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D J SOLOMON and T J STORETON-WEST

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1 Introduction

Tracking individual fish fitted with a transmitting tag is a most effective technique in the study of migratory behaviour. The biologist is able to follow closely the activity of the unrestrained fish which, it is hoped, is behaving in an entirely natural manner without being aware of the observer. Stasko and Pincock (1977) reviewed the literature on fish tracking between 1956, when the first recorded study commenced, and 1977. They compared acoustic and radio tracking methods and concluded that 'the advantages of radiotelemetry are so compelling that use of ultrasonic (= acoustic) signals is rapidly becoming limited to those applications for which radio signals are unacceptable'. They list the advantages of radio tags in a general context, and Solomon (1982) gives details of specific advantages for the study we are conducting. Briefly, the advantages of radio over acoustic tags are: considerably longer life from a given battery (thus for a given tag size; freedom from interference from broken water and entrained air bubbles; and very much greater range of detection as most of the path of the radio signal between tag and receiver is through air. The major drawback of radio is the effectively total opacity of sea water, or of even slightly brackish water, to radio signals. The system is thus virtually limited to freshwater use for fish tracking.

Several studies tracking adult salmon in estuaries and rivers in North America have been reported (see Stasko and Pincock, 1977; McCleave *et al*., 1978) but ours is the first use of fish radio tracking in the UK of which we are aware. Although equipment developed for use with fish was available in North America we undertook development of our own system for the following reasons:

a. the North American equipment was designed and constructed to work at radio frequencies different from those allocated for such purposes by the Home Office for use in the UK, so the tags and receivers would have required modification and then 'Type Approval' by the Home Office;

b. construction of radio tags for mammals and acoustic tags for fish was already undertaken within this Laboratory (see Section 2);

c. we believed that we could develop a system, tailored exactly to the study we wished to undertake, which would be more effective than any available elsewhere;

d. experience had demonstrated the advantages of being closely involved with the development and construction of such equipment, particularly for speedy and effective dealing with problems and equipment failure and for evolution of the system in response to operational requirements which develop as the equipment is in use.

This report describes the evolution and development of the radio system currently used for tracking adult salmonids in rivers. The emphasis is placed on the system and its operation rather than on technical detail of the components; reference is made throughout to sources of equipment and to details given elsewhere of circuit design and related matters.

The particular study for which the system was developed is an investigation of the influence of modified flow regime, by river regulation, on the movements of migratory salmonids in the River Fowey. In particular, it is hoped that an answer can be found to the long-standing problem of the effectiveness of reservoir releases (artificial freshets) in simulating natural freshets and initiating and sustaining upstream migration of salmon and sea trout. The River Fowey system is small, having a drainage area of less than 200 km^2 and a mean flow of 4.53 m^3s^{-1}. A major river-regulating reservoir is currently being constructed at East Colliford on a tributary, the St Neot River. A smaller regulating reservoir is already in commission. It is envisaged that, in the early years of operation, there will be scope for releases to be made from Colliford for experimental purposes. The river has considerable runs of salmon and sea trout in view of its modest size: reported sport catches in the river in 1981 totalled 297 salmon and 2,493 sea trout.

It is hoped that, in addition to being of importance specifically to the Fowey river system and the operation of its regulation scheme, the results of our study will be of significance for all migratory fish rivers experiencing modified flow regimes for water resource purposes.

2 The starting point

The Electronics Section at the Fisheries Laboratory, Lowestoft already had extensive experience of circuit miniaturisation, batteries and encapsulation techniques for acoustic fish tags when in 1977 it assumed responsibility for development and production of radio tags for use on mammals by other MAFF Research and Development establishments. North American experience indicated the potential for the use of radio transmitters for tracking fish in fresh water. Therefore, some preliminary trials were undertaken which involved housing a suitably laid out modification of the mammal tag circuit in a case of the type used for acoustic fish tags. The aerial was integral, comprising five turns of copper wire on an iron dust core. The case was filled with castor oil, as is standard practice for acoustic tags, to inhibit incursion of water when under pressure. The receiver used was developed jointly by one of us (T J S-W) and J G French of Mariner Radar Ltd., from a previous design by the late G E Ashwell (MAFF Worplesdon Laboratory) and produced and marketed as the 'Mariner M54'. Two receiver aerials were tested, a 4-element Yagi and an H-Adcock, both produced by Mariner Radar Ltd. Details of this early equipment and its development are given by Beach and Storeton-West (1982). The frequency used was 102.3 MHz. Tests of this equipment in January 1978, with tags suspended below tethered floats in a local watercourse, were successful and confirmed that this was a realistic approach to fish tracking.

