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THE MOVEMENT OF SEA TROUT SMOLTS, *Salmo trutta* L., ON ENTRY TO THE MARINE ENVIRONMENT

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SUMMARY

The movements of sea trout (*Salmo trutta* L.) smolts were observed in the sea by tracking fish fitted with small, external ultrasonic transmitters (70-86 kHz). Twelve smolts, tagged and released in the vicinity of their capture location, were manually tracked in Loch Ewe, on the west coast of Scotland.

Three smolts returned to fresh water within a few hours of release. The remaining smolts were manually tracked for periods of up to 68 h at the head of the sea loch and one was followed intermittently for over 10 days. The smolts generally remained in shallow water, in the littoral and immediate sub-littoral zones, within 1.5 km of the river mouth. On occasion smolts returned to the river mouth where they were released, particularly at times of high and low tide. One tagged smolt remained close inshore for a period of over 50 h before moving across open water to a bay at the mouth of Loch Ewe about 6 km from its release position. Swimming speeds for this smolt of 20 cm fork length, corrected to allow for tidal flow, are estimated to be between 5.9 cm s^{-1} and 25.4 cm s^{-1}.

The observed pattern of movement for most of the tagged smolts on entry to the marine environment was to remain close inshore, within the shelter provided by seaweed beds. More distant migration across open water, however, may be triggered by inadequate food supply or lack of suitable cover.

INTRODUCTION

Recent large and substantial reductions in adult stocks in many western Scottish and Irish rivers highlight major gaps in our knowledge of the biology of the sea trout, *Salmo trutta* L., the anadromous form of brown trout. In fact, relatively little is known of the marine ecology of sea trout and the factors which influence their survival in the sea, where they are a relatively rare species, and therefore difficult to sample. The movements and behaviour of sea trout smolts on initial emigration from fresh water into the marine environment, therefore, are key areas for investigation.

Based on a study of the distribution and diet of sea trout sampled in west coast sea lochs, Pemberton (1976a,b) found that the movements of the fish during their first few weeks in the marine environment were fairly localised and coastal. His results also indicated that shoaling intensity was maintained for the first few months after smolt migration but was most marked during the peak of migration in May. A study of sea trout migration in the sea from a Norwegian river reported that over 50% of Carlin tagged fish recaptures were made within 3 km of the river mouth (Berg and Berg, 1987) emphasising the local nature of their sea migration pattern.

The migratory behaviour of salmon and sea trout smolts determined by telemetry has been reported by Solomon (1982). More recently, observations of the movements of sea trout smolts through the estuary of the River Avon in southern England have been made with acoustic telemetry (Moore and Potter, 1994). However, there is a lack of information on the individual movements and behaviour of sea trout or indeed of salmon (*Salmo salar* L.) post-smolts in the sea. The small size of the fish means that they can only carry miniature telemetry packages with low power output and so are difficult to track in open water. Nevertheless, tracking of individual Atlantic salmon smolts with miniature acoustic transmitters has provided information on their movements in fresh water (Fried *et al.*, 1978; Solomon, 1978; Thorpe *et al.*, 1981) and on their seaward migration (LaBar *et al.*, 1978; Tytler *et al.*, 1978; Holm *et al.*, 1982; Moore *et al.*, 1992).

The feasibility of tracking sea trout post-smolts, fitted with external acoustic tags, in the sea has been investigated and initial results described by Urquhart and Johnstone (1993). The study was extended during 1994. This paper describes further acoustic tracking observations of sea trout post-smolts during the early phase of their marine life history, in a sea loch on the west coast of Scotland.

MATERIALS AND METHODS

Study Location

The observations were conducted in Loch Ewe during the period 3 May to 2 June 1994. Smolts were obtained from two fresh water sources, the River Ewe, which flows from Loch Maree into the head of the sea loch (57°46.02'N, 5°36.15'W) at the village of Poolewe, and the Sguod Burn, which flows from Loch Sguod into the seaward end of Loch Ewe (57°49.78'N, 5°40.52'W), about 8 km north west of Poolewe (Fig. 1).

The head of the loch is a sheltered, shallow bay approximately 1.5 km wide, with a maximum depth of about 4 m at extreme low water of spring tides. The gently sloping intertidal area is densely covered with beds of fucoids of three species, *Fucus vesiculosus* L. and *F. serratus* L. but predominantly *Ascophyllum nodosum* (Le Jol.). Other algae include *Enteromorpha intestinalis* L., and *Polysiphonia lanosa* (L.) Tandy (attached to *A. nodosum).* The substrate varies from boulders and cobbles on coarse sand and mud close inshore to shell gravel and mud in the deeper offshore regions. Fresh water discharge from the River Ewe influences the surface salinity of the area as it flows northwards across the bay and along the rocky peninsula at Inverewe.

