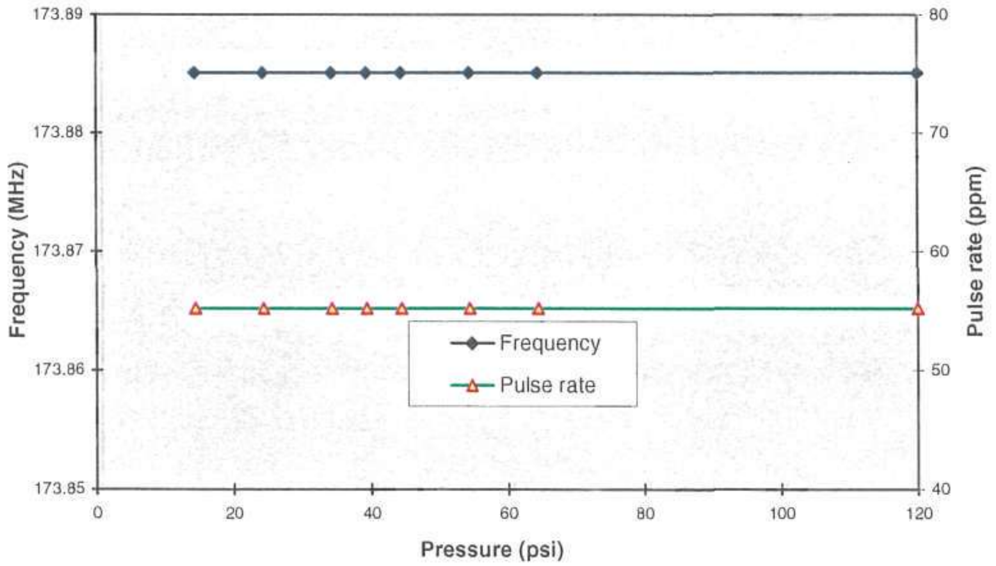


Figure 2. The stability of the frequency, pulse rate and pulse width with temperature (upper graph), and the stability of the frequency and pulse rate with pressure (lower graph) of an ATS Model 10 radio transmitter

Table 1. Measured ranges of the radio transmitters in waters of different conductivity

Manufacturer	Model	id.	Frequency (MHz) Nominal	Frequency (MHz) Measured	River Avon (Conductivity 482 mS, Temperature 12.4 °C) Range (m)	Rutland Water (Conductivity 632 mS, Temperature 13.4 °C) Range (m)	River Trent (Conductivity 994 mS, Temperature 12.4 °C) Range (m)
TELONICS	IMP-100-L	(a)	173.04	173.0404	116	206	146
	IMP-100-L	(b)	173.0214	173.0224	132	222	88
	IMP-200-L	(a)	173.0595	173.06	423	348	215
	IMP-200-L	(b)	173.0803	173.0807	369	458	250
MAFF	SAL3	-	173.825	173.8254	208	309	160
	SAL4	-	173.845	173.8454	193	143	126
ATS	10	(a)	173.883	173.8822	20	70	43
	10	(b)	173.862	173.8617	24	79	50
	393	(a)	173.74	173.7411	80	72	56
	393	(b)	173.722	173.7195	50	42	26
	357	(a)	173.839	173.8372	136	209	60
	357	(b)	173.761	173.7566	229	195	159
	379	(a)	173.818	173.816	39	*	*
	379	(b)	173.73	173.7287	39	52	69
BIOTRACK	SS-2-Ag317	(a)	173.866	173.8625	20	14	19
	SS-2-Ag317	(b)	173.865	173.8619	34	14	46
	SS-2-Hg312	(a)	173.865	173.8611	40	15	27
	SS-2-Hg312	(b)	173.868	173.8639	35	21	21
	TW-4-Ag357	(a)	173.891	173.8875	118	20	55
	TW-4-Ag357	(b)	173.891	173.8875	142	43	40
	TW-4-Ag392	(a)	173.891	173.8874	68	63	68
	TW-4-Ag392	(b)	173.891	173.8872	68	51	74

* unrecoverable after field testing

Table 2. Measured ranges with radio transmitters at 1.5, 4.0 and 15.0 metres depth in Rutland Water

Manufacturer	Model		Requency (MHz)		Depth		
			Nominal	Measured	1.5 metres Range (metres)	4.0 metres Range (metres)	15.0 metres Range (metres)
TELONICS	IMP-100-L	(a)	173.04	173.0404	206	19	Not detected
	IMP-100-L	(b)	173.0214	173.0224	222	18	Not detected
	IMP-200-L	(a)	173.0595	173.06	348	31	Not detected
	IMP-200-L	(b)	173.0803	173.0807	458	41	Not detected
MAFF	SAL3	-	173.825	173.8254	309	34	Not detected
	SAL4	-	173.845	173.8454	143	Not detected	Not detected
ATS	10	(a)	173.883	173.8822	70	Not detected	Not detected
	10	(b)	173.862	173.8617	79	Not detected	Not detected
	393	(a)	173.74	173.7411	*	*	Not detected
	393	(b)	173.722	173.7195	52	Not detected	Not detected
	357	(a)	173.839	173.8372	209	28	Not detected
	357	(b)	173.761	173.7566	198	24	Not detected
	379	(a)	173.818	173.816	72	Not detected	Not detected
	379	(b)	173.73	173.7287	42	Not detected	Not detected
BIOTRACK	SS-2-Ag317	(a)	173.866	173.8625	14	Not detected	Not detected
	SS-2-Ag317	(b)	173.865	173.8619	14	Not detected	Not detected
	SS-2-Hg312	(a)	173.865	173.8611	15	Not detected	Not detected
	SS-2-Hg312	(b)	173.868	173.8639	21	Not detected	Not detected
	TW-4-Ag357	(a)	173.891	173.8875	63	Not detected	Not detected
	TW-4-Ag357	(b)	173.891	173.8875	51	Not detected	Not detected
	TW-4-Ag392	(a)	173.891	173.8874	20	Not detected	Not detected
	TW-4-Ag392	(b)	173.891	173.8872	43	Not detected	Not detected

* unrecoverable after field test

2.2.4 *Biological considerations*

There is no simple formulae for calculating the effects or the suitability of a tag for a fish. Moreover, a particular model of tag which is suitable for one species may not be suitable for other species of fish. The following biological evaluation of the selected radio transmitters is based upon a literature review, the physical characteristics of the tags, their suitability for attachment to a range of sizes of salmonids and the practical experience of the authors. However, there is no substitute for extensive laboratory and field based studies on the effects and efficacies of tag attachments to the study animal. Unfortunately, these types of studies were beyond the remit of this particular study.

There are three recognised methods of attaching transmitters to fish. These are:

1. external attachment
2. insertion into the stomach or gut
3. surgical implantation

The external attachment of radio transmitters is detrimental to the survival and behaviour of many fish species. Studies on the external attachment of tags have been carried out on species such as perch, catfish, Atlantic salmon, sea trout, barbel, rainbow trout, European eel and carp. These studies have indicated that this method of attachment may lead to reduction in survival (Ross & McCormick 1981), entanglement of the transmitter in vegetation (Ross & McCormick 1981), the tag being torn off the fish by rocky substrate (Nettles & Gloss 1987), erosion of scales (Lonsdale & Baxter 1968), erosion of dorsal muscles (Yeager 1982), hypoactivity (Zimmermann 1980), reduced feeding rate (Ross & McCormick 1981), increased oxygen consumption (Lewis & Muntz 1984), increase drag (Tesch 1987), restriction of dorsal fin movements (Trocherie & Bercy 1984), induction of negative buoyancy (Fried *et al.* 1976), irregular swimming (Mellas & Haynes 1985) and fungal infection (Mellas & Haynes 1985). It is therefore recommended that tags, when possible, are not attached externally to fish.

The insertion of tags into the stomachs of fish, while preferable to external attachment, may result in regurgitation of the tag (Solomon & Storeton-West 1983), rupture of the oesophagus (Solomon & Storeton-West 1983), gut atrophy (Haynes 1978) and in salmonids increased down-stream movement (Haynes & Gray 1979). Where fish have been feeding the available space for a tag is greatly reduced, and insertion of a tag at this time can lead to the rupturing of the stomach. This method of attachment is therefore not recommended for use on feeding fish.

The surgical implantation of a tag into the body cavity of the fish in the UK requires that the operator is licensed under the Home Office Animals (Scientific Procedures) Act 1986. Studies have indicated that this method of tag attachment may result in rupture of the incision zone (Wrenn & Hackney 1979), expulsion of the tag through the gut (Chisolm & Hubert 1985) or body wall (Lucus 1989; Moore *et al.* 1991). However, if performed correctly, the method has been demonstrated to have minimal effects on the survival and behaviour of juvenile Atlantic salmon (Moore *et al.* 1991).

Physical characteristics

The shapes of the tags range from cylindrical to gravestone, and it is considered unlikely that when attached they would adversely affect the fish. However, a cylindrical shaped tag would be more appropriate for insertion into the stomach, whereas gravestone or pan-shaped tags may be more appropriate for insertion into the body cavity of fish. The size of the tags examined ranged from 11 to 62 mm in length, and 1.0 to 29.5g in weight, which might be suitable for use on a range of fish from Atlantic salmon smolts through to large carp and pike.

Fish size and species

Tests were conducted to assess the suitability of each of the tags for stomach insertion or surgical implantation into salmonids between 15 and 70 cm in length. The suitability of the tags for external attachment was not considered because this method was reported to have adverse effects on fish.

The assessment was based upon the ease with which the tags could be inserted into the stomach (length and width), and the body cavity of salmonids of fork lengths **15.0, 24.6, 27.5, 37.5, 42.7, 46.1, 52.7, 56.1 and 69.1 cm.** The results are shown in Table 3. Although, this study was carried out on salmonid species (Atlantic salmon and sea trout), the results should also be appropriate for other freshwater species. Except for the European eel, the table could be used as an initial guide for the possible use of the tags on different size ranges of cyprinids, pike, perch, etc. However, studies would be necessary on the effects of the tag and method of attachment on the behaviour and survival of the fish.

2.2.5 Evaluation with regard to the Agency's requirements

The majority of the Agency's fish radio tracking programmes relate to the movements of Atlantic salmon, sea trout and coarse fish in rivers and inland waters in England and Wales. Therefore, the following evaluation of the radio tags is based upon their use within these environments and the physical conditions found therein. Emphasis has also been placed upon the use of the tags in studies using automatic data loggers.

i. Advanced Telemetry Systems (ATS) radio pinger transmitters

All the ATS tags are of the same basic construction; the electronics, battery and coiled aerial being encapsulated in hard, clear, epoxy resin. A visible label is also encapsulated, providing information on the nominal frequency, production date and batch number. The tags are activated and deactivated by a magnet-controlled reed switch. The manufacturers specifications are for tags with external aerials, but for this evaluation the manufacturers were asked to supply tags with internal coiled aerials. Encapsulating the aerial increased the dimension of the tags and decreased their output power.

All models of ATS tags are biologically friendly in construction, relatively stable in terms of pulse rate with temperature, and produce satisfactory signal patterns. The tags would meet the requirements for the tracking of salmonids and coarse fish greater than 25 cm in length in relatively shallow rivers (< 15 m in width) of varying conductivity (100-1200 μS). The reduced range of the Model 10, 393 and 379 tags would require that care is taken in the sighting of receiving apparatus and they would not be suitable for the study of fish in more extensive river systems. Studies of fish in rivers up to 4.0 m in depth would only be possible with the Model 357 tag, and this would not be suitable for use in deeper waters. The poor frequency stability of the Model 10 and 379 tags between the temperature range 2 to 25°C would require that automatic

Table 3. Attachment of radio transmitters in relation to fish length

Body cavity		Fish length (cm)								
		15.0	24.6	27.5	37.5	42.7	46.1	52.7	56.1	69.1
TELONICS	IMP-100-L	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
	IMP-200-L	No	No	No	No	Marginal	Yes	Yes	Yes	Yes
MAFF	SAL3	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
	SAL4	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
ATS	10	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	393	No	Marginal	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	357	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	379	Marginal	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
BIOTRACK	SS2-Ag317	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	SS2-Hg312	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	TW4-Ag357	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Stomach length		Fish length (cm)								
		15.0	24.6	27.5	37.5	42.7	46.1	52.7	56.1	69.1
TELONICS	IMP-100-L	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
	IMP-200-L	No	No	No	No	Yes	Yes	Yes	Yes	Yes
MAFF	SAL3	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
	SAL4	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
ATS	10	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	393	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	357	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	379	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
BIOTRACK	SS2-Ag317	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	SS2-Hg312	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	TW4-Ag357	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Stomach width		Fish length (cm)								
		15.0	24.6	27.5	37.5	42.7	46.1	52.7	56.1	69.1
TELONICS	IMP-100-L	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
	IMP-200-L	No	No	No	No	No	No	Yes	Yes	Yes
MAFF	SAL3	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
	SAL4	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
ATS	10	No	Marginal	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	393	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	357	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	379	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
BIOTRACK	SS2-Ag317	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	SS2-Hg312	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	TW4-Ag357	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes

No | Marginal | Yes

radio receivers are programmed 4 kHz either side of the nominal tag frequency (i.e. require a wide reception band). As a result of the restricted frequency band allocated for telemetry studies in the UK, this would reduce the number of frequency channels that could be used during a study, and hence reduce the number of fish that could be released.

The ATS tags have not been type approved by the DTI for use in the UK. In addition, they have not been certified to comply with the EMC regulations which is now required for all electronic equipment emitting radiated power. Their use for tracking fish in the UK is therefore restricted until the appropriate licences have been obtained.

ii. Telonics radio pinger transmitters

The Telonics tags are cylindrical in shape, with an internal coiled aerial and encapsulated in a white opaque wax compound. The two Telonics tags are biologically friendly in construction, relatively stable in terms of frequency and pulse rate with temperature, and produce satisfactory signal patterns. The tags would meet the requirements for the tracking of large salmonids and coarse fish greater than about 40 cm (model IMP-100-L) or 50 cm (model IMP-200-L) in length, in relatively shallow rivers (< 4 m) of varying conductivity. The Telonics tags are constructed of a soft wax substance which would allow them to be inserted into the stomach or body cavity of an appropriate sized fish without significant damage to tissue. The tags would not be suitable for use on fish that are likely to spend significant periods at depths greater than 4 m. The frequencies of the tags are relatively stable over the temperature range that they would normally encounter during field studies. This would permit their use with a number of automatic radio receivers (see section 13), as long as the frequency band width of each recording channel was programmed 1.5 kHz either side of the measured null.