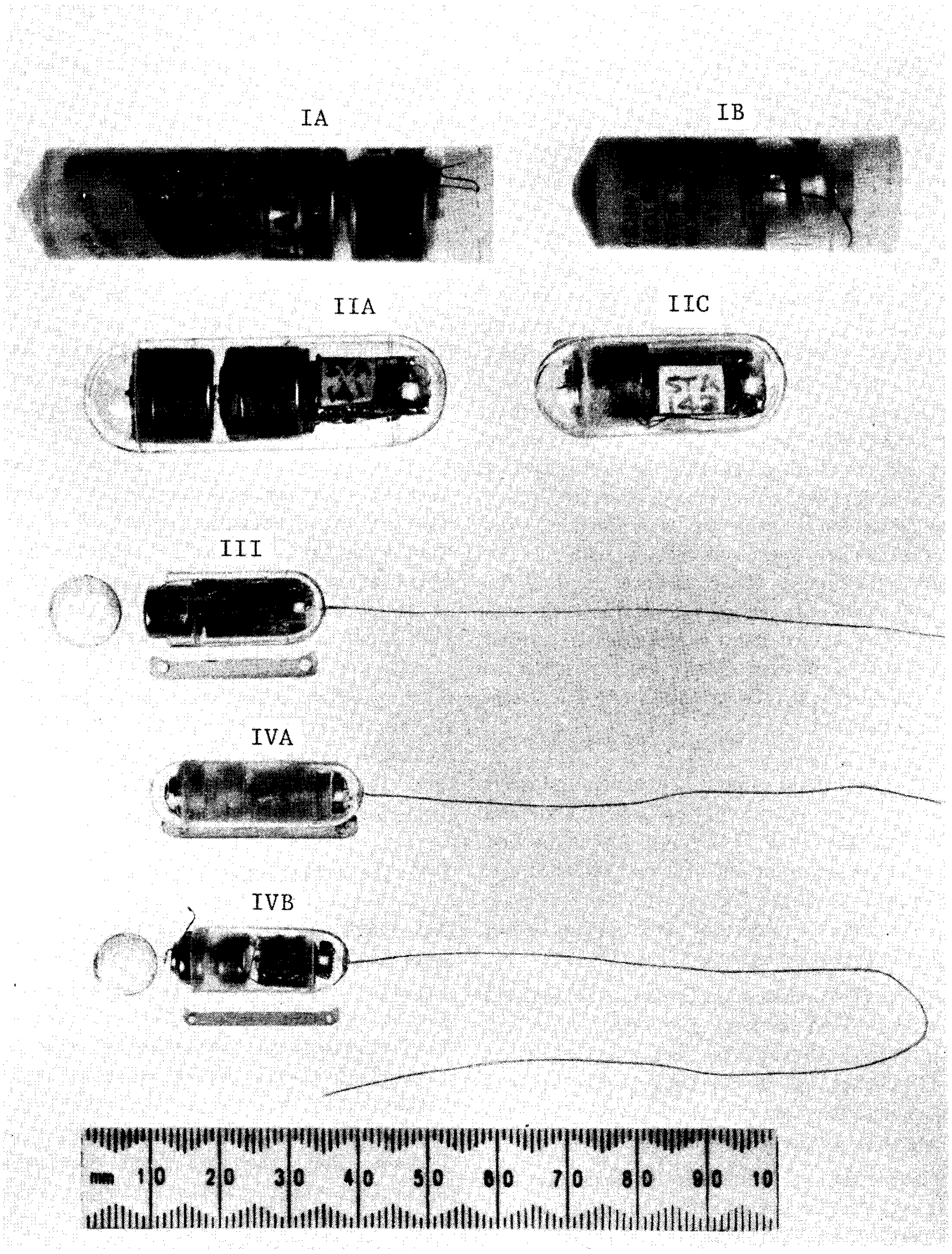

Figure 1 The tag types used. The Mark IIB was identical in appearance to the IIC. Marks I and II were inserted into the stomach, and Marks III and IV mounted externally.

3 The tags and mounting systems

3.1 1978 trials

Following the successful tests with tethered tags, trials using salmon and sea trout commenced on the River Fowey in September 1978. The tags used were as described in Section 2, except that the frequency had been changed to 104.70-104.75 MHz to comply with new Home Office regulations. These tags, designated Mk I (of two sizes, Mk IA and Mk IB) are shown in Figure 1 and more details are given in Table 1. They transmitted 100 ms pulses at repetition rates ranging from 50 to 80 per minute. Identification of individual tags was by a unique combination of radio frequency and pulse rate. The tags were activated shortly before use in the field by soldering a piece of wire between two projecting pins in the dished end cap; melted dental wax was then run over the cap to leave a slightly convex end and to insulate the connection.

Table 1 Specification of tags

MK	Dimensions Length/dia (mm)	Weight in Air/water (g)	Aerial	Dates used	Species/mounting	Tubes	Battery	Comment
IA	69/17	23.4/9.8	Integral – copper wire on iron dust core	1978-9	Salmon stomach	Syringe		
IB	46/17	15.6/6.5	"	1978-9	Seatrout stomach	"		
IIA	51/16.5	13.9/6.9	Integral – copper wire on ferrite core	1980 – present	Salmon 2 kg + stomach	Sarstedt 55.481	2 x SAFT Li 450 mAh	Replaced IA
IIB	36.3/14.9	8.1/2.8	"	1980	Small salmon seatrout 750 g + stomach	Sterilin 142B	2 x Mallory SP675 220 mAh	Replaced IB
IIC	36.3/14.9	8.1/2.8	"	1981 – present	Small salmon stomach seatrout external	Sterilin 142B	1 x Sanyo or Mallory PX 28 (Li) 160 mAH	Replaced IIB
III	28.8*/11.1	3.3/0.6	Trailing wire 17.9 mm	1982	Seatrout external	Sarstedt 55.478	1 x Sanyo CR772 (Li) 30 mAh	
IVA	31.1*/9.7	3.5/2.4	"	To be used 1983	"	Sarstedt 55.480	2 x Duracell silver oxide D393 75 mAh	Replaced IIc for seatrout
IVB	28.1*/9.7	3.0/2.3	"	"	"	Sarstedt 55.480	2 x Duracell silver oxide D392 38 mAh	Replaced III

* Mk III + IV – length excludes trailing aerial.

Note: From 1982 all tags fitted with reed switches – this does marginally alter the weight.

Fish were captured at a range of sites in the river on September 11, using electric fishing apparatus operated by personnel from the South West Water Authority (SWWA) Fisheries Department. Five fish were tagged with gut-mounted tags inserted into the stomach via the oesophagus, a method extensively used on salmonids in North America (Stasko and Pincock, 1977). The tags were pushed into the stomach using a wooden dowel rod. Two salmon were tagged with Mk IA tags, and three sea trout with Mk IB tags. The river level was low at the time, and the fish showed signs of having been in the river for some weeks (colour, lack of sea lice). Irregular spot checks were made and after 21 days all tags were detected and were located within 600 m of the release point. After 58 days only three tags could be located: one was in a salmon about 700 m upstream of its previous position; the other two, in sea trout, were believed to have been regurgitated, as the fish could not be located by electric fishing in the area.

3.2 1979 trials

During August and September, 10 salmon and 3 sea trout were caught by electric fishing and tagged, all the sea trout and the smaller salmon with Mk IB, the larger salmon with Mk IA tags. In addition, five salmon caught on the night of August 10-11 in a temporary trap operated by the SWWA (see Section 5.2) were tagged.