The Sguod Burn flows into the sea at Firemore Bay. At low tide the burn flows over an extensive beach of fine sand with a shallow gradient. There is no substantial estuary and access for fish to and from the burn, other than during spate conditions, is likely to be restricted to periods of high tide when the sea enters the "sea pool" at the mouth of the burn. The sandy bay is bounded to the north west and south east by rocky shores with sea weed beds along the littoral and sublittoral zones. The principal algae in the deeper areas are *Laminaria saccharina* L., *L. hyperborea* L. and, in shallower regions, *F. vesiculosus* and *A. nodosum*. Further details of the habitat and plant and animal communities found in Loch Ewe are given by Howson (1991).

Experimental Animals

Twelve sea trout (*S. trutta* L.) smolts were individually fitted with external acoustic transmitters packaged as pannier tags, similar to those described by Thorpe *et al.* (1981). Each tag was fitted astride the base of the dorsal fin (Fig. 2) using stainless steel wire connected to the transmitter and battery casings with absorbable sutures designed to release the tag after three to four weeks of immersion. Details of the fish used for the study are given in Table 1 which also includes notes of the method of capture employed for each individual since the smolts were obtained using a variety of capture methods depending on the prevailing river flow conditions.

Fish to be tagged were selected on the basis of their appearance and size. Those which were not fully silvered smolts were rejected. Smolts below 18.0 cm fork length were also rejected since they were considered to be too small to carry the ultrasonic transmitter package. Selected fish were anaesthetised in a 0.1 gl^{-1} solution of MS222 (Sandoz), measured, weighed and fitted with an acoustic tag. The fish tagged ranged in fork length from 18.0 to 25.8 cm, weighed from 55.0 to 130.1 g and were aged two and three winters. Tag attachment was completed within a minute and the fish were returned to a holding tank of low salinity water (5 to 15‰) and allowed to recover for a minimum period of 90 minutes prior to release. Soon after they were placed in the holding tank most of the tagged fish were observed swimming at the surface apparently ingesting air to regulate buoyancy by adjusting their swimbladder gas volume. They then swam or maintained station in the water column and rested on the bottom of the tank in a similar manner to untagged fish.

The tagged smolts were released from a water-filled transport container submerged below the sea surface from a 5.0 m long inflatable boat at the mouth of the River Ewe, within 500 m of the various capture locations, or at the confluence of the Sguod Burn with the sea. They were not returned exactly to the point of capture due to changing tidal conditions. Although the sea trout smolts were captured during the day most were released just before dusk since it was predicted that, like salmon smolts (Thorpe and Morgan, 1978), they would normally migrate to sea at night, at least during most of the smolt migration period. The times of release and the nearest high tide are given in Table 1. Smolts captured as a group were tagged with either acoustic or conventional tags and released together. On three occasions several fish within a released group were each fitted with an acoustic tag.

During the study, authority was granted for samples of post-smolts to be taken from the bay at the head of the sea loch using a small mesh gill-net (20 mm bar). The net was also deployed on two occasions to intercept tagged fish for physical examination and for stomach content analysis.

Environmental Parameters

Fresh water temperature was monitored in the River Ewe and the Sguod Burn for the duration of the study with waterproof data loggers (RS Components Ltd, IP68 Tinytalk). Water velocity, direction of flow, temperature and salinity were also monitored by a moored remote sensing current meter (Valeport, series 1000) located in the sea about 4 km from the head of the loch (Fig. 1). Tidal information was obtained from Admiralty Tide Tables (1994) and depth contours indicated in the figures refer to depth below chart datum.

Fresh water temperature measurements varied from 5.6 to 13.3°C in the River Ewe and 4.5 to 20.0°C in the Sguod Burn during the study period. There were considerable diurnal variations in fresh water temperature with a maximum observed range of 10.5°C in the Sguod Burn during one 24 h period due to fluctuation in air temperature and the influence of snow melt. Water temperature in the sea loch varied from 6.4 to 12.8°C during the study. Salinity profiles at different stages of the tidal cycle were obtained using a T/S bridge (Electronic Instruments Ltd, type MC5). At the head of the loch surface salinity in the area influenced by the river discharge varied from 0 to 18.6‰. However, below 1.0 m the salinity increased to over 20.0‰ and at the sea bed it varied from 28.5 to 32.4‰. The salinity of the sea water in Firemore Bay varied from 32.0 to 34.0‰. A restricted area of reduced surface salinity occurred locally where the Sguod Burn discharged into the bay.

In addition to the water velocities and bearings measured by the moored current meter, tidal speed and direction were measured by tracking a cross-vaned drogue. The drogue measured 1.0 x 1.0 m and was suspended at 5.0 m depth from a 12.0 cm diameter surface buoy. The drogue was similar in design to that described by Vachon (1978) but was constructed from plastic sheeting rather than metal vanes. Tidal vectors were determined from drogue measurements after the track of a fish had been determined. This was done during the next corresponding tidal phase when weather conditions were similar. The drogue was deployed from a boat and its position logged with a GPS navigation system at five minute intervals for 30 minute periods every hour throughout one tidal cycle. The methods of calculation of tidal vectors and correction of fish track vectors employed are described by Smith *et al.* (1981).