The Telonics tags have not been type approved by the DTI for use in the UK. In addition, they have not been certified to comply with the EMC regulations which is now required for all electronic equipment emitting radiated power. In addition, the tags provided for the evaluation were outside the frequency band allocated by the DTI for Medical and Biological use. Their use for tracking fish in the UK is therefore restricted until the appropriate licences have been obtained.

iii. MAFF radio pinger transmitters

The electronics, batteries and tuned coiled aerial are all sealed in a hard, clear, polycarbonate cylindrical case with hemispherical ends. The SAL3, contains a visible label detailing the frequency, the pulse rate, pulse length and serial number. The SAL4 contains a similar label detailing the nominal frequency and pulse rate of the tag. The SAL3 is activated and deactivated by a magnet-controlled reed switch, whereas the SAL4 has start-up wires. This requires the user to solder together two wires and then to seal the tag case.

The MAFF SAL3 radio tag has been extensively used by the Agency in England and Wales for studying migratory salmonids. The SAL4 tag has not been used as much, but was initially developed to study the movements of sea trout in rivers in SW England. The tags are biologically friendly, stable in terms of frequency and pulse rate with temperature, and with good omnidirectional signals and ranges under most environmental conditions. The tags would meet the Agency's requirements for the tracking of salmonids and coarse fish greater than about 24 cm (SAL4) and 37 cm (SAL3) in length, in relatively shallow rivers of varying conductivity. The tags would not be suitable for use on fish that are likely to spend significant periods at depths greater than 4 m. The tags have been used in conjunction with the MAFF automatic listening stations for the automatic tracking of salmonids. Both of the tags are DTI approved for use in the UK, and have been certified to comply with the EMC regulations.

iv. Biotrack radio pinger transmitters

The Biotrack implantable tags (SS-2 models) have an internal tuned coil aerial and the back-pack tags (TW-4 models) have an external whip aerial. All the tags are enveloped in a soft black plastic coating. Two start-up wires protrude through the black plastic. To activate the tag these wires are wound or soldered together. A tube of 'Plasti-dip' is supplied with the tags to cover the connection.

The Biotrack tags are the smallest of the tags evaluated and have been considered because they have previously been used to manually track Atlantic salmon smolts in the River Test. They would meet the requirements for the tracking of salmonids and coarse fish only under certain conditions. The TW-4 model tags each have an external aerial, which if the tags were attached to fish, would need to be trailed to the outside, either through the mouth or through the body wall. Both methods have been shown to lead to abnormal behaviour, increases in infection and mortality in fish. These tags do not therefore meet the Agency's requirements for the tracking of salmonids and coarse fish.

The SS-2 model tags are biologically friendly in construction and could be used on fish greater than 15 cm in length in shallow, narrow rivers. However, the tags had low power output and were very unstable in terms of pulse rate over the normal temperature range of most field studies (2-15°C). When individual fish are identified by the pulse rates of the tags this could result in the mis-identification of fish. Alternatively, if the pulse rate separation between tags were increased to reduce the possibility of mis-identification, then fewer fish could be released. The range of tags were also very limited (14-46 m at 1.5 m depth), and this would require that care is taken in the siting of receiving apparatus and that the tags are used to study fish only in small shallow river systems or tributaries. The tags would not be suitable for use on fish that are likely to spend significant periods at depths greater than 1.5 m.

The tags are DTI approved for use in the UK, and have been certified to comply with the EMC regulations.

2.3 Radio receivers and automatic logging systems

The majority of commercially available radio receivers that operate in the VHF band are suitable for tracking studies. Radio receivers that are specifically designed for wildlife tracking are generally of two types. The first is the hand-held receiver used for manual tracking. The second is the automatic or data logging receiver which is programmed to scan through specific frequencies and may also store records of the tag signal and identity. For studies in the UK suitable receivers must cover the frequencies 173.7 to 174 MHz, which is the band allocated for medical and biological telemetry.

Important features to be considered in any receiver for use in the types of studies undertaken by the Agency are:

1. The operating frequency range. A minimum range of 300 kHz is preferable to fully utilise the available space designated between 173.7 - 174 MHz.
2. The ability to tune the receiver in 100 Hz-1 kHz steps. This is also to fully utilise the available space designated between 173.7 - 174 MHz.
3. The value of the minimum discernible signal (measured in dBm). This provides an indication of the sensitivity of the receiver. The lower the value the more sensitive the receiver. A signal of -145 dBm is easily detectable by ear, a signal of -150 dBm is around the limit of detection.
4. Noise (measured in dB). The higher the figure the more difficult it is to discern the signal. A figure of 3 dB is generally adequate.

5. Frequency stability. Measured in kHz this indicates how much the frequency of a receiver may drift. The lower the value the better.
6. Operating voltage and battery operating lifetime. Receivers that operate at mains voltage are more limited for field studies.
7. Programmable memory. A programmable memory is required for the majority of studies.
8. Size and weight. Receivers must be suitable for carrying in difficult terrain.
9. General ruggedness and waterproofing. Receivers should tolerate damp conditions and rough handling.
10. Cost.

Manual (hand-held) radio receivers

A wide variety of hand-held radio receivers are available and could be adapted for use for fish tracking. This is the case with the Yaesu receiver currently widely used in the UK. All Agency radio tracking programmes will require some hand-held receivers. The following section only considers the manufacturers' specifications for receivers that have been purpose-designed for animal tracking or modified for this purpose.

Automatic and data logging radio receivers

Most Agency radio tracking studies will be expected to employ automatic and data logging receivers to allow long-term tracking. These may have to be located in a wide variety of sites including exposed positions on the river bank. Basic requirements are outlined above, (see section 2.8), but ruggedness is particularly important.

2.3.1 Evaluation of radio receivers and data logging systems

The radio receivers and automatic radio receiving systems evaluated were:

Adavanced Telemetry Systems (USA)	Model R2100 Receiver Model R4000 Receiver DCC II Data Collection Computer
Televilt (Sweden)	RX-900 Receiver and Data Acquisition System
Lotek (Canada)	SRX_400 Receiver and Data Logging System
MAFF (England)	Automatic Listening Stations

Any of the manual (hand-held) radio receivers highlighted as suitable could be used in the UK to track fish. There is little to distinguish between them in terms of performance and specifications.

The performance of the radio receivers and automatic data loggers was evaluated during both laboratory and field trials. Laboratory trials included an evaluation of operating capabilities of the recievers and their frequency stability over a range of environmental temperatures.

In addition, three trials were conducted to evaluate the automatic recording capabilities of the radio receivers:

1. A laboratory study was carried out to ascertain whether the receivers and loggers could identify and log the individual pulse rates of 3-4 radio tags transmitting on the same frequency (channel) simultaneously. This evaluation would assess the capabilities of a logger in a situation where two or more fish were detected at the same time.

2. A laboratory based study was carried out to assess whether the receivers and loggers could be used in conjunction with acoustic sonar buoys (see section 3.3.2) as an intermediate link between the receiver and transmitters. This evaluation would assess the capabilities of a logger in a situation such as the tracking of salmon through an estuary where previously the MAFF automatic listening station has been used.

3. An evaluation was carried out to ascertain whether the Lotek acoustic coded system could be used in conjunction with MAFF sonar buoys.

2.3.2 Laboratory and field tests

i. Advanced Telemetry Systems (ATS)

ATS R2100 Receiver

The R2100 is a rugged splash-proof receiver, with the control panel protected by raised brackets on either side. The receiver is further protected by a padded nylon waterproof case with a shoulder strap. All the controls, displays, and input / output sockets are located on the front of the receiver, which permits its use whilst remaining in the case. The receiver operates over the frequency range permitted by the DTI for biological research (173.7 - 174.0 MHz). The desired frequency is selected and programmed into a separate channel on the receiver in 1 kHz steps.

Up to 1999 frequencies can be stored in or deleted from the receivers memory. Once the frequencies are programmed, the memory can then be used for scanning. In scan mode, the receiver advances through the programmed channels in order of frequency, and listens at each for periods of between 4 and 960 s.

The receiver has a built-in interface to work with the ATS Data Collection Computer (DCC), for interpreting and logging signals.

ATS R4000 Receiver

The R4000 receiver is very similar to the R2100 described above and can operate over the 4 MHz range between the frequencies 172 and 176 MHz. Frequencies can be tuned in 1 kHz steps, although only the last 4 digits are displayed. The R4000 has four separate memories each of which can be programmed with up to 3999 frequencies. This receiver offers the same functions as the R2100, but they are operated by separate controls rather than multi-functional switches.

ATS DCC II Data Collection System

The ATS Data Collection Computer is a data logger, data interpreter and automatic receiver. It uses the same housing as the R2100 and R4000, and consequently, it has the same dimensions. The DCC II operates in conjunction with either the R2100 or R4000 receiver. When connected, the DCC II fully controls the receiver's operation.

The program parameters are entered using the initialising function. The frequency range, within which the DCC II operates, is governed by the limits of the receiver to which it is attached. The frequency range is keyed into the DCC II to calibrate it to that receiver together with the scan times. Within the same function, the pulse rates of the transmitters to be tracked are also entered, together with tolerance limits. Three different pulse rates can be programmed into any one frequency channel.

The DCC II logs either the number of pulses in that scan time or the pulse rate for that channel. The date and time, the channel and the antennae code are recorded whether a signal is received or not. Other parameters may be recorded but a different system program would be needed. Other standard system programs are available, or ATS can provide custom programming. The receiver came with a software package to down-load stored data to an IBM compatible PC.

ii. Televilt

Televilt RX-900 Receiver

The RX-900 is a compact, rugged, water proof receiver and data acquisition system. A pivoted bracket/stand/holder allows the receiver to be used easily and comfortably in most situations. When folded up, the bracket offers the control board extra protection.

The controls on the receiver are limited to an on/off switch and a thumb wheel and 24 button key pad which accessed all the functions within the built-in micro-computer. The function menus or the information relating to incoming signals are displayed on a 4 line 20 character LCD screen (58 x 21 mm). Electroluminescent back-lighting allows for easy use at low illumination.

The RX-900 receiver can operate over any specified 2 MHz range within 120 - 240 Mhz, and is therefore suitable for use over the frequency range permitted by the DTI for biological research (173.7 - 174.0 MHz).

The required frequencies are programmed into the receiver in 1 kHz steps. The receiver has a maximum of 9 tables each which can be programmed with 83 frequencies. These tables can then be used for automatic or remote scanning

The RX-900 has a built in micro-processor that operates and controls all the receiver functions and the data logger.In data acquisition mode, the reciever logs signal strength, period and pulse width. The receiver has the facility for checking the amount of memory used and indicates the percentage of the memory remaining. The receiver comes with a software package to down-load stored data to an IBM or a Macintosh compatible PC.

iii. Lotek

Lotek SRX_400 Receiver

The SRX_400 is a powerful data logging, tracking receiver and is the basis for a number of unmanned, remote data acquisition systems. Its adaptability from hand held to remote usage is reflected in a user friendly design. Its controls are limited to a 16 key dual function, weatherproof key pad and an on/off switch which also controls the volume.

All the functions are accessible via the keypad and menu prompts displayed on a 24 character 2 line LCD (94 x 15 mm) with optional back lighting. The display shows the receiver frequency and the numeric value of the receiver gain. When scanning and receiving a transmitted signal, the display can show the pulse rate or pulse interval of the transmitter; the relative signal strength; and scan operating status messages.

The SRX_400 receiver supplied for the trial operated over a 4 MHz frequency band between 172 to 176 MHz which covered the frequency range permitted by the DTI for biological research (173.7 - 174.0 MHz).

The operating frequency can be entered in 1 kHz steps. The receiver provides up to 16 memory banks with 512 possible frequencies (channels) at 1 kHz spacing. The frequencies are programmed either via the key pad or loaded from a PC using the program provided.

A range of software systems is available to detect and record the presence and pulse interval, (or code), of transmitters which have been entered in the frequency tables.

A sensor option is available which is assigned to a particular channel or frequency in the scan table to log temperature or depth etc. For instance, by calibrating the pulse rate of a tag transmitting on a particular frequency to temperature, and transferring that calibration table to the logger, any valid signal received on that channel can be converted to temperature and stored for later retrieval.

Logged and stored data is readily down-load to an IBM compatible PC in a form that is suitable for most Agency applications.

iv. MAFF automatic listening station

These listening stations are widely used in the UK by the Agency and Scottish Office to study the migratory behaviour of salmonids. The listening stations comprise a Yaesu FT 290 ten-channel radio receiver, a processor unit, a tape recorder and a paper tape printer and are powered by an external 12 V DC battery. The listening station has a variable scan rate (continuous, 2 min, 5 min and 10 min), and scans through the programmed frequencies and makes a record of any signal detected. The record takes the form of a paper print-out giving time, date and radio channel number and the audio cassette recording provides a check on aberrant signals activating the scanner. Data cannot be down-loaded to a PC.

2.3.3 Evaluation with regard to the Agency's requirements

The majority of the Agency research programmes on the tracking of fish are related to the study of the migratory behaviour and movements of salmonids and coarse fish in inland waters. One of the requirements of these programmes is to monitor the passage of fish past fixed sites and to automatically record these events. This requirement covers the movements of fish tracked in freshwater using radio tags and the movements of fish in estuarine and coastal waters using acoustic tags and sonar buoys.

In many tracking situations the ATS R2100/DCC II receiver and data logger, the Televilt RX-900 data logger, Lotek SRX_400 and MAFF automatic listening stations would fully meet the Agency requirement for automatic logging of fish movements. However, each receiver does have a number of limitations which under certain conditions and circumstances would limit their use for field studies. Firstly the systems evaluated either did not have the ability to, or did not consistently identify more than one pinger tag occurring simultaneously on one frequency. Where two tags with the same frequency, but different pulse rates were detected on the same channel, then neither tag would be logged or a hybrid or "ghost" pulse rate would be recognised and logged. In situations where tagged fish were moving together, or where large numbers of fish congregated (e.g. salmon holding pools or beneath weirs and obstructions), then the identities of each fish based on pulse rate would not be logged. To successfully identify and log more than one fish at a time, each tag would need to be a assigned a different frequency and channel on the receivers. This is possible with both the Televilt RX-900 data logger and Lotek SRX_400 logger. If the pinger tags used in the study were sufficiently stable in terms of frequency and pulse rates then there is sufficient space allocated by the DTI to allow an adequate number of fish to be released and studied.