Several problems were encountered. First, further evidence of regurgitation of tags by sea trout was obtained when one of the tags was recovered from the river bed using an underwater aerial (Section 4.3). Second, technical problems with tag production meant that the output level of many was poor and unreliable, so many tags were not relocated after release despite extensive searches of the catchment. Third, three of the salmon tagged after capture by electric fishing died within a few hours, and a fourth within a few days: post-mortem examination of one of those which died shortly after tagging showed rupture of the oesophagus, presumably effected by the tag or insertion rod during tagging: probably because of better operating conditions this problem did not occur with the trap-caught fish (Section 5.2).

Three of the trapped fish were not relocated subsequent to release, it is believed because of poor signal strength. The other two were observed, in one case 5 km upstream after 14 days and again after 69 days, in the other 20 km upstream after 31 days.

Once the technical problems with the tag circuitry were solved, the most important problems appeared to be with gut damage and tag regurgitation. It was felt that the solution to these could lie in modified tag case design and, in respect of gut damage, more careful handling and a modified approach to stomach insertion.

3.3 Salmon tags and tag insertion, 1980 onwards

From 1980 onwards the tags used had a modified integral aerial, involving a smaller ferrite core, and a different case. The tags were smaller, due to circuit board refinements, improved battery specification, and a custom-selected case. The cases now used are made from polystyrene test tubes, and have hemispherical end caps sealed with polystyrene cement. The tags are no longer oil-filled, and leakage problems have been minor. The pulse duration was reduced from 100 ms to 50 ms, and the range of pulse frequencies broadened to 30-85 pulses per minute to increase the number of pulse frequency/radio frequency combinations available. This Mk IIA 'large salmon tag' (Figure 1; Table 1), overall dimensions 51 mm x 16.5 mm diameter, has been used unchanged since 1980. Two 450 mAh, 1.5V lithium cells give it a life in excess of 6 months.

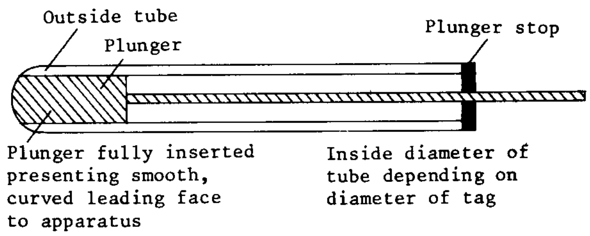

Figure 2 Tag inserter for Mk IIA tags.

The Mk IIA tag is used for salmon of about 2.0 kg or more total bodyweight, and is inserted using a tube and plunger system (Figure 2). The tube with plunger in place is lightly greased with petroleum jelly, and is eased down the oesophagus of the anaesthetized fish to the anterior end of the stomach. The plunger in the tube forms a smooth hemispherical leading face to the apparatus. The plunger is withdrawn, the tag placed in the tube and the plunger slowly re-inserted to project the tag into the stomach. The tube and plunger is then withdrawn. With practice and well-planned facilities the whole operation takes only a few seconds.

Salmon smaller than 2.0 kg are tagged with a smaller version of the Mk II; the IIB (1980) and IIC (1981 on). These differed from the IIA only in the smaller batteries allowing a smaller case (36 mm x 15 mm diameter). The Mk IIC has a 160 mAh, 3V lithium cell giving approximately 60 days life.

The Mk IIB and IIC tags have to date been inserted using a dowel rod with a concave-shaped end, carefully smoothed. A small version of the tube and plunger inserter is currently being constructed.

Radio tagged fish were also marked using a numbered 'Floy' anchor tag to aid reporting of recaptured fish. This has proved most valuable as a tactical measure. Capture of externally tagged fish is usually reported promptly, and can save much wasted time searching for 'missing' fish which have in fact been taken by anglers.

Between 1980 and 1982 a total of 21 salmon were tagged with Mk II tags. Details of the tracking will be given elsewhere (Solomon and Sambrook, in preparation), but some points are relevant here. Five were subsequently reported caught by anglers after elapsed periods of a few days to 97 days. Two were removed from the water by predators; in one case the fish was almost certainly alive at the time it was caught by an otter 63 days after release and 25 km upstream. No fish are known to have died as a direct result of handling and tagging, though two were recaptured after a considerable period in a poor condition, infected with *Saprolegnia* fungus. However, fish in such condition frequently occur naturally after a lengthy stay in fresh water as spawning time approaches. Two fish were observed dropping downstream apparently after spawning successfully with the tags still *in situ,* though generally tracking had been discontinued before this. One of the *Saprolegnia* infected fish, recaptured 69 days after tagging, was killed and dissected; there was no trace of damage to the gut. The longest 'track', with the fish detected and located almost every day, has been 93 days between tagging and, it is believed, the fish leaving the river as a kelt.

3.4 1980 sea trout trials

Thirteen sea trout between 40.5 cm (740 g) and 64.9 cm (3.55 kg) were tagged with Mk IIB tags inserted into their stomachs as described in Section 3.3. All were trapped at Restormel between 30 May and 12 September. It is believed that all the tags were regurgitated between 4 and 7 days after tagging. The average distance travelled before regurgitation was 7.3 km upstream (range 2.1-13.0 km). Several of the tags were recovered from the river bed using the underwater aerial (Section 4.3). One fish passed through a temporary trap at Two Waters Foot, 12 km upstream from Restormel, after 4 days; this fish regurgitated its tag 1 km further upstream. Another passed through the trap after 5 days, having lost its tag 1.2 km downstream.

An attempt was made to overcome the regurgitation problem by modifying the case shape in 1981, without success. Gut mounting of tags for sea trout was therefore reluctantly discontinued. It should be pointed out, however, that the system works well if short-term tracks (4-7 days) are all that is required.