Acoustic Tracking

The general principles for manual acoustic tracking which were employed in this study are described by Hawkins and Urquhart (1983). The acoustic transmitters were 36.0 mm long with a maximum diameter of 10.0 mm tapering to 7.0 mm at the transducer end (Fig. 2). The transmitter package weighed 3.49 g in air, 1.08 g in water and was connected to a separately packaged battery which was approximately 20.0 x 9.0 x 6.0 mm and weighed 1.59 g in air, 0.98 g in water. With the complete pannier tag assembly weighing 5.08 g in air (2.06 g in water) an estimation of hydrodynamic drag of the tag and battery pack together at 0.2 m s^{-1} (1 BL s^{-1} for a 20.0 cm fish) gives a value of 0.29 gf.

The tags were coated with acrylic paint to give a counter-shaded appearance with a matt black dorsal surface graduating to a matt white underside to reduce the visibility of the transmitter and battery pack to potential predators.

The transmitters operated at a frequency within a nominal range of 70 to 86 kHz with a pulse repetition rate of approximately 1 s^{-1}. Details of the frequency of each transmitter are provided in Table 1. Bench and field evaluation of battery life indicated that the tags had an effective operating period of 14 to 21 days. Signal source level measurements in the laboratory gave an average value of 141.2 dB re 1 µPa at 1.0 m and practical trials to determine the range of detection of the acoustic output from a 75.3 kHz transmitter are reproduced in Table 2. Under good conditions, ie relatively calm sea and no rainfall, the signal could be detected at a range of over 400 m.

Hand-held directional hydrophones and portable receivers were used to detect and maintain contact with tagged fish.

Position Determination

The tracking equipment and personnel were carried in a 5.0 m long inflatable boat, powered by a 12 volt electric outboard motor, which was used to reduce incident noise and local water disturbance. Under ideal signal detection conditions the boat could maintain contact with the tagged fish up to a range of 400 m, but under noisier weather conditions the effective detection range was reduced to within 50 m. Generally a distance of approximately 100 m was maintained between the tracking boat and the tagged fish by reducing the sensitivity of the receiver by 20 dB. On occasion, tagged fish swam within a few metres of the boat and care was taken to minimise noise and movements to avoid alarming them.

The tracking boat carried a global positioning system (Garmin GPS75) which displayed position in Ordnance Survey coordinates with a stated accuracy of 15.0 m but subject to accuracy degradation to 100 m depending on satellite geometry. In practice, during field trials at a precise location, the error of position determination was found to be within 33.0 m. During tracking the GPS system automatically logged position every 15 minutes; however, when specific events had to be noted additional positions were logged manually and were stored as separate waypoints. The information stored in the GPS receiver was transferred to a computer at the end of each fish track.

RESULTS

Twelve sea trout smolts were released with acoustic tags. Tracking durations varied from a minimum of 1 h 6 min (STS1) to a maximum continuous tracking duration of 68 h 21 min (STS4) (Table 1a and b). One fish (STS6) was tracked intermittently and eventually recaptured with the transmitter still operating 10 days after release. Two fish were released at the mouth of the Sguod Burn. One (STS3) appeared to return to fresh water after five hours, and was not detected again. The second fish (STS4) was tracked almost continuously for over 68 h and moved across Loch Ewe into Slaggan Bay, where deteriorating weather conditions prevented further observations.

Two smolts from the River Ewe (STS1/STS2) were released separately and returned to the river almost immediately and were not detected again. A further eight fish were then released in four batches, STS5 with nine companions, STS6, STS7 and STS8 with six others, STS9 and STS10 together and STS11 and STS12 with six others. These fish remained at the head of the sea loch and were not observed to move more than 1.5 km from the river mouth during periods of up to 10 days. The area of movement for five post-smolts tracked in the vicinity of the River Ewe is indicated by the movements of the tracking vessel as shown in Figure 3. Boat tracks relating to the individual fish are shown in Figure 4 (a, b, c and d). During periods of flood tide the post-smolts often moved into the littoral zone and generally remained within the cover of the extensive weed beds. Following high tide they moved offshore as the tide ebbed and exposed the intertidal weed beds.

On three occasions when several tagged individuals were released simultaneously (see Table 1) they appeared initially to maintain station together but generally within an hour or so they separated and only selected individuals could then be tracked. However, tagged fish sometimes aggregated in the same general area and up to three tags were detected simultaneously on several occasions. The sea trout post-smolts tended to aggregate in or over deeper water at extreme low water of spring tides when the intertidal reaches were completely exposed. At high tide, they sometimes aggregated close inshore at the mouth of the river.

Fish STS11 and STS12 were intermittently tracked together during a period of over 36 h when continuous contact was maintained with STS12. A third fish, STS6, detected at the end of this track and then recaptured in a sampling net, had been tracked intermittently for over 10 days.