The ATS R2100/DCC II receiver and data logger, the Televilt RX-900 data logger, Lotek SRX_400 logger and MAFF automatic listening station could all be used successfully to monitor the radio signals from the MAFF acoustic sonar buoys. However, the limitations of the receivers under these circumstances are similar to those addressed above. If two tags with different pulse rates were detected by a sonar buoy at the same time then the Televilt RX-900 data logger and Lotek SRX_400 logger would not be able to distinguish and log the two tags. The ATS R2100/DCC II receiver and data logger would be able to identify and log a maximum of three previously defined pulse rates, but would also log a number of spurious signals. The MAFF automatic listening station would log all the pulse rates but it would be difficult to sort out and identify the individual tags. It was noted that each of the receivers operated better with the sonar buoys than they did with radio tags. This was the result of the sonar buoys transmitting a radio signal at a fixed and consistent output irrespective of the power output of the individual tags.

The evaluation also indicated that the Lotek coded acoustic tags could be used in conjunction with the MAFF acoustic sonar buoys and the Lotek SRX_400. This capability would allow the Lotek SRX_400 logger to be used for estuarine and coastal studies without the need for the SRC_400 upconverter or hard wired acoustic hydrophone (see section 14.3).

None of the receivers except the MAFF automatic listening station, have been certified to comply with the EMC regulations which is now required for all electronic equipment emitting radiated power. Their use for tracking fish in the UK is therefore restricted until the appropriate licences have been obtained.

2.4 Ancillary radio equipment

2.4.1 Receiving aerials

The design and construction of the receiving aerial is critical to the overall performance of a tracking study. A poorly designed or off-frequency aerial can significantly counteract the effectiveness of the other components (e.g. transmitters or radio receivers) of the system.

There are five basic types of receiving aerial used in wildlife tracking studies. These are the "Yagi", the "H-aerial", dipole, whip and loop. The choice of the receiving aerial and its characteristics will depend very much upon the type of study to be undertaken and the proposed method of use (e.g. hand-held receiver, vehicle or aeroplane mount, passive scanning, etc.) Important characteristics of aerials are the range (a function of the gain measured in dBm), operating frequency and its directionality.

Yagi aerials have high gain and excellent mechanical and electrical properties. Addition of elements can increase the effectiveness of a Yagi aerial in terms of gain and pattern but will make the overall aerial larger. H-aerials are lighter and more compact is design. Loop aerials are suitable where increased directionality or smaller size is required; these aerials are often used in conjunction with aircraft. Dipoles are omni-directional and are easy to mount in a variety of ways (e.g. on vehicles or boats, or for use with fixed stations).

The majority of the commercial manufacturers of radio tracking equipment produce custom built receiving aerials for a wide range of conditions. The type of receiving aerial will therefore depend upon the choice of the other components of the tracking system such as the tags and the receiver.

3. ACOUSTIC TELEMETRY

3.1 Introduction

Sound propagates particularly well through open water and acoustic tracking techniques are often applied to free ranging aquatic animals. Radio signals from tags are rapidly attenuated through sea water and will not normally penetrate more than a few meters of fresh water. Acoustic tags are thus normally used for tracking studies in the marine environment and are often used in fresh water, particularly in deep still waters such as lakes. These tags can be located more precisely than radio tags making them more suitable for high resolution tracking. However, acoustic signals suffer severe attenuation in shallow or fast-flowing water, aquatic vegetation or turbid conditions, where acoustic noise, entrained air bubbles and suspended solids can drastically reduce range.

Acoustic signals are usually generated by driving an annular ceramic transducer at its resonant frequency. Since frequency is proportional to transducer diameter, this is an important factor in determining tag size. The higher the frequency, the smaller the transducer ring. This allows the tag to be smaller but there will also be a significant decrease in the range of detection. The lowest practical frequency is about 30 kHz, which is primarily used for large fish, due to the large size of the tag, in open sea studies where maximum range is required. A frequency around 76 kHz is generally used for coastal and freshwater studies, and the higher frequencies 160 - 300 kHz are used for freshwater and studies where a small tag is required. The range of the small high frequency tags is, however, short (often less than 150 metres).

It is also possible to drive a transducer at a harmonic frequency. This may allow a high frequency (small) transducer to produce a lower frequency signal. The reduced efficiency of the tag may be balanced by the increased propagation and range at the lower frequency.

Simple receiving systems comprise a hand-held directional hydrophone, portable receiver and headphones. More complicated and advanced systems may use fixed arrays of hydrophones or acoustic buoys to detect and analyse the signal. Transponding systems allow the range to the transmitter to be calculated, and the more sophisticated systems, such as the MAFF Sector Scanner, display the tag signal on a sonar screen superimposed on the acoustic image of the sea floor.

3.2 Acoustic transmitters

There are two types of acoustic tags used in tracking studies and these are referred to as "pingers" and "transponder" tags. As with radio tags, the effects of the acoustic tag (size and attachment) on the behaviour and survival of the fish should be assessed before they are used in a research programme. Acoustic tags can generally be attached internally or externally because there is no external antenna as there is in some radio tags..

Acoustic pinger transmitters

The majority of studies on the movements of free ranging animals have used pinger tags which emit acoustic signals at predetermined frequencies and rates. The signals are detected by a directional hydrophone operating on the appropriate frequency. Directional hydrophones, which have a relatively narrow field of detection, will indicate the approximate bearing of the fish from a tracking platform, but with a single hydrophone, the distance can only be estimated from the strength of the received signal, or by taking several bearings on the signal.

These tags are suitable for Agency tracking studies where fish are followed actively in estuaries and coastal waters. They may also be used in conjunction with automated tracking systems employing acoustic sonar buoys (see section 3.3.2). However, the number of tags that can be used simultaneously is quite limited and there is a greater need for coding than there is for radio tags.

Acoustic transponding transmitters

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

A transponding tag tracking system that could be used on a small vessel, possibly with a conventional sonar system, could greatly simplify tracking in coastal waters where fish may move close to the shore.

Two transponding systems are known which are specifically designed to study fish behaviour. These are the Aberdeen University Deep Sea Code Activated Transponder and the MAFF Sector Scanning and Transponder Tags. However, neither are commercially available at present.

Coded acoustic tags

The number of acoustic transmitters that can be distinguished is generally smaller than for radio transmitters because most systems use a single or small number (5-8) of frequencies. Thus there is a need to develop coding systems that will permit larger numbers of fish to be tracked simultaneously and to simplify the interpretation of tag signals. Unfortunately it is more difficult to transmit codes acoustically than by radio due to various sources of interference. These tags are suitable for Agency tracking studies where a large number of fish are required to be followed actively in estuaries and coastal waters. They may also be used in conjunction with automated tracking systems employing acoustic sonar buoys.

3.2.1 Evaluation of acoustic transmitters

The acoustic tags evaluated during the study were:

Sonotronics (USA) Pinger and Coded Tags	Model MT91-1
	Model CT82-1
	Model CT82-3
	Model DT-88
	Model CHP87-S
	Model PRG-94HP

MAFF (UK) Pinger and combined radio tags	Model PT2J Combined Acoustic and radio Tag (CART) Model AP300-18 (Smolt)
Vemco (Canada) Pinger tags	Model V8-1L Model V16-1L Model V22-5XS Model V16TP-1L
•Lotek (Canada) Coded tag	Model Coded

The performance of the acoustic tags was evaluated during both laboratory and field trials. Laboratory evaluations included the measurement of the polar output plots of each tag, their frequency and pulse rate stabilities under a range of environmental temperatures and pressures (depth) and the resolution of the telemetry tags sensors. The field trials compared the signal range of the tags in an estuary, freshwater reservoir and the open sea. The tags were also considered from a biological viewpoint in terms of the size of fish to which they may be attached and the most appropriate method of attachment.

3.2.2 Laboratory tests

Polar output plots

As with the radio tags the ideal acoustic tag would produce an omnidirectional signal of equal strength in all planes. However, in most tags the circuitry and transducer is such that there are blind spots or nulls in the radiation pattern transmitting from the tag. The polar plots indicate where these blind spots occur and the relative loss of signal strength.

A typical polar output plot of an individual acoustic tags is similar to that of a radio tag as shown in Figure 1.

Stability of frequency and pulse rate with pressure and temperature

Typical results of the evaluations of the stability of the frequency and pulse rate of a single acoustic tag with pressure and temperature are similar to those shown in Figure 2. Tags were evaluated up to pressures which equated to approximetely 125 m depth, and at temperatures between the range 2-30°C.

3.2.3 Field tests

The field tests were carried out in three different aquatic environments representing the conditions under which the Agency is likely to use acoustic tags. These were a reservoir, an estuary during all states of the tide, and the open sea.

The results of the range tests are shown in Table 4 (lake and open sea), and Table 5 (estuary during high, ebbing and low tides). The Lotek coded tags had not been delivered prior to the lake and estuary evaluations, and are therefore not included. In addition, during the lake and estuary evaluations a Vemco V16 tag was not operating, and during the lake evaluation a Sonotronics

MT-91-1 was also not operating. However, both tags were serviced and the faults corrected at the Lowestoft laboratory prior to the open sea evaluations. The MAFF AP300-18 smolt tags were not available for the lake or estuary evaluations, but ranges based on previous studies under similar conditions in the Avon estuary have been included.

Table 4. Measured ranges of the acoustic transmitters in Rutland Water (lake) and the North Sea (open sea).

Manufacturer	Model	id.	Lake: Conductivity 645mS, Temperature 12.6° C — Range (m)	Open sea: Salinity 33 psu, Temperature 3.5° C — Range (m)
VEMCO	V8-1L	1432	269	580
	V8-1L	1433	***	***
	V16-1L	1434	***	679
	V16-1L	1435	>1600	680
	V22-5XS	1436	>1600	>1060
	V22-5XS	1437	>1600	>1060
	V16TP-1L	1564	>1600	517
SONOTRONICS	MT-91-1(mini)	1058	***	266
	MT-91-1(mini)	1063	315	306
	CT-82-1	249	282	256
	CT-82-1	258	290	260
	CT-82-3	267	351	508
	CT-82-3	339	360	218
	DT-88	73	>1600	650
	CHP-87-S	348	481	597
	CHP-87-S	357	460	635
	PRG-94HP	984	1200	750
	PRG-94HP	1024	1180	770
MAFF	AP 300-18	red	250*	235
	CART	black	>1600	549
	PT2J	25	>1600	540
LOTEK	Coded	122	****	233 and 187**
	Coded	140	****	805 and 551**

* data from previous study
** measured with Lotek SRX400 receiver and acoustic upconverter
*** faulty
**** not delivered at time of evalaution

As expected, the ranges of all tags in the estuarine environment were significantly less than those measured in either the lake or the open sea (Table 5). The range of acoustic tags is very dependent upon the acoustic properties of the water which can vary considerably in estuarine environments due to such factors as turbidity, current speed, suspended solids, salinity and air entrainment. In general the ranges of all the tags were lowest during the middle of the ebb flow (Table 5) when an increase in suspended solids reduced signal propagation.

Table 5. Measured ranges of the acoustic transmitters in the River Avon estuary, Christchurch

Manufacturer	Model	id.	High Tide			Middle Ebb			Low Tide		
			Salinity psu	Time	Range (m)	Salinity psu	Time	Range (m)	Salinity psu	Time	Range (m)
VEMCO	V8-1L	1432	31.50	09 15	141	19.80	14 00	163	8.90	14 05	126
	V8-1L	1433	**	**	**	**	**	**	**	**	**
	V16-1L	1434	**	**	**	**	**	**	**	**	**
	V16-1L	1435	31.50	09 20	214	19.80	14 10	193	8.90	16 05	191
	V22-5XS	1436	31.00	09 35	636	19.60	14 15	437	8.90	16 15	421
	V22-5XS	1437	31.50	09 35	636	19.60	14 15	444	8.80	16 15	426
	V16TP-1L	1564	31.60	09 45	174	19.40	14 25	179	8.80	16 20	161
SONOTRONICS	MT-91-1(mini)	1058	32.00	09 55	83	19.60	14 30	67	8.80	16 25	116
	MT-91-1(mini)	1063	32.00	09 55	263	19.50	14 35	63	8.80	16 25	114
	CT-82-1	249	32.00	10 10	189	19.50	14 40	152	8.70	16 30	147
	CT-82-1	258	32.00	10 20	214	19.70	14 40	165	7.60	16 30	153
	CT-82-3	267	32.00	10 25	137	19.75	14 40	82	7.60	16 35	102
	CT-82-3	339	32.00	10 25	140	19.80	14 40	95	7.60	16 35	114
	DT-88	73	32.00	10 30	345	19.80	14 55	184	7.55	16 40	236
	CHP-87-S	348	32.20	10 40	209	19.80	14 55	65	6.70	16 40	154
	CHP-87-S	357	31.00	10 40	210	19.80	14 55	76	6.70	16 45	160
	PRG-94HP	984	31.00	10 45	255	19.80	15 00	126	6.10	16 50	186
	PRG-94HP	1024	31.00	10 45	260	19.80	15 00	130	6.10	16 50	191
MAFF	AP 300-18				121*			92*			113*
	CART		31.00	10 25	295	19.60	14 20	148	8.80	16 25	175
	PT2J	25	31.00	10 05	310	19.80	15 10	157	6.00	16 55	158

blank entries indicate that no information was available

* data from previous study

** faulty

The ranges at which all Vemco tags were detected in the open sea exceeded 500 metres. The ranges of the Sonotronics were also good under these conditions, and individual tags were detected at distances between 218 and 770 m. The range of the MAFF PT2J pinger tag also exceeded 500 m, whilst the AP 300-18 smolt tags were detected at ranges in excess of 230 m. One Lotek coded tag (code 122) was only detected at a range of 187 m, whilst the other (code 140) which had a source level close to the manufacturers specification, was detected at a range of 805 m.