3.5 Sea trout tagging, 1981 onwards

Having discounted gut mounting, two alternatives were investigated; mounting in the peritoneal cavity, and external attachment. Preliminary trials with the former proved most promising. Unfortunately, negotiation with the Home Office for exemption or approval, under the terms of the Cruelty to Animals Act, 1876, resulted in the ruling that authority to proceed could not be granted. It is unfortunate that this approach is closed to UK researchers as it is proving to be a most successful one in North America (Stasko and Pincock, 1977; Einhouse and Winter, 1981).

External attachment was initially tried using Mk IIC tags, with a polystyrene strip glued along the length of the tag. A small hole near each end of the strip enabled the tag to be attached with suture thread to the back of the fish as shown in Figure 3. Absorbable suture material was used so that the tag would be shed after a period. Further details are given below.

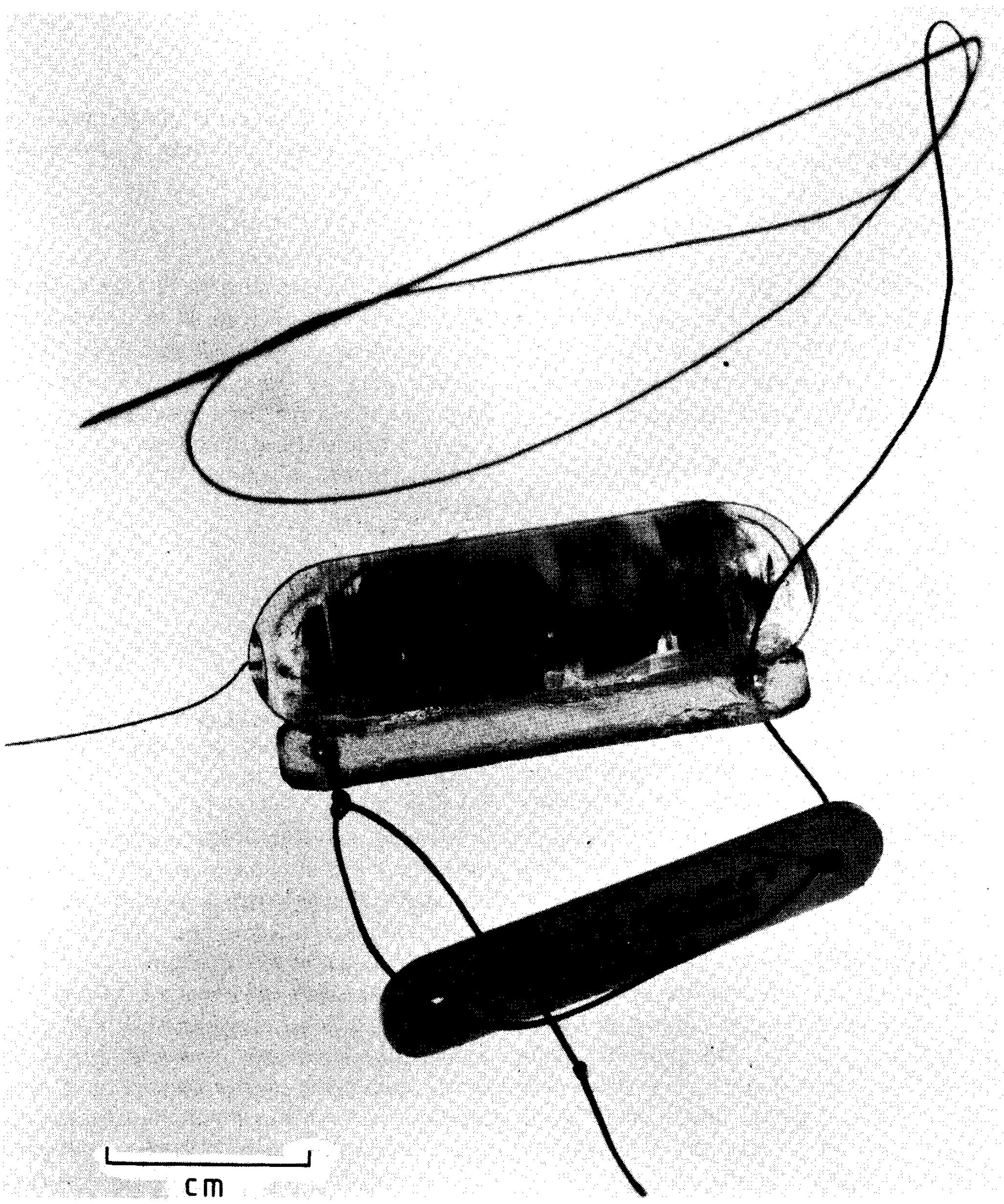

Figure 3 Attachment method for Mk III tags. The suture needle was passed through the back of the fish at the base of the dorsal fin. The "reward" plate is on the opposite side of the fish from the tag.

The relatively large cross-section area of the Mk IIC tag has three disadvantages for external mounting. First, it is unsuitable for use on fish of under about 1 kg: much of the sea trout run comprises fish between 300 and 500 g which are too small for Mk IIC tags, either in the gut or attached externally. Second, buffeting by fast currents and possibly by contact with rocks loosens and weakens the attachment thread and so leads to premature tag loss. Third, the back of the fish suffers some minor damage. Nevertheless, some excellent results involving extended tracks have been achieved with this system.

The above constraints led to the development of a much smaller tag for external use. The limits on size reduction of the Mk II are effectively the bulk of the batteries and the integral aerial. We were able to produce a smaller tag (Mk III) by compromising on battery capacity and adopting an external trailing aerial (Figures 1 and 3). The case is again of polystyrene, with hemispherical ends, 11 mm diameter and 28 mm long. The 17.9 cm, 'Teflon'-covered, wire aerial is passed through a hole drilled in the rear end-cap, sealed with 'Araldite'. Incorporation of a magnetic reed switch allows the case to be sealed and checked for leaks well in advance of field use, without length of operating life suffering. The reduction in battery capacity to 30 mAh (cf 160 mAh for Mk IIC) has been to some extent countered by allocation of low pulse repetition rates (e.g. 30 per minute). Several Mk III tags have operated in excess of 30 days, although dropping battery voltage gives a falling pulse-rate in the last days of operating life.