One of the post-smolts from the Sguod Burn displayed a similar initial offshore movement pattern to that described for another fish tracked in the same area during 1993 (Urquhart and Johnstone, 1993). The post-smolt (STS4) initially remained close inshore within the littoral and immediate sublittoral zones (Fig. 5), but then moved offshore across the loch with an ebbing tide, just before dusk, 50 h 37 min after release (Fig. 6). Movement of this fish (STS4) commenced just after the period of slack water following high tide and continued in open water for four hours during the ebb tide. The fish swam with the tidal current at first, but gradually altered course and eventually swam across the flow towards the eastern shore of the loch, then northwards to the mouth of Slaggan Bay. It then moved across the Bay to a sheltered location close inshore where it remained for several hours without extensive movent. While crossing the open water of the sea loch, directional hydrophone observations indicated that the fish may have made contact with the sea bed at a depth of 20 m briefly on one occasion, but generally remained in the upper part of the water column (ie surface to 10 m), while swimming over depths of up to 54 m.

The track obtained for STS4 during the offshore phase (Fig. 6) involved movement at an average ground speed of 21.84 cm s^{-1}. Compensation for tidal flow vectors obtained from drogue measurements (see Smith *et al.*, 1981) allowed a course and true swimming speed (ie relative to the water) to be calculated. The fish displayed an estimated minimum swimming speed of 5.9 cm s^{-1} (0.30 BL s^{-1}) during inshore movement and a maximum of 25.4 cm s^{-1} (1.27 BL s^{1}) when moving offshore. The compensated true course, determined at approximately one hour intervals, is also indicated where appropriate in Figure 6. The fish appeared to swim in open water for most of the ebb tide but moved inshore and north along the coast during slack water and the first few hours of the flood tide until entering and crossing Slaggan Bay. It subsequently remained close inshore amongst the littoral zone for the remainder of the flood tide and until tracking ceased later that day (see Table 1).

Post-smolts at the edge of the sea weed zone at the head of Loch Ewe were sometimes seen to be feeding at the water surface on terrestrial insects. Two acoustically-tagged and 29 untagged sea trout post-smolts were captured by gill-netting in this area. Apart from immediate net damage both tagged fish appeared to be in good condition and the tag attachment points did not show any signs of infection or excessive tissue damage or erosion. Stomach content analysis showed that both tagged post-smolts had been feeding. One contained mainly fish and Crustacea, the other mainly Crustacea and terrestrial insects. The untagged post-smolts examined contained a similar range of dietary items (Fig. 7).

Potential predators observed throughout the period of study included several species of piscivorous birds such as the grey heron (*Ardea cinerea* L.), cormorant (*Phalacrocorax carbo* [L.]), shag (*P. aristotelis* [L.]) and red-breasted merganser (*Mergus serrator* L.) as well as predatory mammals - otter (*Lutra lutra* L.) and both common (*Phoca vitulina* L.) and grey (*Halichoerus grypus* [Fabricius]) seals. Large predatory fish such as saithe (*Pollachius virens* [L.]), cod (*Gadus morhua* L.) and pollack (*P. pollachius* [L.]) are also known to inhabit the loch (Howson, 1991). Interactions with some predators were observed and mainly concerned common seals which appeared to hunt close to the river mouth and in the estuary as well as along the weed beds close inshore at locations where smolts tended to aggregate. On several occasions individual seals were seen to pursue fish at the edge of and through the weed beds close inshore. On one occasion a larger post-smolt was pursued at the water surface for 100 m or so before being captured by a common seal. Avian predators were also commonly observed in the vicinity but it was difficult to determine whether sea trout post-smolts were being preyed on. One post-smolt was seen to be taken from the surface by a greater black-backed gull (*Larus marinus* L.) while a common seal was pursuing fish at the river mouth.

DISCUSSION

The observations made in this study are limited mainly because manual tracking of individual fish is time consuming and labour intensive. Sea state, wind strength and rainfall influence the detection range of the tag signal and poor weather conditions are a major cause of the cessation of tracking activity. The results obtained, however, provide an indication of the range of movements and behaviour of sea trout smolts during the early phase of their existence in the marine environment.

Effects of External Tagging

External tags may affect the swimming performance and stamina of fish due to increased hydrodynamic drag (Arnold and Holford, 1978; Mellas and Haynes, 1985; McCleave and Stred, 1975). Our results demonstrate that the tagged fish were able to swim - in some cases actively upstream - feed and avoid capture by predators. Tagged fish moved through dense weed beds apparently without hindrance. Previous observations with salmon parr just prior to smolting fitted with external "pannier" tags demonstrated that growth and survival was related to fish size. Fish from 10.1 to 18.0 cm in length were adversely affected but fish over 18.0 cm length increased in length and weight with 100% survival at the end of the 15 day period of the experiment (Greenstreet and Morgan, 1989).