3.2.4 Biological considerations

When considering whether a particular acoustic tag is suitable for use on a fish, similar considerations outlined for radio tags in section 2.4 should be taken into account.

The following biological evaluation of the selected acoustic tags is again based upon a literature review, the physical characteristics of the tags, their suitability for attachment to a range of sizes of salmonids and the practical experience of the authors. However, there is no substitute for fulllaboratory and field-based studies on the effects and efficacies of tag attachments to the study animal. Such detailed studies were beyond the remit of this study.

Physical characteristics

All the tags were cylindrical in shape which would be appropriate for insertion into the stomach or the body cavity of a fish. However, the Vemco V16, V16PT and V22 have been designed to be attached externally to fish from a securing loop. In addition, these tags have flattened ends which together with the loop may cause damage to the fish if inserted onto the stomach or body cavity. The Sonotronics tags were designed to be inserted into the body cavity of fish and have been machine finished to produce smooth edges to prevent damage to the fish. The MAFF and Lotek tags were also smoothed and rounded which would prevent damage when attached internally to a fish.

Except for the Lotek coded, Sonotronics DT-88 depth and Vemco V22 pinger tags, the sizes ranged from 16 - 71 mm in length, and 1.5-25.5g in weight, which depending upon the tag used, would permit a range of fish to be studied from Atlantic salmon smolts through to large freshwater and marine species.

Fish size and species

An assessment of the suitability of each of the tags for stomach and surgical attachment to a range of sizes of salmonids was carried out as detailed above in section 2.6.2. Again the suitability of the tags for external attachment was not considered because this methods is reported to have adverse effects on fish (see section 2.6).

The assessment was again based upon the ease with which tags could be inserted into the stomach (length and width) and the body cavity of salmonids (see section 2.2.5). The results of the assessment are shown in Table 6.

The telemetry tags would need to be attached externally to fish if accurate measurements of depth and environmental temperature are required. Further more extensive studies are needed to ascertain the suitability of the Vemco V16PT and Sonotronics DT-88 telemetry tags for use on a range of sizes of free swimming fish. However, these types of study were outside the scope of the present study.

Table 6. Attachment of acoustic transmitters in relation to fish length

Body cavity		Fish length (cm)								
		15.0	24.6	27.5	37.5	42.7	46.1	52.7	56.1	69.1
VEMCO	V8	No	Marginal	Marginal	Yes	Yes	Yes	Yes	Yes	Yes
	V16	No	No	No	No	Yes	Yes	Yes	Yes	Yes
	V22	No	No	No	No	No	No	No	No	Marginal
	V16PT	No	No	No	No	No	Marginal	Yes	Yes	Yes
SONOTRONICS	MT-91-1(mini)	No	Marginal	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	CT-82-1	No	No	No	No	Yes	Yes	Yes	Yes	Yes
	CT-82-3	No	No	No	No	Yes	Yes	Yes	Yes	Yes
	DT-88	No	No	No	No	No	No	Yes	Yes	Yes
	CHP-87-S	No	No	No	No	Yes	Yes	Yes	Yes	Yes
	PRG-94HP	No	No	No	No	Yes	Yes	Yes	Yes	Yes
MAFF	Pinger PT2J	No	No	No	No	Yes	Yes	Yes	Yes	Yes
	CART	No	No	No	No	Yes	Yes	Yes	Yes	Yes
	AP300-18	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
LOTEK	Coded	No	No	No	No	Yes	Yes	Yes	Yes	Yes

Stomach length		Fish length (cm)								
		15.0	24.6	27.5	37.5	42.7	46.1	52.7	56.1	69.1
VEMCO	V8	No	Marginal	Marginal	Yes	Yes	Yes	Yes	Yes	Yes
	V16	No	No	No	No	No	Marginal	Yes	Yes	Yes
	V22	No	No	No	No	No	No	No	No	Marginal
	V16PT	No	No	No	No	No	No	Yes	Yes	Yes
SONOTRONICS	MT-91-1(mini)	No	Marginal	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	CT-82-1	No	No	No	No	Marginal	Yes	Yes	Yes	Yes
	CT-82-3	No	No	No	No	No	No	Yes	Yes	Yes
	DT-88	No	No	No	No	No	No	Yes	Yes	Yes
	CHP-87-S	No	No	No	No	No	No	Yes	Yes	Yes
	PRG-94HP	No	No	No	No	No	No	Yes	Yes	Yes
MAFF	Pinger PT2J	No	No	No	No	Marginal	Yes	Yes	Yes	Yes
	CART	No	No	No	No	No	No	Yes	Yes	Yes
	AP300-18	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
LOTEK	Coded	No	No	No	No	No	No	Yes	Yes	Yes

Stomach width		Fish length (cm)								
		15.0	24.6	27.5	37.5	42.7	46.1	52.7	56.1	69.1
VEMCO	V8	No	Marginal	Marginal	Yes	Yes	Yes	Yes	Yes	Yes
	V16	No	No	No	No (Ruptured)	No	Marginal	Yes	Yes	Yes
	V22	No	No	No	No	No	No	No	No	Marginal
	V16PT	No	No	No	No	No	No	Yes	Yes	Yes
SONOTRONICS	MT-91-1(mini)	No	Marginal	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	CT-82-1	No	No	No	No	No	Marginal	Yes	Yes	Yes
	CT-82-3	No	No	No	No	No	Marginal	Yes	Yes	Yes
	DT-88	No	No	No	No	No	Marginal (Split at lower limit)	Yes	Yes	Yes
	CHP-87-S	No	No	No	No	No	Marginal	Yes	Yes	Yes
	PRG-94HP	No	No	No	No	No	Marginal	Yes	Yes	Yes
MAFF	Pinger PT2J	No	No	No	No	Yes	Yes	Yes	Yes	Yes
	CART	No	No	No	No	Yes	Yes	Yes	Yes	Yes
	AP300-18	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
LOTEK	Coded	No	No	No	No	Yes	Yes	Yes	Yes	Yes

No | Marginal | Yes

3.2.5 Evaluation with regard to the Agency's requirements

The majority of the Agency's acoustic fish tracking programmes are in relation to the movements of Atlantic salmon, sea trout and coarse fish in rivers, lakes, estuaries and coastal waters in England and Wales. Therefore, the following evaluation of the acoustic tags is based upon their use within these environments and the physical conditions found therein. Emphasis has also been placed upon the use of the tags in conjunction with automatic data loggers.

i. Vemco acoustic pinger transmitters

The Vemco V8, V16, V22 and V16PT tags are all of the same basic construction, with the electronics and battery potted in cylindrically shaped inert waterproof epoxy. A waterproof adhesive label with the Vemco logo and address, together with the serial number of the tag is attached to the outside. The V8 label does not include the Vemco address. Except the V8 tag, all models include a hemispherical plastic loop embedded at one end for securing the tag to the fish. The tags are activated and deactivated by soldering together two wires protruding from the epoxy. The wires are then sealed with additional epoxy. The V8, V16, V22 are all pinger tags, and the V16PT tag is a temperature and pressure telemetry tag.

All models of Vemco tags are crystal controlled and as a result had stable frequency, pulse rate and pulse duration with changes in temperature and pressure. All tags produced good omnidirectional signals in a range of aquatic environments. However, the tags were not considered to be particularly biologically friendly in their present form for insertion into the stomachs or body cavity of fish. The manufacturer however, would be willing to discuss a more appropriate construction if required. If the shape of the tags were modified they would meet the requirements for the tracking of freshwater and marine fish greater than about 25 cm in length in rivers lakes, estuaries and the open sea. The reduced range of the tags in estuaries during ebb tides would need to be taken into account when siting automatic acoustic receiving equipment in more extensive systems.

Each model of tag can be obtained at a range of frequencies and pulse rates. This would permit greater numbers of fish to be identified during a tracking programme than if the tags were operating at different pulse rates on a single frequency. Greater numbers of fish could be released at any one time with a certain amount of confidence in identifying individual fish. However, the use of multiple frequencies increase the chance of fish being missed by automatic acoustic receivers. The tags have been used successfully with the Vemco VR20 automatic pinger receivers and the Vemco Radio Linked Acoustic Positioning System.

ii. Sonotronics acoustic pinger transmitters

All the Sonotronics tags are of the same basic construction, the electronics, batteries and transducers are encapsulated in a white, biologically inert plastic. The models MT91-1 and PRG-94HP are acoustic pinger tags, whilst the models CT82-1, CT82-3 and CHP87-S are coded. Each code is 18 bits in length. For instance, code 267 is transmitted as 2 pulses; rest; six pulses; rest; seven pulses; rest, this is then repeated. The DT-88 is a crystal controlled depth tag.

The operating frequency and pulse code of each tag is written on the outside with waterproof pen. All the tags are machine finished to produce a smooth surface. At the ends of each cylindrical tag 1 mm holes are drilled to allow the attachment of the tags to the fish. The DT-88 includes a pressure transducer at one end for measuring depth. Included with the tag was a calibration table to calculate the depth of the tag from changes in the interval between transmitted pulses. The PRG-94HP CT82-1, CT82-3, DT-88 and CHP87-S tags are activated and deactivated by a magnet-controlled reed switch. The smaller MT91-1 tags are activated and deactivated by soldering together two external wires.

The Sonotronics tags were biologically friendly in construction, relatively stable in terms of frequency, pulse rate and duration with temperature and pressure, and produced omnidirectional signals of good range. The tags would meet the requirements for the tracking of freshwater and marine fish greater than 40 cm in length in rivers lakes, estuaries and the open sea. The reduced range of the tags in estuaries during ebb tides would need to be taken into account when siting automatic acoustic receiving equipment in more extensive systems.

The Sonotronics pinger tags, models MT91-1 and PRG-94HP can be obtained at 17 different frequencies (range 30 -83 kHz) and 35 different pulse rates. This again would permit greater numbers of fish to be identified during a tracking programme than if the tags were operating at different pulse rates on a single frequency. Greater numbers of fish could be released at any one time with a certain amount of confidence in identifying individual fish. However, scanning such a large number of frequencies would take a considerable period and could result in fish being missed by automatic acoustic receivers. The Sonotronics coded tags also permit individual fish to be identified using an 18 bit code. However, this method of coding requires that the tag must be detected for a minimum of 18 seconds to identify the code. This type of tag would only permit a limited number of fish to be tracked at any one time when operated with an automatic acoustic receiving system.

iii. MAFF acoustic pinger transmitters

The MAFF Combined Acoustic and Radio Tag (CART), PT2J pinger tags and AP300-18 smolt tag have been widely used in the UK to study the migratory movements of juvenile and adult Atlantic salmon and sea trout in river estuaries and coastal waters. In addition the AP300-18 smolt tag has been used to study the movements of juvenile bass in the River Medway estuary in southern England.

The CART casing is constructed of clear polycarbonate with a label on the inside providing details of the tags serial number, operating frequency, pulse rate and pulse duration. The tags are activated and deactivated by magnet-controlled reed switches. The electronics, battery and transducer is encapsulated in a cylindrical casing of polycarbonate with rounded ends.

The tags are biologically friendly, with omnidirectional signals and good ranges under most environmental conditions. The pulse rate of the AP300-18 smolt tag is relatively unstable with temperature and the identification of fish based on pulse rate may be difficult if studied in waters with a larger temperature range (>10°C). However, the tags would meet the requirements for the tracking of freshwater and marine fish greater than 12 cm in length in rivers lakes, estuaries and the open sea. The reduced range of the tags in estuaries during ebb tides would need to be taken into account when siting automatic acoustic receiving equipment in more extensive systems.

iv. Lotek acoustic coded transmitter

The Lotek coded tag is cylindrical in shape with one rounded and one flattened end covered in clear plastic. Beneath the clear plastic is printed the name of the tag operator, the frequency and the tag's code. The tags are activated and deactivated by magnet controlled reed switches.

The Lotek tags were biologically friendly in construction, relatively stable in terms of frequency and duration with temperature and pressure, and produced omnidirectional signals of good range. The frequencies of the Lotek coded tags varied significantly with changes in temperature between 2-15 °C, and this would need to be taken into account when using automatic acoustic receivers.

However, the tags would meet the Agency's requirements for the tracking of freshwater and marine fish ranging in size from 42.7 cm and above in rivers lakes, estuaries and the open sea.

3.3 Acoustic receivers and automatic acoustic receiving systems

Although increasing use is being made of semi-automated acoustic tracking systems (e.g. using acoustic buoys and radio receivers), hand-held acoustic receivers are still required for active tracking programmes (e.g. in coastal waters) and for making spot fixes.

3.3.1 Evaluation of Acoustic receivers and automatic acoustic receiving systems

The acoustic receivers and automatic acoustic receiving systems evaluated were:

Sonotronics (USA)	Model USR-5W Receiver Model DR-92 Decoder Model USR-90 Automatic Logging System
Vemco (Canada)	Model VR60 Acoustic Receiver Model VR20 Automatic Monitor
Lotek (Canada)	Model SRC_400 Acoustic Upconverter and SRX_400 Radio Receiver
MAFF (UK)	Acoustic Sonar Buoy

The acoustic hydrophones produced by each manufacturer for tracking studies have generally be designed to be used with their own receivers and tags. The type of hydrophone used will therefore depend upon the choice of the other components of the tracking system.

3.3.2 Laboratory and field tests

The Sonotronics equipment was evaluated during both a visit to the Sonotronics factory in Tuscon, Arizona, and a field trip to the Sea of Cortez, Mexico. Similarly, the Vemco VR60 and VR20 receivers were evaluated during a visit to the factory in Shad Bay, Nova Scotia, Canada. As a result, it was difficult to undertake comparative trials of the receivers and to carry out a number of the laboratory tests due to the lack of suitable facilities. A Lotek ultrasonic receiver was loaned by the company for evaluation. In addition the deployment and operation of the equipment was discussed with the Department of the Marine scientists during a visit to Dublin, Ireland.

i. Sonotronics

Model USR-5W Receiver, DR-92 Decoder

The Model USR-5W is a wide band receiver and operates at frequencies of 30 - 90 kHz. It is generally used for active tracking and for measuring the pulse interval of tags which may identify a particular tag or indicate changes in parameters (e.g. depth or temperature) measured by telemetry tags. The receiver is made of military grade di-cast aluminium with an O-ring seal, and is both robust and splashproof. It is simple to operate and the frequency is displayed in 0.1 kHz steps and the pulse interval in milliseconds.