The external attachment method has been the same as that used for Mk IIC tags. Suture materials used in 1982 were Ethicon coated vicryl, thickness 2/0 and 3/0. Sutures with a ready-mounted 60 mm straight needle (Ethicon W9415 and W9418) allow very rapid fixing. The fish is anaesthetized using Benzocaine (Laird and Oswald, 1975). Use of these sutures has generally led to tag shedding after 20-30 days. Although several fish have subsequently been recovered having suffered no apparent long-term harm, some damage to the fish does still occur – in the worst cases the sutures tear out. Two approaches being made to remedy this are to find an improved method of attachment and to develop even smaller tags. The latter approach has led to the development of the Mk IV tag. Although the circuit design is little changed, the circuit board has been totally redesigned and many of the components miniaturized (Figure 1, Table 1). Once again the case is based on a polystyrene test tube, 9.7 mm diameter. Two types are being constructed: the Mk IVA has two, 1.5V silver oxide cells giving 75 mAh, and the Mk IVB two, smaller, silver oxide cells giving 38 mAh. These Mk IV tags, yet to be used on fish, should effectively replace the Mk IIC and Mk III respectively for use on sea trout.

4 The receiving system

4.1 Long-range aerials

The H-Adcock aerials supplied by Mariner Radar Ltd proved effective and reliable and are one of the very few features of our system that have remained unchanged throughout. The dipole elements, made of GRP-covered wire, can be folded flat along the horizontal member for transport, which makes it simple to carry and to use on overgrown river banks. The aerial is generally used on a 2.4 m collapsible pole, but is almost as effective on a 1.2 m pole. The signal strength is maximised when the dipoles are in line with the signal source, and drops almost to zero when the aerial is rotated through 90°. Using the null direction gives a good directional indication of the position of the tag.

The 4-element Yagi aerial mentioned in Section 2 is effective, but being less easily folded is less suitable for bankside use.

At times in 1982, to raise the H-Adcock aerial for improved performance, we used an 11 m, compressed air operated mast mounted on the back of a Land Rover. The mast is manufactured by Clark Masts Ltd. Apart from increasing range due to escape from ground-plane effects, it is particularly valuable where buildings, trees or intervening land masses otherwise obscure a 'line of sight' between tag and aerial.

4.2 Short-range aerials

For accurate location of tags it is more satisfactory to use perceived signal strength as an indication of proximity of the signal source, rather than directional information. However, the high efficiency of the H-Adcock aerial means that signal strength drops little with distance, making comparison difficult. This can to a large extent, be overcome by folding the dipole elements flat when near the tag, which greatly reduces aerial efficiency, and resolves the position within ± 20 m along the river. Greater precision and portability can be achieved by the use of a small and even less efficient aerial: a 12 inch hacksaw blade has proved ideal, and is very cheap; it is hand-held, connected to the receiver via the centre conductor of the co-axial aerial lead, and allows location within ± 5 m where the stream is narrow (< 10 m), and ± 10 m where it is wider. For most tracking purposes it is unnecessary to locate tags with greater precision than this.

4.3 Underwater aerial

In some situations, e.g. where it is suspected that the fish is dead or the tag has been regurgitated, it is desirable to be able to locate the tag precisely. For this purpose we developed an underwater aerial, shown in Figure 4. It comprises a simple formed loop of co-axial cable, approximately 120 mm in diameter, mounted at 90° to the end of a 1 m, plastic pipe handle, with the cable running through it. Using this aerial in air, a tag underwater is normally detectable from about 30 m. When signal maximisation indicates the location of the tag within a few metres, the aerial is immersed and the signal maximised by search. The signal strength is maximal when the tag is in the centre of the loop. Although practice and patience are required, on several occasions tags have been recovered 'blind' in muddy water conditions. On another occasion this aerial was used to pinpoint and recover a tag which was buried under 5 cm of soil beneath a riverside thicket; it is believed that the remains of the fish had been buried by a predator.

4.4 Radio receivers

The Mariner M54 receiver used for the initial trials had two minor disadvantages for this project. First, each set covered only half the radio frequency range we used, requiring the use of two receivers for tracking. Second, the tuning was by fixed 5 kHz steps, with a fine tuner for interpolation; this system is elaborate when searching a 50 kHz waveband for tag transmissions. By the time the first trials using fish were conducted a new receiver had been developed by Mariner Radar Ltd, in association with one of us (T.J. S-W.). It allowed continuous tuning over the whole waveband used. This receiver, the Mariner M57, has proved reliable and effective throughout our programme of work. Our sets have withstood several years of field use with only minor repairs being necessary, and are substantially weatherproof.

In 1982 another new receiver was used extensively. It is based on an amateur band (144 MHz) transceiver, the Yaesu FT-290 R., with a frequency converter for use around 104 MHz. The set was selected because its frequency scanning facility appeared suitable for passive recording station use (see Section 4.5), but it also proved to be a very effective tracking receiver with several advantages over the M57. These include slightly more convenient size and shape for field use (especially with the subsequent development of placing the frequency converter stage inside the case), rechargeable batteries, digital frequency readout allowing more accurate frequency identification, and greater repeatability of frequency determination. A major drawback is the receiver's lack of weatherproofing; unless or until a waterproof case is developed great care must be taken when using the set in wet conditions. Details of the frequency conversion and other technical aspects will be reported elsewhere.