It seems likely that at speeds up to about one body length per second the drag of the externally-placed acoustic tag is insignificant. This is consistent with our observations of acoustically-tagged fish in tanks in the company of other untagged fish of similar size and with our observations of their behaviour after release within groups of untagged fish while both remained within sight.

At faster speeds, however, both drag from the fish's body and from the tag increase rapidly in proportion to the velocity squared. For a fish fitted with an external tag more energy will be required to sustain a given swimming speed. In extreme bursts, a lower maximum speed will be attained for a given amount of energy. Tagged fish, however, were not observed to act differently from their untagged neighbours during bursts of fast swimming to avoid capture in a tank, for example, or to escape predators in the wild. This is probably because the onset of rapidly increasing drag is progressive. The fish appeared to react and behave normally although their ability to respond and their swimming performance will undoubtedly be compromised to some extent.

Fish Movements

During the study, all of the acoustically-tagged smolts which stayed in salt water after release at the head of Loch Ewe remained within 1.5 km of the river mouth (Fig. 4) although one fish (STS9; Fig. 4c) moved more extensively within this area than the others. For the initial few days of their marine life the post-smolts exhibited a restricted local migration and distribution pattern as found in conventional tag-recapture studies (Berg and Berg, 1987). Three other tagged fish (STS1, STS2 and STS3) returned almost immediately to fresh water and were then lost due to the acoustic disturbance of the turbulent river flow. These latter observations indicate that the fish were able to select their preferred environment after release since the post-smolts had access to a range of environmental conditions.

In contrast with the localised movements of the fish tracked from the mouth of the River Ewe, one of those released at the mouth of the Sguod Burn (STS4), moved across and out to a bay at the mouth of Loch Ewe. During the period of open water migration the tracked smolt generally appeared to swim in the upper part of the water column although on one occasion the fish possibly made brief contact with the bottom at 20 m. The first few hours of this offshore movement was generally with the direction of the tide and course vectors are shown where available in Figure 6. Estuarine movements of sea trout smolts generally occurred during an ebbing tide (Moore and Potter, 1994). The start of the offshore movement out of Firemore Bay displayed by STS4 appeared to coincide with the start of the ebb tidal flow. This sea trout smolt, although swimming with the tide for the initial part of the track, actively swam inshore, across the direction of the current after several hours. Observations of adult Atlantic salmon movements at sea have indicated that they are capable of maintaining a constant heading despite the influence of the tide (Smith *et al.*, 1981); however, the method of detection of flow direction and velocity by a fish in a pelagic habitat is unknown.

Another post-smolt tracked from the mouth of the Sguod Burn during 1993 also moved offshore across the loch initially on an ebbing tide (Urquhart and Johnstone, 1993). Moore and Potter (1994) found that the movement of sea trout smolts through the estuary of the River Avon was predominantly nocturnal and occurred mainly during ebb tides, or periods of slack water. They suggested that nocturnal movement during ebb tidal flows may be an effective means of migration away from the concentrations of predators in estuaries.

Many potential predators of post-smolts were observed at the mouth of the River Ewe during the present study, although the extent of their predation could not be ascertained. Jonsson *et al.* (1994) considered the possible effects of heavy predation upon "ranched" brown trout smolts passing through Norwegian estuaries. However, they found no difference in the survival rates of trout released at sea compared with releases in rivers or fjords. They suggested that the lack of difference in survival rates may be because the trout released at sea may have returned to the same habitat as those released in the estuaries.

Svärdson and Fagerström (1982) found from tag recapture information that four stocks of sea trout smolts of hatchery-reared and wild origin behaved differently when released in the Baltic Sea. Most of the wild smolts (14-19 cm total length) distributed slowly along the coast during the first three months, while a few returned to the river and others swam further offshore. There was a tendency for greater dispersion with time and by the autumn some trout returned to the river at an average length of 38 cm.

Pemberton (1976a) suggested that sea trout post-smolts left the localised areas in Argyllshire sea lochs (north western Scotland) which they initially inhabited and moved into the open sea from July onwards, returning to the rivers in October to November. Pratten and Shearer (1983) reported large numbers of finnock (post-smolt sea trout) migrating upstream from July onwards, with a peak of movement in the autumn, through a trap on the River North Esk, on the east coast of Scotland. In reviewing UK and Irish information on sea trout, Le Cren (1985) noted that immature and mature finnock usually run into the fresh water environment later than older sea trout and generally between July and September. In recent years, however, large numbers of post-smolts have been observed and sampled returning to north western Scottish and western Irish rivers during May and June. This has been attributed to infestation with the ectoparasitic sea louse (*Lepeophtheirus salmonis* [Krøyer]) and the movements of sea trout post-smolts in relation to sea louse infestation is discussed by Johnstone *et al.* (in press).