The DR-92 Decoder is similar in design and shape to the USR-5W and is generally used in conjunction with this receiver. The Decoder is most usually used to decode pressure and temperature data from telemetry transmitters. Depth is displayed in either metres or feet and temperature in ° C, and the options are initially selected via the key pad. All data is transmitted to a small computer for storage by means of the 1200 baud RS-232 link. The data on the computer is displayed as the pulse interval of the tag, and the time and date the tag was detected. The decoder evaluated during this study was linked to a Tandy 102 computer.

The receiver and decoder are simple to use and being manufactured out of military grade di-cast aluminium are rugged and splashproof. When used in conjunction with pressure tags, the depth of the tag is continually displayed in either pulse intervals or whole units of either feet or metres. These data were down-loaded to the computer at 5 seconds intervals. However, the computer software permits the sampling rate to be varied, and data to be collected and down-loaded at intervals between 1 - 120 s.

USR-90 Ultrasonic Receiver (Automatic Logging System).

The USR-90 receiver was designed to operate as a fixed station automatic data logger. The receiver is similar in design and shape to the USR-5W and has an RS 232 port for downloading the data to a PC. The receiver is controlled by an EPROM which can be interchanged to operate over frequency ranges of 65 - 90 kHz (low range) and 30 - 90 kHz (high range).

The receiver is simple to set up and programme, and is both rugged and splashproof. The receiver is able to operate with tags with pulse intervals of between 250 - 2000 ms (15-120 ppm), and is best used in conjunction with crystal controlled tags, although it will work with other types of tags.

The receiver can be operated in scan mode whereby it moves through the frequency range (65-82 kHz) in 1 kHz steps. At each frequency the receiver "listens" for 2 seconds before moving on to the next frequency. When a signal is detected within the 2 seconds, the receiver listens for another second to verify the signal before logging the pulse interval of the tag. The pulse interval and the time and date that the tag is detected, are then down-loaded to the computer. The hydrophone is hardwired to the receiver and so the system is deployed close to the water's edge.

Theoretically, using tags with pulse intervals that are separated by 5 ms, the receiver could be operated with 180 tags on any one of the 18 frequencies. However, the receiver is unable to discriminate between the pulse rates of tags that were detected simultaneously on a single frequency. When two or more tags occur together the receiver did not log their presence. In addition with 18 frequencies being used it would take at least 36 seconds to scan through the channels and this might result in fish being missed.

ii. Vemco

VR60 acoustic receiver

The receiver is simple to programme and rugged. The programming of the receiver is achieved via either a keypad on the front, or a PC terminal. Software had been especially written for the programming of the receiver and for logging the collected data. The software has the same capabilities as the VR20 receiver (see below). The software is menu driven, very user friendly, and can be modified for a particular customer's requirements. The receiver is best operated in conjunction with crystal controlled tags, although it will work with other types of tags. When programming the receiver prior to use, the serial numbers, frequencies (kHz) and pulse intervals (ms) of each of the tags to be used are keyed in. When in scan mode the receiver sequentially moves through each of the programmed frequencies. The receiver "listens" at each frequency for a period of 12 x the maximum interval between programmed tags. For instance if the slowest pulse rate of a programmed tagged is 60 ppm (pulse interval of 1000 ms), then the receiver will listen for 12 seconds before moving onto the next programmed frequency.

The receiver was able to distinguish and log two tags (60 and 180ppm) simultaneously and although not tested, the manufacturers are confident that the receiver will distinguish between up to 8 fish simultaneously on any one frequency. Frequencies available are between 10-100 kHz with a 2 kHz separation between each tag.

VR20 Automatic Acoustic Receiver

The VR20 is most commonly used as a fixed site logger either in estuaries or the immediate coastal waters to monitor the movements of a number of pinger tags. A number of these receivers have been used in the Bay of Fundy, Canada to monitor the movements of emigrating salmon smolts.

The VR20 is controlled and programmed via DOS menu driven software loaded into a PC. The software is very user-friendly and can be modified to fit a customer's requirement. To operate the VR20, it is initially attached to the PC via a serial cable.
The serial number, frequency in kHz, and pulse rate in milliseconds of each pinger tag to be used is then keyed into the memory. Once entered, the pinger set-up information is then loaded into the receiver ready for deployment.

When deployed and in scan mode, the receiver sequentially moves through each of the programmed frequencies listening for the pulse intervals of the pre-programmed tags. As for the VR60, the receiver "listens" at each frequency for a period of 12 x the maximum pulse interval of the programmed tags. If, for instance, 10 tags (maximum pulse interval 1s), each on a different frequency (e.g. 25, 30, 35, 40, 45, 50, 55, 60, 65, 70 kHz) are deployed, then the receiver will take 120 seconds to scan through all frequencies. This is likely to result in some fish not being detected. The manufacturers claim the receiver is able to discriminate up to 5 different pulse rates from tags detected simultaneously. As a result up to 50 different tags could be released at any one time with confidence that they will all be distinguishable. However, it was not possible to test this during the field evaluation. When a tag is detected, the receiver logs the serial number of the tag, together with time and date it is first recorded. The receiver then only recorded the time and date when the tag was last detected. This provided data on the time of arrival and departure of the tag within the detection range of the receiver.

The data from the receiver can be down-loaded directly to the PC or via a cellnet phone link. The stored data can be down-loaded at any time, or the receiver can be programmed to transmit data to the PC every time a tag is detected. During downloading the receiver stops scanning and the data is stored to a directory or file. The software allows data from two or more receivers to be sorted and to provide information on the sequential movement of a single tag between recording sites. Alternatively, the PC software can obtain a status report from the receiver without stopping scanning. This report provides details on the remaining memory and battery life, the gain levels and the serial number of any detected pingers.

The hydrophone could also be programmed to emit an acoustic signal itself after a predetermined period. This would allow the receiver to be detected again should it become lost during a study.

iii. Lotek

SRC_400 Ultrasonic Upconverter and SRX_400 Receiver

The Lotek Ultrasonic receiver comprises the SRX_400 radio receiver (see section 2.3.2) and the plug in SRC_400 acoustic upconverter which converts the 76 kHz acoustic signals from the tags to 173 MHz for logging in the radio receiver.

In laboratory trials, the Lotek SRX_400, SRC_400 upconverter and hydrophone did not successfully decode two coded tags transmitting simultaneously on the same frequency. However, a single tag was successfully decoded for a limited period.

iv. MAFF

Acoustic sonar buoy

The MAFF sonar buoy has been used extensively in the UK to study the migratory behaviour of salmonids in river estuaries. The buoy operates at either 300 kHz or 76 kHz frequencies. Operating at 300 kHz the buoys have been used to track salmonid smolts, and operating at 76 kHz adult salmonids. The sonar buoy produce a radio transmission in the 173.7 - 174.0 MHz range which duplicates the acoustic signal of a tag within its detection range. This radio transmission is usually logged by the MAFF automatic listening station (see section 2.3.2), although it may also be logged by the AST, Televilt and Lotek recievers (see section 2.3.3). The circuitry and battery (12 v) is housed in a waterproof plastic case with an external omni-directional hydrophone and radio aerial mounted on the top. When an acoustic signal was detected the sonar buoy re-transmitted a radio pulse which in turn was detected by a radio receiver or logger. The range that the sonar buoys could detect a tag would depend upon the tags characteristics and power output. The capabilities of the sonar buoy to be used in conjunction with other tags and automatic radio logging systems are described in sections 2.10.

3.3.3 Evaluation with regard to the Agency's requirements

The following evaluation of the suitability of the different acoustic systems for the Agency's requirements is based upon the problems that might be encountered tracking salmonid smolts and adults through a typical river estuary in England and Wales.

i. Sonotronics - USR-90 ultrasonic receiver automatic logging system.

The hydrophones have to be hard-wired to the USR-90 receivers, and so the receivers must be placed close to the water. If placed on the river bank then the hydrophones may need to extend 30 metres or more into the water to the centre of the river channel to record fish movements. Alternatively, the receivers could be placed on floating platforms in the middle of the estuary, but they would need to be accessed to download the data. The receivers are linked to a small PC for data logging and storage, and would require that the PC is protected from the elements.

It would not be possible to track wild smolts of less than about 180 mm in length using the Sonotronics MT-91 mini-tags (see section 3.2.4). The only available tag that is of suitable size for smaller smolts is the MAFF AP300-18 tag. However, because this tag is not crystal controlled, and the pulse interval can vary with temperature, it could not be used with any confidence with the USR-90 ultrasonic receiver automatic logging system. Until the development of a miniature crystal controlled smolt tag, it is unlikely that the USR-90 ultrasonic receiver would meet the Agency's requirements for estuarine smolt tracking programmes.

Adult salmon above 40 cm in length could be satisfactorily tagged using the Sonotronics MT-91 minitags and the CT-82-1 coded tags (see section 13). The range of these tags would be sufficient to allow the receivers to be located on the river bank with the hydrophones extending into the centre of the channel. The receivers could be used to detect the movements of single fish and log the event. The scan time is sufficient to log the movements of 10 fish even if they were moving rapidly through an estuary. However, if two or more fish were located together, then the receiver would not be able to discriminate the pulse intervals and would not log the presence of the fish.

The main disadvantages of the receiver is that the hydrophones are hardwired to the receiver which requires that they are located close to the site of use. In addition the USR-90 automatic logging system is unable to discriminate between the pulse rates of tags that are detected at the same time. For example, the system would not be able to log the presence of two or more salmon either residing together beneath an obstruction or migrating through an estuary at the same time. Therefore, the system may only be operated with any confidence in situations where the tags are significantly separated in time and space. It is unlikely that under the conditions outlined above the Sonotronics USR-90 ultrasonic receiver automatic logging system would meet the Agency's requirements.

The USR-5W receiver and DR-92 decoder would meet the Agency's requirements for a manual acoustic tracking receiver to monitor the positions and movements of single fish within an estuary or coastal waters. In addition, the system could be used to monitor the vertical movements of large salmon (>40 cm), using stomach mounted Sonotronics DT-88 depth tags.

The Sonotronics acoustic receivers and automatic receiving systems were simple to operate, rugged and splashproof. The equipment is widely used in North America mainly by University and Federal Government Departments, and by all the major marine laboratories (e.g. Scripps and Woods Hole). The receivers are used to study a wide range of fish species including shad, trout, pike, salmon, bass and walleye. The equipment is relatively inexpensive compared to other manufacturers, and Sonotronics has a good reputation for reliability and quality.

ii. Vemco - VR20 Monitor

The VR20 receivers are submersible and could be moored within an estuary or in coastal waters. Communication with the receiver by cellular phone would allow stored data to be down-loaded remotely without having to access the receiver. A single PC could be used to log automatically fish movements recorded by any monitors within range of the cellular phone. Recent studies have indicated that the VR20 receivers and V8 miniature acoustic tags have been successfully used to study the movements of emigrating hatchery smolts in the Bay of Fundy, Canada. However, it is considered that without further extensive biological studies, these tags are not of a suitable size to be attached to fish the size of the wild smolts normally encountered in UK river systems. The only available tag that is of suitable size is the MAFF AP300-18 tag. However, because this tag is not crystal controlled, and the pulse interval can vary with temperature, it could not be used with any confidence with the VR20 receivers. Until the development of a suitable miniature crystal controlled smolt tag, it is unlikely that the VR20 receivers would meet the Agency's requirements for estuarine smolt tracking programmes.

Adult salmonids above 30 cm in length could be satisfactorily tagged using the Vemco V8 tags, and salmonids above 40 cm in length could be satisfactorily tagged using the Vemco V16 tags. If for example, 50 tags (5 different pulse intervals [max. 2 s] on each of 10 different frequencies e.g. 25, 30, 35, 40, 45, 50, 55, 60, 65, 70 kHz), were deployed simultaneously, then the receiver would take 240 seconds to scan through all frequencies, would probably be able to discriminate all the tags within this time period. However, where fish may move past a particular receiver in less than 240 seconds, it is possible they could move through the detection range of the receiver without being logged.

The Vemco VR20/Cell automated receiver and V16 tags would fully meet the requirements of the Agency's field based estuarine and coastal tracking programmes. The crystal controlled tags operating at a range of frequencies would permit larger numbers of fish (>50) to be released at any one time than with existing systems. The VR20 pinger identification algorithm is also able to distinguish multiple tags with different pulse rates on the same frequency. The automatic data collection and cell phone transmission of the data to a shore based PC would negate the requirement of manpower to service the receivers in the field and manually collect the stored information.

The VR60 acoustic receiver would also meet the Agency's requirements for a versatile manual acoustic tracking receiver to monitor the positions and movements of single fish within an estuary or coastal waters. In addition, the system could be used to log the movements of fish at a fixed site, and also monitor the vertical movements of large salmon (>40 cm) around a barrage, using stomach mounted V16-PT depth and temperature tags.

iii. Lotek - coded SRC_400 acoustic upconverter and SRX_400 receiver

The hydrophones have to be hard-wired to the SRC_400 upconverter, and so the receivers must be placed close to the water. If placed on the river bank then the hydrophones may need to extend 30 metres or more plus into the water to the centre of the river channel to record fish movement. Alternatively, the receivers could be placed on floating platforms in the middle of the estuary, but they would need to be accessed to download the data.

It would not be possible to track wild smolts using the Lotek system as a suitable coded tag is not available. Until the development of such a coded smolt tag, it is unlikeky that the Lotek system would meet the Agency's requirements for estuarine smolt tracking programmes.

Adult salmon greater than 46 cm in length could be satisfactorily tagged using the Lotek coded tag (see section 13). The range of these tags would be sufficient to allow the receivers to be located on the river bank with the hydrophones a distance of 30 metres. The receivers could be used to detect the movements of single fish and log the event. The scan time is sufficient to log the movements of 10 fish even if they were moving rapidly through the estuary. However, if two or more fish were located together, then the receiver would not be able to discriminate the pulse intervals and would not log the presence of the fish.