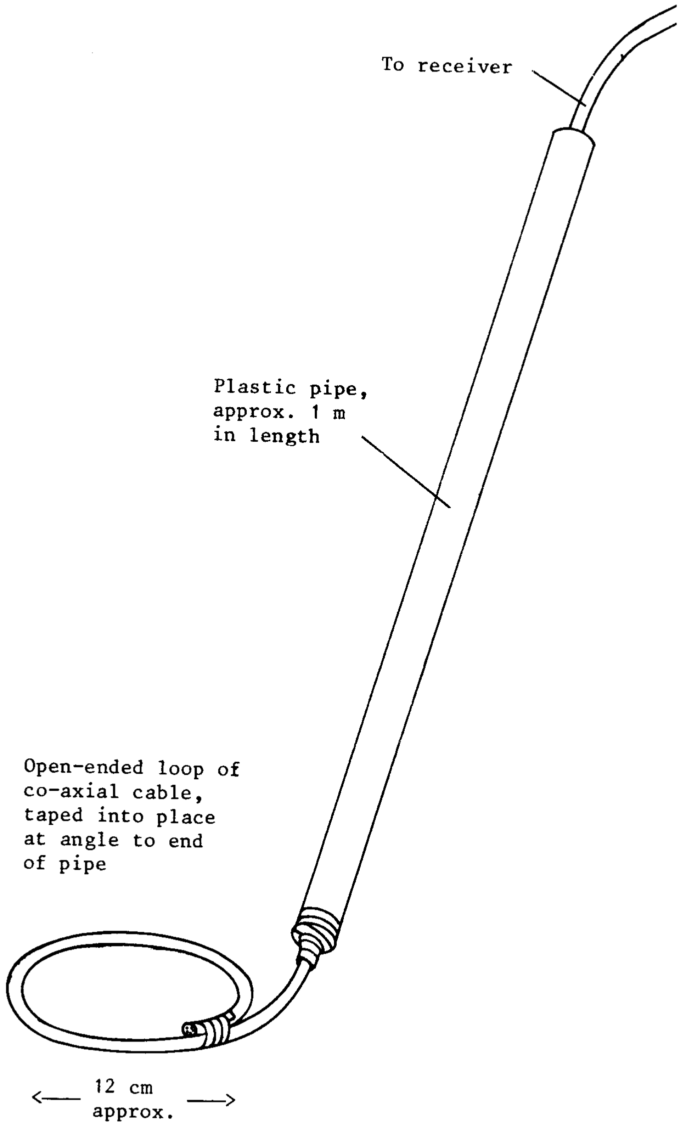

Figure 4 Underwater aerial

With the Mariner M57, as the receiver is tuned towards the tag frequency, an audio tone is generated at a frequency equivalent to the difference between tag frequency and that indicated on the receiver. Thus the tag pulses are heard as a descending tone as the tag radio frequency is approached, no tone at all when exactly on frequency (the null), and a rising tone after the frequency has been passed. Identification of tag radio frequency is effected either by judging the null point or by halving the frequency difference between two dial frequencies which generate the same tone each side of the null. In this way the M57 allows identification to better than 500 Hz. With the Yaesu FT-290R only one 'sideband' is usable at any one time. i.e. the audible tone is only generated while tuned either above or below the tag frequency, but not both. However, identification to 100 Hz is possible using the 'null' method.

4.5 Passive listening stations

One of the most important developments in our experimental approach has been the use of passive recording stations (see Section 5.4). In 1982 we used three such stations. Each comprised a receiver (Mariner M54 or M57) with short-range aerial (Section 4.2), a tape recorder, a timer/control box and a power supply, all enclosed in a weatherproof box. The timer/control box was developed and constructed by a local electronic contractor to our specification. Its function is to supply power to the receiver and tape recorder for a period (e.g. 1 min) at accurately controlled intervals, e.g. every 5 or 10 min. An audio frequency tone of 1 s duration is generated at the start of each record cycle, so that the 1 min periods can be counted on playback of the tape. The tape recorder (Phillips Model N3302) is modified so that the tape transport speed can be reduced by a factor of about 2.5. Details of this simple circuit modification can be supplied on request. Thus by recording at slow speed, one minute in ten, a 'C120' tape will record for 25 h per side. Playback at normal speed takes 1 h; in future reduced record times (e.g. 5 or 10 s) will be used to reduce playback time. The receiver is tuned just off the tag frequency null to produce an easily recorded audio tone (e.g. 2 kHz); only that tag, or perhaps others within 4 kHz of the tuned frequency, will be recorded. The recording stations are concealed on the river bank and are generally positioned close to stationary fish in order to record their time of departure, but are also used to record the time of passage of moving fish (Section 5.4).

A much more versatile system has been developed within this laboratory, using the frequency scanning facility of the Yaesu FT-290 R receiver. This has yet to be tested under field conditions, but will allow ten channels to be searched in each listening period, and thus the presence of a large number of tagged fish to be detected. Details of the design and operation of this system will be published elsewhere.

4.6 Aircraft tracking

Several studies in North America (e.g. McCleave *et al.*, 1978) have used aircraft for fish and animal tracking with radio tags. As part of our development of a tracking system, a trial flight was made in February 1981 by a Cessna 172 single engine aircraft chartered from West Air Photography. Mk II tags were fixed to bushes on Middle Hope, a promontory on the Bristol Channel coast adjacent to Bristol Lulsgate airfield from which the flight was made. The receiver aerial was a single dipole, mounted vertically on a bracket fabricated by West Air Photography fixed to a wing strut; horizontal mounting should give a better signal at close range, with no loss at long range. The receiver used was a Mariner M57 with headphones.

Six passes were made over Middle Hope at various heights between 50 m and 150 m above the tags. A range of airspeeds between 65 and 105 knots was tried, but the lower speeds required higher engine revolutions, and the increased noise level nullified any theoretical gain in time of detectability; the optimum speed appeared to be about 80 knots. Depending upon the tag signal strength, airspeed, height etc., tags were detectable for between 15 and 53 s, indicating ranges up to 900 m. These observations suggest that aerial tracking with the equipment currently in use is feasible. We have not used it in practice as the need (e.g. several 'missing' tags in a long length of river) has not arisen. However, for large rivers it could be a cost-effective method of tracking.

5. Considerations in conduct of tracking exercises

5.1 Strategy

The strategy adopted will, of course, be heavily dependent upon the aims of the exercise. In the case of the River Fowey study we are interested in the movements of salmon and sea trout during the drier part of the year (e.g. May-October) as this is the period which is likely to be most affected by the modified flow regime. We aim to tag fish as soon as possible after entry to the river, and follow their movements in relation to environmental variations, in particular, fluctuations in discharge.