One factor triggering more extensive movements may be prey availability. In his study of sea trout in Argyllshire sea lochs, Pemberton (1976b) found that as post-smolts grow they change from a mainly crustacean and insect diet to one dominated by fish such as sandeels (*Ammodytes* spp), sprat (*Sprattus sprattus* L.) and juvenile herring (*Clupea harengus* L.). Their increased consumption of fish may result from a tendency to select larger food items as a consequence of increasing body size, or it may be because more fish become available as prey in the sea lochs during the summer and early autumn. Post-smolt sea trout may then begin to forage more widely in search of shoals of small fish.

Sea trout smolts migrating from the Sguod Burn into the open sand substrate and rocky shore habitat in Firemore Bay may subsequently migrate further to find an environment which provides better shelter from predators and/or a more appropriate food supply. This may explain the offshore movements of acoustically-tagged post-smolts from Firemore Bay.

There may be an even more marked difference in behaviour between migrating salmon and sea trout smolts. No salmon smolts were sampled when netting at the mouth of the River Ewe, even though many were sampled in the river during electro-fishing and trapping exercises. It seems likely that salmon smolts move rapidly away from shore on initial entry to the marine environment whereas sea trout remain inshore (Jonsson *et al.*, 1994), although recent evidence of dietary components of salmon post-smolts indicates that, at least initially, a proportion of their prey is obtained from the inshore zone (Levings *et al.*, 1994). A valuable extension of the present studies would be to compare the behaviour of both species during their early days in the sea, since so little is known of their movements and ecology during this critical period for their survival.

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TABLE 1

Details of the sea trout smolts fitted with acoustic transmitters and tracked in Loch Ewe, Scotland

Fish number	STS1/94	STS2/94	STS3/94	STS4/94	STS5/94	STS6/94
Length (cm)	23.0	25.8	19.5	20.0	19.2	18.1
Weight (g)	92.64	130.1	73.4	85.0	63.3	65.0
Time (GMT) and date caught	1500 h 03 05 94	1500 h 03 05 94	1530 h 09 05 94	1045 h 10 05 94	1600 h 18 05 94	1900 h 21 05 94
Location	River Ewe, electro-fished above bridge	River Ewe, trap above bridge	Sguod sea pool, electro-fished	Sguod sea pool, electro-fished	River Ewe, electro-fished above bridge	River Ewe, electro-fished above bridge
Time (GMT) and date tagged	0810 h 04 05 94	1300 h 04 05 94	1600 h 09 05 94	1115 h 10 05 94	1920 h 18 05 94	0908 h 22 05 94
No of companions	4	7	3	12	9	8
Time (GMT) and date released	1110 h 04 05 94	1430 h 04 05 94	1920 h 09 05 94	1912 h 11 05 94	2057 h 18 05 94	2104 h 22 05 94
Time (GMT) of high tide	1511 h	1511 h	1821 h	1920 h	0047 h (19 05 94)	1647 h
Location	Mouth of River Ewe	River Ewe estuary	Mouth of Sguod burn	Mouth of Sguod burn	Mouth of River Ewe	Mouth of River Ewe
Nominal (actual) tag frequency (kHz)	74.0 (74.3)	82.0 (82.4)	78.0 (78.2)	86.0 (86.7)	80.0 (81.3)	70.0 (70.4)
Tracking stopped	1216 h 04 05 94	2040 h 04 05 94	0030 h 10 05 94	1533 h 14 05 94	0615 h 21 05 94	0604 h 23 05 94
Location	River Ewe sea pool	River Ewe estuary	Mouth of Sguod burn	Slaggan point	Inverewe point	River Ewe estuary
Track duration	1 h 06 min	6 h 10 min	5 h 10 min	68 h 21 min	57 h 18 min	9 h 0 min

TABLE 1 (continued)

Fish number	STS7/94	STS8/94	STS9/94	STS10/94	STS11/94	STS12/94
Length (cm)	18.7	19.6	21.3	22.5	18.0	19.3
Weight (g)	60.0	73.0	93.7	108.5	55.0	70.0
Time (GMT) and date caught	1900 h 21 05 94	1900 h 21 05 94	1400 h 24 05 94	1400 h 24 05 94	1100 h 31 05 94	1100 h 31 05 94
Location	River Ewe, electro-fished above bridge	River Ewe, electro-fished above bridge	Inverewe Bay, gill net	Inverewe Bay, gill net	Lady's Pool, River Ewe, rod caught	Lady's Pool, River Ewe, rod caught
Time (GMT) and date tagged	0905 h 22 05 94	0902 h 22 05 94	1830 h 24 05 94	1830 h 24 05 94	1335 h 31 05 94	1339 h 31 05 94
No of companions	8	8	1	1	7	7
Time (GMT) and date released	2104 h 22 05 94	2104 h 22 05 94	2117 h 24 05 94	2117 h 24 05 94	2035 h 31 05 94	2035 h 31 05 94
Time (GMT) of high tide	1647 h	1647 h	1812 h	1812 h	0012 h (01 06 94)	0012 h (01 06 94)
Location	Mouth of River Ewe	Mouth of River Ewe	Inverewe Bay, capture point	Inverewe Bay, capture point	Mouth of River Ewe	Mouth of River Ewe
Nominal (actual) tag frequency (kHz)	76.0 (76.6)	84.0 (84.5)	72.0 (73.3)	74.0 (74.7)	70.0 (71.4)	76.0 (77.8)
Tracking stopped	0845 h 23 05 94	0724 h 23 05 94	0415 h 27 05 94	2249 h 24 05 94	0840 h 02 06 94	0840 h 02 06 94
Location	Off Stage House	Shore at head of Loch Ewe	Shore near village hall	Near release point	Inverewe Bay	Inverewe Bay
Track duration	11 h 41 min	10 h 20 min	55 h 58 min	1 h 22 min	36 h 05 min	36 h 05 min