The main disadvantages of the receiver is that the hydrophones are hardwired to the receiver which requires that they are located close to the site of use. In addition the Lotek system is unable to discriminate between the codes of tags that are detected at the same time. Therefore, the system may only be operated with any confidence in situations where the tags are significantly separated in time and space. It is unlikely that under the conditions outlined above the Lotek coded system would meet the Agency's requirements.

iv. MAFF acoustic sonar buoy

Operating at 76 and 300 kHz they have been widely used by MAFF, the Agency and the Scottish Office to study the migratory behaviour of juvenile and adult salmonids in river estuaries. They have also been used to study the movements of salmonid smolts and adults in relation to the Tawe Barrage, south Wales (Moore *et al.* 1996; Mee *et al.* 1996). The acoustic sonar buoys are known to meet the Agency's requirements for fish tracking studies.

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4. HIGH RESOLUTION POSITION FIXING

4.1 Introduction

There is an increasing need to describe the movement and position of fish within a defined area with greater precision. The Agency have given an outline specification for such a system which requires an accuracy of 1 m or less for both horizontal and vertical movements. A number of position fixing systems have been developed to study the behaviour of fish in a variety of conditions and environments.

Most of the position fixing systems have been designed to utilise acoustic signals. There have been two principal reasons for this. Firstly, most systems fix the position of the tags by measuring the differential time delay in arrival of a signal at a fixed array of receivers. Acoustic signals have been used because the velocity of sound waves in water (1500 ms^{-1}) produces a measurable time interval. The velocity of radio waves (speed of light) precludes the use of radio telemetry to calculate position precisely because the time intervals would be extremely short and difficult to measure. Secondly, acoustic designs can be deployed in saline as well as freshwater conditions.

Lotek Engineering Inc. produce a system of fixed site radio receivers and aerials which can be used to automatically locate the position of tags. However, the accuracy of this system is poor in comparison to acoustic positioning systems; positions can be fixed with an accuracy of ±100 metres. An alternative approach possible with the Lotek receivers is to use underwater aerials tuned to detect transmitters only within a limited areas (e.g. $1m^2$). However, this would not allow precise position fixing over a wide area and it has therefore not been included in this section.

Each of the acoustic systems operates on essentially the same principle. The position of the tag (fish), is fixed using a minimum of 3 hydrophones positioned at known co-ordinates. The tag position is determined by measuring the differential time intervals between signal detection by each of the receivers. A system using 3 hydrophones positioned in the same plane will determine the movements of the tag in 2 dimensions. Additional hydrophones positioned in a different plane to the others will allow the position of the tag to be fixed in 3 dimensions. Alternatively, vertical movements may be measured by using a pressure tag in conjunction with surface buoys.

Most systems use acoustic tags which continuously emit acoustic signals at predetermined pulse rates (e.g. 60 ppm). Where pressure tags are used to give depth information, this will be telemetered by varying the pulse rate. The maximum time that a system may be used to continuously monitor the position of a fish will therefore be limited by the life of an individual tag. Most acoustic tags have a maximum life measured in weeks rather than months. Long term studies (e.g. 6 months) using position fixing would require that the pulse rate of the tags is significantly reduced to maximise battery life (e.g. < 5 ppm). Under these circumstances there will be a corresponding increase in the interval at which the position of the fish may be fixed.

Propagation of acoustic signals can be significantly affected by environmental conditions. The range of the tags may be significantly reduced by turbulence, air entrainment and suspended solids in the water. In addition, in certain environments (rocky substrates, underwater cliffs, etc.), the acoustic signals may be reflected or distorted which will effect the accuracy of the position fixing.

The total area that may be studied by any system is related to the minimum range over which the fixed hydrophones can detect the tags. The accuracy of position fixing in general will be greater when the tag is inside the area defined by the hydrophone array. As soon as the tag moves outside this area the margin of error increases.

Under certain circumstances the total area that may be studied may change with time and be affected by environmental conditions; for example, in an estuarine environment where there is an effect on tag range due to changes in the levels of suspended solids or salinity at different states of the tide.

The size and species of fish that may be studied using a positioning system will depend upon the size, weight and method of attachment of the tag to the fish. It is advisable that appropriate studies on the effects of the tags on behaviour and survival of each species be carried out prior to each study.

However, there is only one system that is commercially available and that is manufactured by Vemco (Canada)

4.1.1 Evaluation of High Resoultion Positioning Fixing Systems

The equipment considered for evaluation was:

Vemco (Canada) Radio Linked Acoustic Positioning System

The manufacturer, Vemco, was not willing to loan or hire this equipment for evaluation in the UK and it was not considered cost-effective to purchase it. The equipment was therefore evaluated during a visit (11-14 September, 1995) to the factory in Shad Bay, Nova Scotia, Canada and a visit (16-18 August, 1995) to a field site near Tromso, Norway where scientists from the Institute Marine Research, Bergen were using the equipment to track cod.

As a result, it was difficult to undertake detailed trials of the equipment and it was not possible to conduct laboratory tests due to the lack of suitable facilities.

The Vemco Radio Linked Acoustic Positioning System operates with the standard Vemco V8, V16 and V22 pinger tags, and operates on frequencies between 10 and 80 kHz. The system uses three acoustic buoys, which each contain a hydrophone, frequency synthesised acoustic receiver, two-way radio link and a microprocessor controller. The receiver is a modified version of the model found in the VR20 automatic receiver (see section 14). The buoys evaluated measured approximately 90 cm high (excluding aerial) by 60 cm in diameter (float collar), however the size of the buoys can be modified for a particular customer's requirements. The system is operated from the base station by a windowed program running in DOS on a lap-top PC; this communicates with the buoys by two-way radio via an interface box and calculates the position of the tags from the information sent back.

The three buoys should each be placed at the same depth below the surface and at around the mean depth at which the fish are likely to swim. Prior to operation the serial number of each buoy is entered into the PC. At the beginning of a study and periodically during it, the system instructs the buoys to transmit and receive acoustic signals from each other in order to calculate their relative positions; these are then stored by the base station.

As tagged fish are released the serial number, frequency in kHz, and pulse rate in milliseconds of each pinger tag is also entered into the programme. Each tag must operate on a different frequency, and up to 10 tags can be tracked at the same time. In Canada, the system was tested using one fixed and one towed tag, while in Norway the system was observed tracking free swimming fish.

The system begins by instructing each of the buoys to listen for the tag on the first frequency. Each buoy then listens for a pre-set time (up to 120 s). The base station then interrogates each buoy for signals received and, when a signal has been recorded by all three buoys, it calculates the tag's position. If several tag signals are received by each buoy, the system will calculate the average position of valid fixes (the user can also request that only a certain proportion (e.g. 60%) of valid fixes closest to the mean are used to calculate the average). The system then repeats the process for the remaining tags.

With the system used in Norway, it took about 25 s to obtain a position fix for each fish (with the buoys listening for 15 s). Thus with ten fish released, the position of each fish would be recorded at 250 s intervals. In Canada, the system was set up to provide a fix every 8 s, and so with 10 fish released it could record the position of each fish every 80 s. However, it was suggested that this time could be reduced.

One way to obtain more continuos tracks is to use the Fast Track facility. Instead of averaging the positions recorded during each listening period this plots every successful fix separately. Short sequences of fixes are obtained for each fish, but data can only be obtained on one fish at a time. Thus, if two tags were used together then each recorded track would be:

Tag A ...... 8 secs ...... 8 secs ......

Tag B 8 secs ...... 8 secs ...... 8 secs

The calculated positions of the tags can be presented in real time on the PC during the study and the approximate resolution of the positioning system was around 1 m.

4.1.2 Evaluation with regard to the Agency's requirements

The Vemco Radio Linked Acoustic Positioning System, if used in conjunction with V8 or V16 pinger tags would largely meet the requirements of the Agency's field based estuarine and coastal tracking programmes. The system could be used effectively to monitor the movements of fish both above and below a barrage site, provided there was suitable acoustic propagation within the study area. The system was user-friendly and easy to programme, and once the buoys were deployed status reports on battery life, gain and noise levels could be obtained. Up to ten fish could be tracked at any one time, but at best this would only provide a position fix for each fish every 40 seconds. If fish positions are required at shorter intervals, fewer fish would have to be studied.

The buoys evaluated in this study may have restricted use at some sites due to their physical size. However, smaller versions may be available after consultation with the manufacturer. The system evaluated was only able to fix the position of the tags in 2 dimensions. If the vertical position of the fish is required as well, then depth tags need to be used in conjunction with the system. The software provides a facility for automatically logging the depth indicated by a pressure tag.

However, software is now available to fix the position of a tag in three dimensions if a fourth sonar buoy is positioned at depth. It was not possible to evaluate the capabilities of this new facility.

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5. DATA STORAGE AND ARCHIVAL TAGS

5.1 Introduction

Data storage and archival tags collect and store environmental, physiological and positional data over extended periods for later retrieval and analysis. The Agency have identified a need for such tags particularly in relation to open ocean migrations of Atlantic salmon and coastal movements of sea trout.

The concept of such a miniature fish tag was described over a decade ago, when Northwest Marine Technology (NMT) completed a feasibility design for an archival tag to be used on tuna (Hunter *et al.* 1986). At the same time, a study on the design of a data storage tag to record environmental data was underway at the MAFF Fisheries Laboratory, Lowestoft (Robinson 1985). Both NMT and MAFF have now produced working versions of their tags and other miniature data loggers have also been produced by other manufacturers for use on a range of animals.

All of the available data storage, archival tags and data loggers have sensors to collect and store environmental data such as temperature and depth. In some examples, physiological data such as heart rate and internal temperature may also be monitored and stored. There are, however, only three manufacturers who have produced an archival or data storage tag that will also determine the geographic position of the tag over a given time period. All of these tags utilise an additional light intensity sensor, and the data collected may be used on its own or in conjunction with the depth and temperature data to obtain a geographic position.

Obtaining geographic positions based on light intensity alone can be problematical. Longitude can be determined quite accurately by calculating local noon from the midpoint between dawn and dusk; this may give a resolution of $\pm 1°$ of longitude. Latitude may be determined from the day length calculated as the difference between either dawn and dusk, or sunrise and sunset. However, the potential error in calculating latitude is greater and is dependant upon both the latitude and the season. Additional errors can complicate geographic position of fish when using light intensity. Cloud cover, differences in the opacity of water and the depth at which the fish may swim may all effect the accuracy of position fixing.

Latitude may be determined more accurately in some areas by using the temperature of the water at specific depths once longitude has been calculated. A simulation study of the precision of latitude estimates has been carried out by Smith and Goodman (1986) for the Pacific Ocean. Five degrees of latitude was the minimum precision that could be expected from the model. Taking into account the previous position of the fish and having real-time oceanographic measurements of the surface temperature from satellites and other sources an 2 or 3 fold increase in precision could be expected. Alternative parameters which may be used to estimate position include magnetic dip.

All the archival and data storage tags are fishery dependant because the tag has to be recovered, usually through a commercial or sport fishery, before the stored data can be obtained. Thus the number of tags required for a study will depend in part upon the expected recovery rate.

Sea trout in the sea (ref. Sea Trout R&D Project D01(91)03)

It will be very much more difficult for data storage tags to provide information on the movements of sea trout in the sea than it will be for salmon (Potter and Moore 1993). Salmon undertake extensive migrations and it may be feasible to use the sensors described above to determine a rough geographic track of the fish to within ± 1° of longitude and latitude. The accuracy of this position fixing is unlikely to be precise enough to determine the more localised movements of sea trout (100 -150 km) in coastal and off-shore waters.

Data storage tags that measure temperature could provide information on the movements of sea trout in relation to thermal and other oceanic features. This information used in conjunction with oceanographic measurements of the surface temperature obtained from satellites and other sources might be used to model movements of sea trout in the sea in some areas. However, water temperatures in coastal waters can be very variable and are difficult to obtain from satellites.

An alternative method for logging the position of sea trout in the sea would be a pop-up tag. Such a tag would become detached from the fish after a specified condition was met (e.g. elapsed time, temperature or salinity). It would then float to the surface where it would transmit to a receiving station or the ARGOS satellite system (see section 9). This would provide a single position fix but if sufficient data from a number of fish could be collected over a period of time the general movements of sea trout in coastal waters could be modelled.

5.1.2 Evaluation of archival and data storage tags

The tags and loggers that were evaluated were :-

Northwest Marine Technology, Inc. (USA)	Archival Tag
MAFF	Data Storage Tag Mk 1
Wildlife Computers (USA)	Dive Recorder Mk 5
Vemco (Canada).	Minilog TDR

The Zelcon Technic Pty Ltd (Australia) SBT100 Fish Logger which was considered suitable for evaluation in Phase 1, but a tag could not be obtained from the manufacturer during the period of the study.

5.1.3 Laboratory and field tests

i. Northwest Marine Technology Inc. Archival Tag

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

The archival tag is housed in a 96 mm long x 16 mm diameter stainless steel cylinder. The light sensor and a temperature sensor is housed at the end of a 2 mm diameter flexible wand which extends from one end of the cylinder. The wand was sealed into the steel cylinder by a silicon rubber collar. The length of the wand is optional although its minimum length requirement was 30 mm; the sample tag we received had a wand of 185 mm. Within the main body of the tag were a pressure sensor and second temperature sensor. The tag is interrogated and programmed through two optical fibres that extend within the silicon rubber collar.

ii. Wildlife Computers Dive Recorder Mk 5

The Mk 5 time - depth recorder (TDR) was developed to record temperature, depth and light intensity. The light intensity and temperature data are used in conjunction with a GEOLOCATION analysis software package to calculate the position of the TDR with an accuracy of $\pm$ 60 miles (manufacturer's specification). The TDR has principally been used to study the diving behaviour and migrations of birds and mammals such as seals.

The electronics and batteries of the TDR are enclosed in a 65 x 16 x 37 mm block of epoxy resin. The light sensor and pressure transducer are situated on one face of the block, together with a conductivity sensor and a four pin communications connector. On the opposite face is a window for an LED which indicated whether the TDR was active. Each sensor can be programmed independently to sample at different rates.
The tag also has the option of conditional sampling. For instance, sampling of the depth and water temperature will only occur when the conductivity sensor is activated. Samples will only be recorded when the tag is underwater.

iii. Vemco Minilog TDR

The Vemco Minilog TDR has been developed to record time, depth and temperature.

The Minilog TDR was embodied in a 95 mm long x 21 mm diameter PVC cylinder. At one end were the sensors and at the opposite end was a 6 mm diameter hole to allow attachment to the animal.