5.2 Catching and handling the fish

The considerations for most studies will be similar, viz. to catch and tag the fish at the right time at the right place, and to undertake the operation with the minimum of damage and trauma to the fish. As described in Section 3.2, some problems were experienced in our study with salmon dying after release. Soution of this problem coincided with adoption of improved tag casings, and a move from electric fishing to trapping as a capture method; it is suggested that both contributed to the improved performance. The chief disadvantage with electric fishing lies not so much with any directly adverse effect of capture by electricity, but with aspects of the logistics of the exercise. Generally it has to be done in daylight, and a considerable stretch of river fished to obtain the desired numbers of fish. This means that the tagging equipment has to be easily portable, and is used under a wide variety of bankside conditions. This is not conducive to an efficient operation.

Since 1980 all fish tagged have been captured at night in temporary traps operated by Mr H Sambrook of the SWWA, initially being operated for a SWWA investigation but in 1982 operated specifically for obtaining fish for radio tagging. Details of the traps will be published elsewhere (H Sambrook, in preparation). The siting of the main trap a short distance above the head of tide means that fish captured are actively migrating and have entered fresh water, it is believed, within the previous 24 h. The overwhelming majority of fish caught are infected with intact sea lice (*Lepeophtherius* spp), which indicates very recent salt-water residence. Thus the trap site used satisfies the 'right place, right time' condition. Fish are generally removed from the trap in an undamaged condition, and are handled and tagged on a stable, well-organised platform. As the equipment is not moved during a night's operation, holding, anaesthetizing and recovery facilities can be extensive. After tagging the fish are carried short distance upstream in a small volume of water of water in a 'salmon carrying bag' designed by our colleague, Mr E Potter. The place of release appears to affect the behaviour of the fish. If they are released in a pool with sheltered lies, they will generally remain there for the rest of that night and most will move upstream on the following night. However, it appears from most recent practice that if the fish are released where there are no suitable lies they continue to migrate upstream without delay, perhaps for several kilometres and well beyond the next resting pools upstream.

5.3 Effects of tagging and handling on the fish

A major concern with all fish tracking studies is the possibility that the trauma of capture, handling and tagging and the continued presence of the tag in or on the fish will modify its behaviour in some way and reduce the validity of the behavioural observations made. Throughout the development of the present system this factor was carefully considered and all reasonable steps taken to minimize the risk. The following considerations are relevant here:

a. The trapping and tagging procedures have been developed to minimize trauma – see Section 5.2.

b. The tags are small relative to the size of the fish. In the case of the largest tag, the MK IIA (Table 1) the tag weighs about 6.9 g in water and is used in the stomach of fish heavier than 2 kg, i.e. it represents at most 0.35% of the bodyweight. Fried *et al.* (1976) demonstrated that smolts of Atlantic salmon weighing about 90 g were able to adjust their buoyancy to compensate for tags weighing 4 g (4-5% body weight) in water, inserted into their stomachs. McCleave and Stred (1975) reported that the swimming ability of smolts (21-24 cm length, 85-105 g) was not affected by placing a tag (33 mm x 8 mm diameter, 4 g weight in water) into the stomach. It is therefore suggested that the size and weight of the MK IIA tag is insignificant to the fish.

The smallest fish tagged with a Mk III tag (26 mm x 11.5 mm diameter, weight in water 0.6 g), attached externally was 28.5 cm long, weight 280 g. Although this fish apparently behaved normally, i.e. in a similar manner to larger fish, it is suggested that this size is near the limit for use of tags of such dimensions. McCleave and Stred (1975) reported that an external dummy tag, 31 mm x 18 mm diameter (1.25 g in water), significantly reduced the swimming performance of salmon smolts of 20 cm length.

c. Some fish when tagged resumed their upstream migration within an hour of release, and most by the following night (Section 5.2). This suggests only limited interference with the fish's behaviour.

d. Most fish were tracked for a considerable period after tagging, which should have allowed recovery from trapping and tagging trauma. Apart from the fact that most fish delayed continuing their movements for 24 h, no other subsequent change in behaviour was observed, i.e. there was no evidence that there was only a gradual return to normal.

e. The rates of travel of fish are generally consistent with the apparent rates of travel of conventionally tagged fish trapped at the same time, and subsequently recaptured upstream. As the two categories thus experienced similar trapping and handling trauma, this suggests that the presence of the radio tag itself does not radically influence the movements of the fish.

5.4 Tracking tactics

The approach to tracking will depend upon the performance of the tracking system, constraints of the watercourse, and what information is required, e.g. whether continuous tracking or daily spot positions are needed.

Considering first the performance of the tags and receiving equipment, all our tag types currently in use have a similar signal strength and thus theoretical range of detection. This range, however, depends upon such factors as depth of tag below the water surface, aerial elevation, and intervening topography between tag and receiver aerial, e.g., undercut banks and hills. In the best situation, with the tag in shallow water and the receiver on a ridge of high land with a good line of sight, ranges of up to 2 km have been achieved. In the worst situation, with the fish in deep water under an overhanging bank with dense trees and the receiver at river level, the range may be reduced to 500 m or even less. In most cases, using a series of selected vantage points along the river at 1-2 km intervals, all tags are easily located. Towards the end of the battery life of a tag, or sometimes before, signal strength drops significantly. However, if by then a picture of the pattern of movements has been built up it is often possible to locate tags with a detectable range of only 100-200 m by searching around the last known holding point and the predicted new one. Continuous tracking would be possible with tags of lower output, but would be highly labour intensive.

In the river system on which we are working, which has a total main river length accessible to migratory fish of perhaps 30 km plus a similar total length of tributaries, relocation of fish each day is relatively straightforward. Many fish are found in their previous position; of those that move, most are found between 1 and 3 km upstream.