The internal mini-processor was developed to record and store temperature and depth readings at intervals from 1 second to 6 hours. These sampling intervals equate to 2.25 hours or 5 years full deployment. The internal Lithium battery is also given a 5 year life span (full deployment) in the specifications, and the unit can be rebatteried. The manufacturers stated that the memory EPROM had a data retention of 20 years. With the sample interval set at 128 seconds the tag will have a sampling life of approximately twelve days.

The Minilog TDR is programmed and down-loaded to an IBM compatible PC/AT (with an RS232C serial port) via a communication interface - the MINILOG PC. The communication link between the TDR and the interface is an infrared LED.

iv. MAFF Data Storage Tag

The MAFF Data Storage Tag (DST) was developed to record temperature and pressure at specified time intervals. The particular model evaluated had been designed for attachment to flat fish, and has been used successfully on plaice in the North sea.

The tag is encapsulated in a 46 mm diameter dome of epoxy resin, 22 mm in height. The pressure sensor is situated at the apex of the dome and the temperature sensor is embedded in the surface. On the ventral surface is a clear epoxy window for communications. Communications are achieved through an infra-red optical link. The tag can be attached to the fish by two lugs on opposite sides of the dome.

The tag is powered by seven internal batteries (5 -11 v) which provides approximately 9 months of logging time. Another battery supplies the power for 5 to 10 years of data retention. The sampling intervals can range from 1 minute to 65 535 minutes. A real time clock is not incorporated into the tag.

The tag is programmed and down-loaded using an IBM compatible PC running MS-DOS or Windows version 3.11 with an RS232 serial port. To establish communications with the tag, a MAFF data storage tag reader had to be purchased. This provides the necessary hardware and power.

The software programme TAGTALK down-loaded the stored data from the tag into a Comma Separated Variable (ASCII) file. The sampling table of protocols can be retrieved from the tag on recovery. Other information such as the start time and date, and deployment details are programmed by the user in the tag. The sampling regime, and calibration formulae for the sensors are particularly important for analysis of the retrieved data. The down loaded data requires to be converted by the user using the calibration formulae for each sensor which is stored by the tag.

Accuracy of position fixing

The Wildlife Computers Mk 5 Dive Recorder and the NMT Archival Tag were the only tags examined which had been designed to calculate geographical position. The Zelcon tag also provides geographic position was was not tested. The accuracy of the position fixing of the two tags was assessed under two different conditions. Firstly, the tags were placed on the roof of the Lowestoft Fisheries Laboratory for 20 days, and secondly the tags were deployed at a depth of 10 m in the North Sea for a period of 6 days. During the study in the North Sea, the Vemco Minilog and MAFF data storage tags were also deployed to evaluate the accuracy of the temperature and depth sensors.

i. Archival tag position estimation - rooftop evaluation

The Wildlife Computers and NMT tags were initialised and placed on the roof of the CEFAS Lowestoft Laboratory North Extension (Latitude N52°27.51'; Longitude E01°44.36' by WGS84 datum) at 1300 h on the 19/12/1995 until 1500 hours on the 08/01/1996.

The Wildlife Computers Mk 5 Dive Recorder estimated position within zones approximately 80 miles (E to W) by 120 miles (N to S). The longitude calculation depended upon the calculated midpoint between dawn and dusk (apparent noon). The latitude calculation effectively depended on day length.

The accuracy of the longitude calculated by the NMT tag was ± 76 miles. The NMT software did not compute an estimate of latitude, but provided the means of doing so by stratified temperature sampling. This data could be used in conjunction with satellite information on surface temperatures to further estimate the latitudes.

ii. Archival tag geographical position, depth and temperature estimations - North Sea

The Wildlife Computers Mk 5 Dive Recorder and NMT Archival Tag, together with the Vemco Minilog and MAFF Data Storage Tag were deployed on a subsurface rig, (depth 10 m), at 1400 hours (latitude 52°00.00'N and longitude 02°20.00'E) on 18/01/96 and retrieved at 0907 hours on the 29/01/96.

Position estimation

The Wildlife Computers tag was unable to estimate its geographical position when deployed at a depth of 10 m in the North Sea. The WCGLLOC plots of light intensity against time indicated a rapid decrease in the recorded light levels at night. The sudden rather than gradual changes in light intensity may not have permitted the GEOLOCATION program to calculate the necessary times of dawn and dusk. In addition, the renowned turbidity of the North sea, especially in the winter months, may also have not provided sufficient light for the sensor.

The daily estimated longitudes provided by the NMT tag were not very accurate (± 235 miles), but the average estimate over 6 days was only 28 miles east of the actual position. This suggests that if smoothing functions could be applied to data obtained by these tags they might provide good tracks of fish.

Depth and temperature estimations

All the tags evaluated provided reasonable estimates of temperature and depth, provided they were calibrated correctly before deployment. The accuracy of the resolution of the sensors was difficult to assess from this experiment, but the measurements of each tag appear to agree within 1.0 m or 0.4 °C. Apart from the MAFF tag these figures fall close to or within the accuracy stated by the manufacturers.

5.1.4 Evaluation with regard to the Agency's requirements

Positional information

The Agency's principal requirement for a tag to store positional data would be in relation to the coastal and oceanic movements of salmon and seatrout (ref. Sea Trout R&D Project D01(91)03). The limited movements of sea trout together with the large errors in position estimation derived from a light sensor data would make this type of tag more appropriate for use on salmon, which undertake more extensive migrations. However, a tag that stored temperature and depth could be used in conjunction with satellitte data on sea surface tempearture to estimate the coastal and oceanic movements of sea trout.

The Wildlife Computers Mk 5 Dive Recorder and NMT Archival Tag both have the facility to actively log positional data for periods up to 6 months for later retrieval after fish capture, which may be in excess of 1 year. In this respect both tags would fully meet the requirements of the Agency. However, in the conditions experienced within the North Sea the light sensor of the Wildlife Computers Mk 5 Dive Recorder was unable to collect sufficient data to calculate geographical position. It is also probable that the light attenuating properties of UK coastal shelf waters would severely limit its use in this environment. Whether, the light sensor would function within the waters of the North east Atlantic Ocean would need to be further evaluated. However, the biological assessments carried out for both radio and acoustic tags in sections 2 and 3 would suggest that the tag would be unsuitable for attachment to even the largest salmon. Therefore, its use on sea trout and salmon would be restricted and the tag would not meet the Agency requirements for the long term position fixing.

In comparison, the NMT tag was able to calculate the longitude of its position under similar conditions. Although the average daily longitudinal position was in the order of ± 235 miles on the same latitude, averaging the position over a number of days provided a calculated position of 28 miles of its actual position. Together with the calculated latitude from day length and sea surface temperature, the position fixing capabilities of the tag could be used for logging the position of a salmon during its feeding and return migration.

Although, the NMT tag could log positional data for later retrieval, the size and weight of the tag may limit its use on certain species of fish. The biological assessments carried out for both radio and acoustic tags in sections2 and 3, would suggest that the tag could only be implanted into the body cavities of fish which are in excess of about 70 cm in length. This would preclude the use of the tag on all except the largest of sea trout. Body cavity implantation of the NMT tag would also require that the stalk containing the sensors extrude through the body wall so that the sensors could adequately collect light, and temperature data. The long term effects of this type of tag attachment on adult salmon is not known, and would need to be further evaluated.

Environmental information

The Agency's principal requirement for a tag to store environmental data would be in relation to the movements and changes in local conditions of both freshwater and marine species. The Wildlife Computers Mk 5 Dive Recorder and NMT Archival Tag both have the facility to actively log environmental data for periods up to 6 months for later retrieval after fish capture, which may be in excess of 1 year. Both the Vemco Minilog and MAFF DST could also log environmental data over a similar period, but not at the same rate as the other two tags. The sampling regime of the Vemco and MAFF tags would need to be reduced to continue to log for 6 months. However, all tags would meet the Agency's requirements for the collection and storage of environmental data at a suitable resolution. The restrictions in use of the Wildlife Computers and NMT tags in terms of biological considerations have been outlined above. The Vemco Minilogger would be unsuitable for use on fish that are less than 70 cm in length. The shape of the MAFF tag was designed specifically for use on flatfish. The domed shape of the tag evaluated would restrict its use on most species of fish. It is not considered an appropriate shape for either attachment within the stomach or body cavity of round fish. In this respect it does not meet the Agency's requirements for a tag for the collection and storage of environmental data. However, a smaller cylindrical version with a light sensor has since been developed which would meet the Agency's requirements.

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6. TELEMETRY AND SENSORS

6.1 Introduction

Local environmental (external) data or physiological (internal) data can be telemetered from sensors attached to an animal by altering the frequency or pulse rate of radio or acoustic tags or by other simple codes. Temperature is relatively easy to monitor since thermistors provide a compact solid-state sensor. For aquatic animals, pressure sensing is used as a means of depth determination. Electrochemical sensing transmitters have been developed for measuring dissolved oxygen and salinity.

Compass sensors have been used with acoustic tags to determine the bearings of migratory fish and light sensors have been used on archival tags to calculate the position of fish in the oceans. Miniature sensors are available that measure pH but these have so far not been built into a usable transmitter.

For telemetry of internal physiological state, heart rate tags have received much attention. The data derived from such tags can be used to give an indication of metabolic rate. Sensors to measure swimming speed, tail beat frequency and feeding activity have also been developed. Other parameters such as internal temperature, blood pressure, activity and inter cranial pressure can also be telemetered but these are generally used in relation to monitoring laboratory animals.

This section covers the potential sensors and telemetry transmitters identified by the Agency as being requirements for future tracking studies.

6.2 Transmitters

6.2.1 External parameters

The sensors considered as being requirements for future tracking studies include temperature, pressure/depth, salinity, oxygen, light, pH, compass bearing and ammonia. Certain sensors such as temperature, pressure/depth, oxygen, light and compass bearing have been incorporated into either radio, acoustic or DSTs, but only temperature and pressure/depth tags are commercially available. Tags containing sensors such as pH and ammonia have not yet been developed.

6.2.2 Internal parameters

The sensors considered as being requirements for future tracking studies include tail-beat frequency, feeding activity, swimming speed, heart rate, muscle activity and opercular rate. Certain sensors such as tail-beat frequency, feeding activity, swimming speed, heart rate, muscle activity have been incorporated into either radio, acoustic or DSTs, but only muscle activity and heart rate tags are commercially available.

6.3 Evaluation of telemetry tags

Only a limited number of telemetry tags are available commercially. These measure temperature, pressure (depth), heart rate and muscle activity. However only the following tags were supplied for evaluation:

- The Sonotronics pressure acoustic tags
- The Vemco temperature and pressure

The tag dimensions and general specifications were similar to equivalent pinger tags, and the resolutions of both the Sonotronics DT-88 pressure sensor and Vemco V16PT temperature and pressure sensors were within 10% of the manufacturers specifications

7. OTHER FISH TRACKING SYSTEMS

7.1 Biosonics (USA)

Biosonics produce the Passive Integrated Transponder (PIT) system. The PIT tag is a passive radio- frequency identification tag designed to work in conjunction with a compatible radio-frequency ID reading system. The transponder consists of an electromagnetic coil and microchip sealed in a glass tube. There are three types of PIT tags ranging in size from 11 mm in length and 2.1 mm in diameter to 28 mm in length and 3.5 mm in diameter. The smallest tag weighs 76 mg. The tags are normally implanted into the fish with a hypodermic injector. When the PIT tag is interrogated by the reader it transmits its code (1 of over 34 billion codes) to the reader which decodes and displays the alpha numeric ID number.

The tags are read with one of two readers. The HS5105 Mini-Reader operates at 125 or 400 kHz has the capability of storing up to 1478 codes at a time which can be down-loaded via an RS232 port to a computer. The HS5600 Handi-Reader is a basic model reader without a memory. After displaying the code for 1 minute the tag ID is erased. The hand-held reader normally has to be within about 10 cm to read the tag code; alternative detectors take the form of tubes (~300 mm diameter) or strips that may be placed on the stream bed.

These tags may have a number of applications in studies of fish behaviour and movements particularly of small fish. They are widely used in North America to study fish movements in the field. It was not considered appropriate to investigate them further in the study, but they should be considered by the Agency as a potential method for fishery investigations. Recently, a system based on PIT tags has been developed to study the movements of juvenile salmonids in Scottish streams (Armstrong *et al.* 1996).

7.2. Satellite tracking

Satellite systems provide a means of tracking animals over large distances. Potentially a large number of identified individuals can be tracked simultaneously without the need for surface craft. The only satellite system currently available for tracking studies is the ARGOS data collection and location system carried on board the National Oceanic and Atmospheric Administration (NOAA) series of polar orbiting satellites (altitude 850 km). The capacity of the ARGOS system is expected to increase with the advent of new satellite models. Commercial, technical and administrative management of the system is provided by CLS/Service Argos in Toulouse who have a regional office in London. Radio transmitters that are used in conjunction with the ARGOS system are know as platform transmitter terminals (PTT).

The systems can generally provide position fixing with a precision of ± 350 m. This may provide an alternative means of tracking salmon and sea trout in coastal waters and open ocean. However, there are potentially two factors limiting the use of satellite systems to track fish.

- The size of the PTT may be prohibitive for use on all but the largest species.
- The tags operate at a frequency of 401.650 MHz in the UHF radio band and there use is severely limited in the marine environment due to the rapid attenuation of radio signals in saltwater.

Priede (University of Aberdeen) has developed a prototype PTT which might be suitable for use on salmon. The basic PTT module weighs 6g and is rectangular in shape with dimensions 55 mm x 17 mm. It has a lithium battery pack 55 mm long x 14.5 cm in diameter and weighs 18 g. The battery gives a life if around 10 days at 400 mW power output. The prototype achieved 11 locations in 16h ; 4 at class 0 (poor quality unknown error), 4 at class 1 (not guaranteed, precision ca. 1 km) and 3 at class 2 (standard quality precision 350 m). The tag is not commercially available.

The PTT still has to be at the surface of the sea for a long enough period to transmit a signal to the satellite system. Priede proposes two possible methods of attachment to overcome this problem. The first is a towed module where the PTT is attached to a float and is towed by the fish as it migrates. This requires that the fish remains close to the surface for long periods. The second is a pop-up version that will become detached from the fish after a predetermined time and transmit data to the satellite from the surface. This will however only give a single position fix for an individual fish.

The advantage of satellite systems is that the tags do not need to be recovered to obtain the data; they are therefore independent of fisheries. The development of PTTs is progressing rapidly in terms of miniaturisation and the inclusion of environmental sensors. A combination of the data storage tag technology together with the pop-up satellite technology would provide a very potent tool for fisheries studies. A tag that collected environmental and positional data over a number of months, then detached from the fish and transmitted all the data back via satellite would be truly fisheries independent. Microwave Telemetry Inc. (USA), Telonics (USA) and Toyocom (Japan) are the principle manufacturers and developers of PTTs for use in wildlife tracking.

8. DEFICIENCIES IN REQUIRED TECHNOLOGY

The Agency has indicated that their principal areas of interest which would benefit from tracking technology are:

- definition of freshwater flows to maintain in-river migration and catchability of migratory salmonids and coarse fish;
- definition of in-river habitat requirements of migratory salmonids and coarse fish;
- description of behaviour patterns during estuarine passage of adult salmonids and smolts;
- marine phase behaviour of smolts and adult salmonids; and
- behaviour of salmonids and coarse fish at barriers and fish passes.

This encompasses a wide range of studies in freshwater, estuarine and marine environments on fish ranging in size from around 10 to 120 cm in length. The information collected in Phase 1 of this study and the evaluation of equipment in Phase 2 has highlighted a number of deficiencies in the available technology with regard to these requirements. These deficiencies are discussed below under the appropriate headings.

8.1 Radio and acoustic transmitters

Rapid advances in electronics in recent years have allowed many developments to be made in radio transmitters, and much of the commercially available equipment already meets the Agency's requirements. While some further developments can be planned, others may depend upon unanticipated developments in certain fields (e.g. battery technology). The main developments required to meet the Agency's immediate requirements are:

Further miniaturisation of tags

It is essential that tags should have minimal effects upon the fish, and one of the best ways of achieving this is to reduce their size. Most manufacturers are therefore continuing to put much of their development effort into reducing the size of their tags. However, one of the largest components in any radio tag is the battery, and so miniaturisation of tags will, in part, be dependent upon developments in this field. In addition, there will always be a trade-off between size, power and operating life of tags, and reducing the size of a tag may also affect the stability of the frequency or pulse rate. Any proposal to reduce the size of a tag must therefore be balanced against the other effects on its operation.

While a reasonable size range of radio transmitters is currently available there is a particular need for small tags suitable for use on fish between about 10 and 25 cm in length. Existing miniature radio tags will be inadequate for some purposes because of their limited power output or because they have trailing aerials.

The currently available Combined Acoustic and Radio Tag (MAFF) is only suitable for use on fish over 45 cm in length; smaller versions are required for use on smaller salmonids, smolts and other fish. It is not thought that such developments would present major problems, although until battery technology is improved the operating life of miniature CARTs would be fairly limited. However, because these tags incorporate both radio and acoustic transmitters, they are always likely to be larger than similar single function tags.

Unique coding of radio tags

Most radio tags currently use a combination of frequency and pulse rate to allow different transmitters to be discriminated. This generally limits the number of tags that can be identified to around 100 and means that tags cannot always be identified quickly. In order to increase the numbers of fish that can be tracked simultaneously, and to simplify the interpretation of tag signals by automated recording equipment, uniquely coded tags are required. Although coded radio tags are currently supplied by Lotek (Section 2.2.1), they do not conform to the Agency's requirements because they have external aerials; versions with internal aerials were not made available by the manufacturers for evaluation in Phase 2 of this study.

Coded radio tags with internal aerials are therefore required. These should permit tracking of the full size range of fish of interest to the Agency and will therefore need to include miniature versions less than 20 mm in length. Certain manufacturers have indicated that such developments are practical.

Environmental sensors

Radio telemetry tags with temperature sensors are available from Lotek, but transmitters with internal aerials could not be obtained for the Phase 2 evaluation on the frequencies used in UK. There are no commercially available radio tags incorporating the others sensors of interest to Agency, namely depth, light, compass bearing, dissolved oxygen, pH, salinity and ammonia. However, potentially suitable sensors have been developed for all these parameters except ammonia, and some have been used on acoustic or archival tags.

The development of radio telemetry tags with many of the environmental sensors required by the Agency is thus practical, but it must be noted that many of the sensors are still quite large, and in the short-term most such telemetry transmitters would be relatively large. It has not been possible to establish whether the development of an ammonia sensor is currently a practical proposition; a more detailed assessment of the technological problems would be required.

Biological sensors

Radio tags with muscle activity sensors are available from Lotek, but tags with internal aerials could not be obtained for the Phase 2 evaluation on the frequencies used in UK. Some of the other sensors of interest to Agency, namely heart rate, tail-beat frequency, opercular activity and feeding activity, have been or are being developed by various groups, but are not commercially available on radio tags. It therefore appears that the development of appropriate telemetry transmitters is practical although it is difficult to predict how small they could be made without a more detailed evaluation of the specific technological problems. It is also likely that such tags will initially only be suitable for use on fairly large fish (>50 cm in length).

Multiple sensors

Most telemetry tags are currently limited to a single sensor because of the constraint on size. Sensors generally take up a significant proportion of the tag volume/weight and the use of telemetry tags with sensors is already limited to larger species or individuals. In principle, putting two or more sensors into a single tag should present no serious problems. The archival tags, for example, generally include multiple sensors (e.g. temp, pressure and light), and the MAFF Data Storage Tag has facility for eight sensors. However, when more than one sensor is used on a telemetry tag, there will be a need to code the different data sources in some way in order to transmit the data to a remote receiver. With two sensors, the information could be transmitted by varying the pulse rate and frequency, but with more sensors an additional form of coding will be required. While this may be possible, it appears that archival tags currently offer the best option for collecting data from a large number of sensors.

Improved encapsulation and attachment

While most manufacturers pay particular attention to the finish of their tags in order to ensure that they are 'biologically friendly', further studies are required to improve encapsulation and attachment methods to ensure that the tags have minimal effects upon the fish. Where external sensors are required, for example, the possibility of the fish towing the tag should be considered. This would require that the best attachment point be found and that the shape of the tag is modified to give stable movement and minimal drag.

8.2 Radio receivers and loggers

The equipment evaluation has listed a number of commercially available radio receivers and loggers. Most of these are broadly compatible with a range of different tags and fulfil most of the Agency's requirements. However the development of more sophisticated tags will require improved receiver systems, and further developments of data loggers are required to reduce the manpower required for tracking programmes.

Discrimination of multiple signals

There remains a problem of distinguishing more than one tag on the same frequency at the same time. This problem may be simplified by the development of coded tags (see above), or of algorithms capable of discriminating a number of overlapping pulsed signals. Where coded tags need to be developed this will, of course, require the parallel development of compatible receivers and loggers.

Loggers for telemetry data

Interpretation of data from telemetry tags can be time consuming and complex. Some data loggers provide for the recording of telemetered data (e.g. depth or temperature) however further developments will be required in parallel with developments on any telemetry tags. Collection of environmental data from other points in the study area could also be simplified if it were logged by the same equipment that was recording the fish movements. This would not only improve the handling of data but could permit intelligent data gathering, such as collecting additional information when fish were recorded to be passing a particular point. These developments are not thought to present any significant practical problems.

8.3 Acoustic transmitters

The requirements for acoustic transmitters and receivers are very similar to those for radio tracking equipment as are the constraints on their design and construction. As a result many of the comments made about radio equipment above apply equally to acoustic equipment.

Further miniaturisation of acoustic tags

As with radio tags there is a desire to reduce the size of acoustic tags, but there is a trade-off between battery size, power output and life. However, acoustic tags are also constrained by the size of the transducer. Acoustic signals travel further at lower frequencies, but the size of the transducer increases as the frequency is reduced. Thus there is another trade-off to be considered. A compromise may be reached by operating small transducers at a harmonic frequency below their resonant frequency, and this needs to be investigated further.

While a satisfactory size range of tags is currently available, there is a particular need to improve the stability of existing miniature tags for use with more advanced data loggers and receivers.

Unique coding of acoustic tags

The number of acoustic transmitters that can be distinguished is generally smaller than for radio transmitters because most systems use a single or small number (10-15) of frequencies. Thus there is an even greater need to develop coding systems that will permit larger numbers of fish to be tracked simultaneously and to simplify the interpretation of tag signals. Unfortunately it is more difficult to transmit codes acoustically than by radio due to various sources of interference.

One coded tag (Lotek) was tested and found to satisfy some of the Agency's requirements. However, work will be required to: improve the stability of coded tags, reduce their size and increase the number of fish that can be discriminated simultaneously.

Environmental sensors

Acoustic tags with temperature and depth sensors were evaluated during this study and found to be suitable for use on large (52 cm) fish. There is a need to reduce the size of these tags and to develop acoustic telemetry transmitters with other sensors of interest to Agency, namely: light, compass bearing, dissolved oxygen, pH, salinity and ammonia. While some suitable sensors have been developed it is likely to be some time before it is practical to build such telemetry tags for use on the smallest fish. Such work should run in parallel with that on radio tags to ensure that there is no duplication of effort on sensor development.

Biological sensors

No acoustic tags with biological sensors could be obtained for evaluation in Phase 2 of this study. There is therefore a need to develop a full range of biological telemetry tags to satisfy Agency's requirements. This work should run in parallel with that on similar radio tags.

Improved encapsulation and attachment

As with the radio tags, further studies are required to improve encapsulation and attachment methods to ensure that the tags have minimal effect upon the fish.

8.4 Acoustic receivers and loggers

There are a number of commercially available acoustic receivers and loggers that are broadly compatible with a range of different tags and fulfil most of the Agency's requirements. However as with the radio tracking equipment, the development of more sophisticated tags will require improved receiver systems, and improved data loggers are required to simplify and reduce the staffing costs of tracking programmes. The principal requirements are essentially the same as those for radio receivers:

- discrimination of multiple signals;
- increase the number of individual fish tracked;
- loggers for telemetry data; and
- receivers to record environmental parameters.

8.5 High resolution tracking systems

Only one high resolution tracking system is currently commercially available (produced by Vemco), although others have been developed by groups in the UK and elsewhere (section 5). The Vemco system would be satisfactory for many studies. However, the position fixing resolution of the system falls short of the Agency's requirement for a resolution of ±1 m radius in three dimensions, particularly towards the edge of the study area. In addition, the time between position fixes will exceed the minimum specification of once per second if the system is programmed to detect more than one fish at a time. It would also be desirable to be able to increase the coverage area of the system by incorporating up to 10 acoustic sonar buoys.

8.6 Archival and data storage tags

The Agency has specified that their target requirement for an archival tag is that it should actively log environmental and positional data for periods up to 6 months for retrieval at least 1 year later. They also require that the tag should be able to log fish position in coastal and offshore waters.

The archival tags currently being developed will generally exceed the first specification, most recording data for at least 1 year and storing it for 2 or more years. However, power constraints clearly create a trade-off between the period over which data are collected, the frequency with which records are taken and the length of time for which data can be stored. As with other equipment, it is understood that several manufacturers are currently developing new models. As these tags are likely to be used in fairly specialised studies, it may be appropriate to relate modifications to specific requirements.

A number of the archival tags that were tested or are being developed also provide geolocation facilities which will give approximate positions in the open ocean. In such areas relatively imprecise fixes may be adequate. However, a significant increase in precision will be required for the tags to be of use in tracking fish in UK coastal waters. This does not appear to be practical at present but it may be possible with the development of new sensors or approaches.

As these tags are designed to operate on the fish for extended periods, there is a particular need for them to be miniaturised in order that they are 'biologically friendly' and can be attached to the fish early in the life cycle (e.g. the smolt stage in salmonids).

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ANNEX 1. A LIST OF MANUFACTURERS, DEVELOPERS AND DESIGNERS OF TRACKING EQUIPMENT REFERRED TO IN THE REPORT

- **Aberdeen University (UK)** design and develop a range of acoustic and radio systems for tracking wildlife.
- **Alec Electronics Co. (Japan)** produce miniature data recorders.
- **Argus Electronics (UK)** produce MAFF radio equipment under licence.
- **AST - Advanced Telemetry Systems (USA)** are a major manufacturer and developer of radio tracking equipment for wildlife.
- **bionics Inc. (USA)** produce the Passive Integrated Transponder (PIT) products.
- **Biotrack Ltd. (UK)** produce a range of radio tags for wildlife.
- **Custom Telemetry & Consulting Inc. (USA)** produce custom built radio and acoustic tracking equipment for wildlife.
- **Holohil Systems Ltd. (Canada)** produce a range of radio tags for wildlife.
- **H.S. Electronics (UK)** produce MAFF radio and acoustic equipment under licence.
- **Lotek Engineering Inc. (Canada)** are a major manufacturer and designer of radio telemetry systems for environmental, industrial and wildlife applications.
- **Mariner Radar (UK)** produce a range of radio tracking equipment for wildlife.
- **Microwave Telemetry Inc. (USA)** produce satellite transmitters for wildlife.
- **Ministry of Agriculture, Fisheries and Food (England)** design and develop a wide range of acoustic and radio systems for tracking fish.
- **Northwest Marine Technology, Inc. (USA)** produce an archival tag for fish.
- **Sirtrack Tracking and Telemetry Systems (New Zealand)** produce a range of radio tracking equipment for wildlife.
- **Smith-Root, Inc. (USA)** produce a range of radio tracking equipment for fish.
- **Sonotronics (USA)** produce a range of acoustic tracking equipment for fish.
- **Televilt AB (Sweden)** produce a range of radio tracking equipment for wildlife.
- **Telonics Inc. (USA)** produce a range of radio tracking equipment for wildlife.
- **Toyocom Communications Equipment (Japan)** produce satellite transmitters for wildlife.
- **Vemco (Canada)** are a major manufacturer and developer of acoustic tracking equipment for wildlife.
- **Wildlife Computers (USA)** produce a range of miniature data loggers for wildlife.
- **Wildlife Materials Inc. (USA)** produce a range of radio tracking equipment for wildlife.

ANNEX 2. MANUFACTURERS OF TRACKING AND TELEMETRY SYSTEMS

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***** denotes commercial manufacturers of tracking equipment who provided details of their products.***