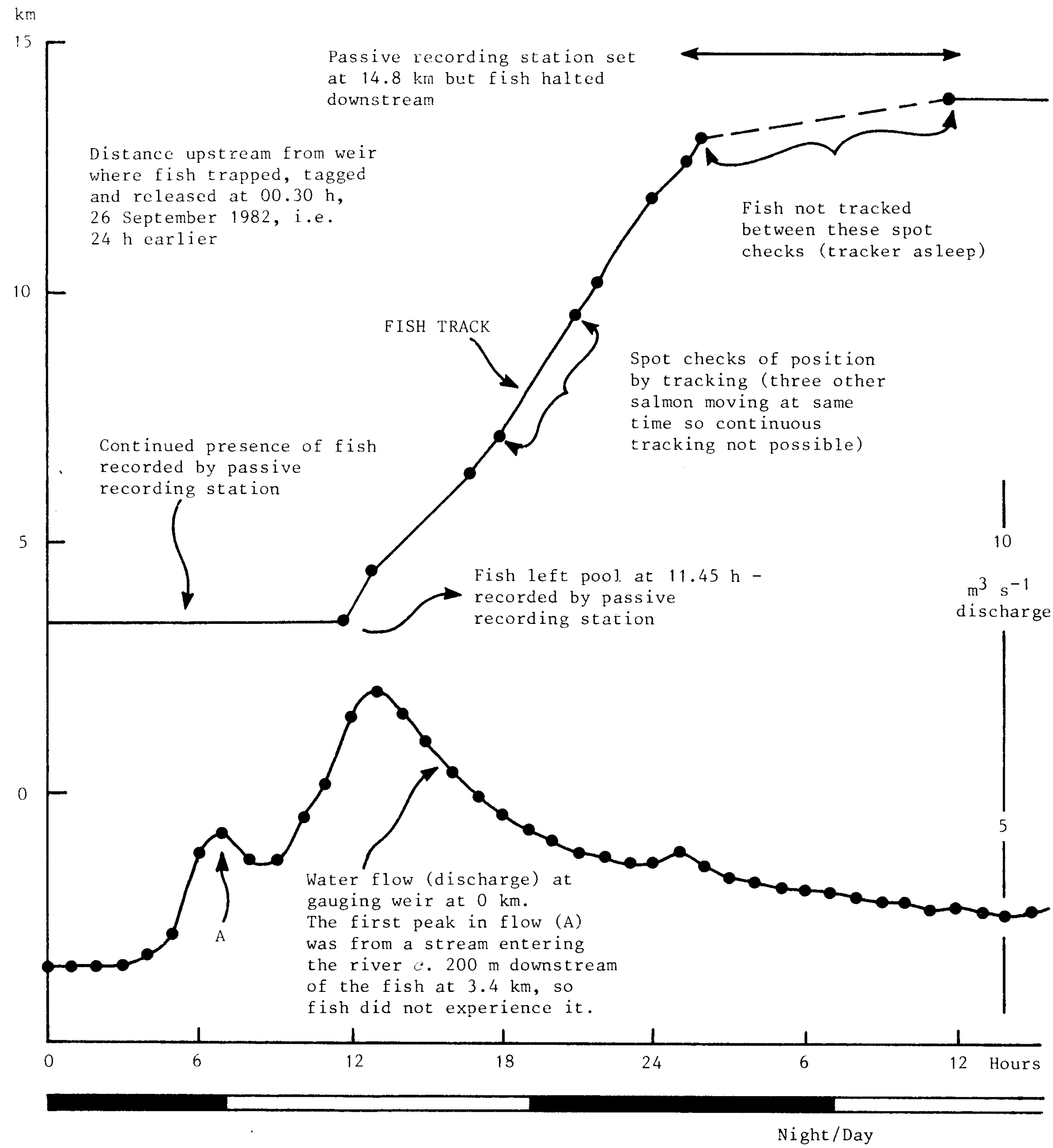

Figure 5 Thirty-six hours of a track of a salmon in September 1982, with several features of the tracking operation annotated. This fish was eventually killed (almost certainly by an otter) after 67 days.

The greatest distances travelled in 24 h have been 11.3 km for salmon, and 6.4 km for a sea trout.

For our study it is important that we know exactly when the fish start to move on each leg of their upstream journey, and what the pertinent environmental conditions are at that time. For this purpose, the passive recording stations described in Section 4.5 have proved invaluable. Each time a tagged fish lies up for a period a fixed frequency recording station is hidden on the bank nearby; this records the proximity or otherwise of the tag each 5 or 10 min. Once the fish has moved the station is recovered and is then used at points upstream to record the time of passage of the fish; a station may thus be moved several times in 24 h following a period of a week or more of total inactivity. Coupled with spot checks of progress by normal tracking, this method allows one man with, say, five recording stations to keep track of five fish moving simultaneously but in different parts of the river in response to a freshet, for example. Included in the data would be accurate records of the time when the movement of each fish commenced. A 36-h track of a salmon produced in this way is shown in Figure 5. Continuous records of river flow (discharge) are available from five SWWA gauging weirs on the catchment, and a water temperature recorder is usually deployed throughout a tracking exercise.

Acknowledgments

Many of the ideas incorporated into the development of the radio tracking system originated during discussion with colleagues. It is not possible to list or even recall all such contributions but specific mention must be made of Hugh Sambrook, South West Water Authority. He has been involved throughout with the capture and much of the tracking of the fish and has been responsible for initiating and influencing much of the improvement to the system.

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7. Manufacturers and suppliers

The following commercial companies and their products are mentioned in this report. This should not be construed as an official endorsement of these products, nor is any criticism implied of similar products which have not been mentioned.

Clark Masts Ltd Binstead Isle of Wight PO33 3PA	(Radio masts)
Ethicon Ltd PO Box 408 Bankhead Avenue Edinburgh EH11 4HE Scotland	(Absorbable sutures)
Arnold R. Horwell Ltd 2 Grangeway Kilburn Highway London NW6 2BP	("Sterilin" polystyrene tubes)
Mariner Radar (Lowestoft) Ltd "Bridleway" Camps Heath Lowestoft Suffolk	(Radio receivers, aerials)
Sarstedt(UK) Ltd 165 Scudamore Road Leicester LE3 1UQ	(Polystyrene tubes)
West Air Photography 23 Cecil Road Weston-super-Mare Avon BS23 2NG	(Aircraft charter for tracking)