TABLE 2

Evaluation of the range for detection of a 75.3 kHz acoustic tag suspended 1 m above the sea bed in a water depth of 5 m

a) Sea state 2 moderate northeast wind. Ultrasonic transmitter in open water close to shore

Distance from acoustic tag (m)	Receiver attenuation (dB)	Comments
77	-20	Detectable but faint signal
109	-20	Borderline for signal detection
143	-20	Limit of detection, only occasional pulses heard
259	0	Detectable
411	0	50% of pulses detected
459	0	Only occasional pulses heard

b) Sea state 5, fresh northeast wind, wave crests breaking. Ultrasonic transmitter a kelp (*Laminaria* spp) forest close to shore

Distance from acoustic tag (m)	Receiver attenuation (dB)	Comments
19	-20	Easily detected
74	-20	Signal detection less than 50%
96	0	Faint signal but all pulses audible
202	0	Limit of detection against high background noise

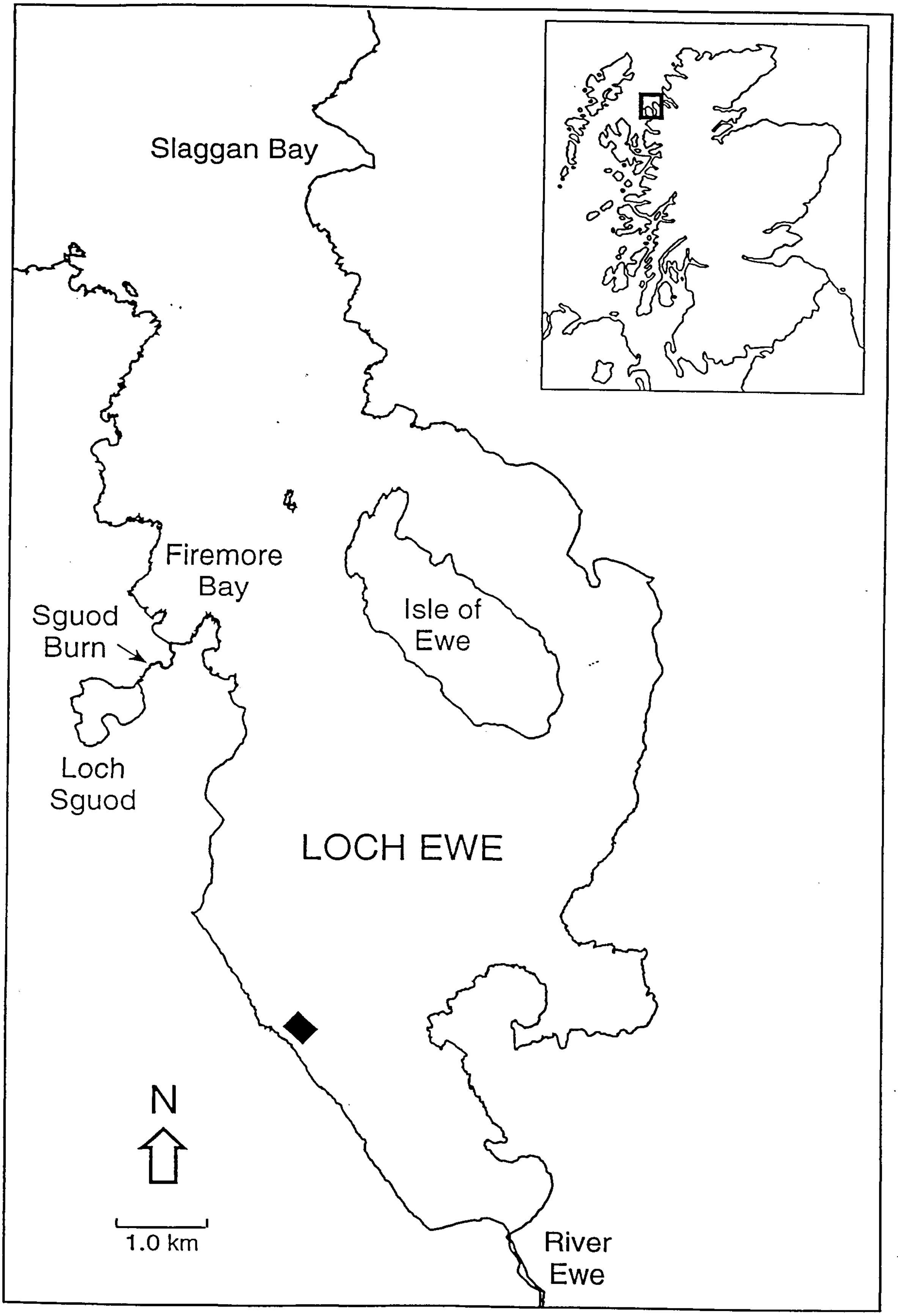

Figure 1 The location of the study sites in Loch Ewe, Ross-shire, on the west coast of Scotland. The River Ewe and the Sguod Burn are shown and the position of the recording current meter mooring at the head of the sea loch is indicated (■).

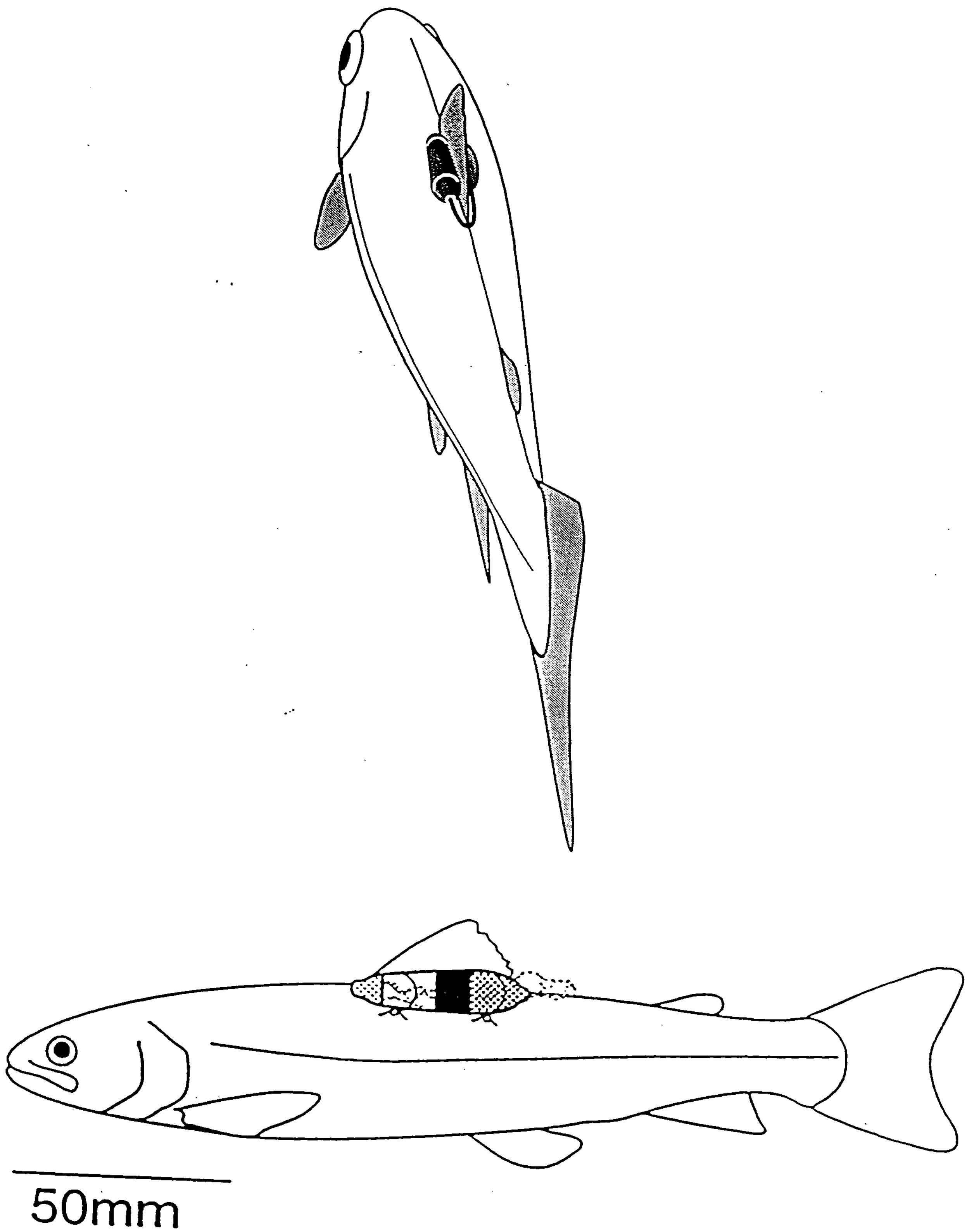

Figure 2 Drawings of a "pannier" acoustic transmitter attached to a sea trout smolt.

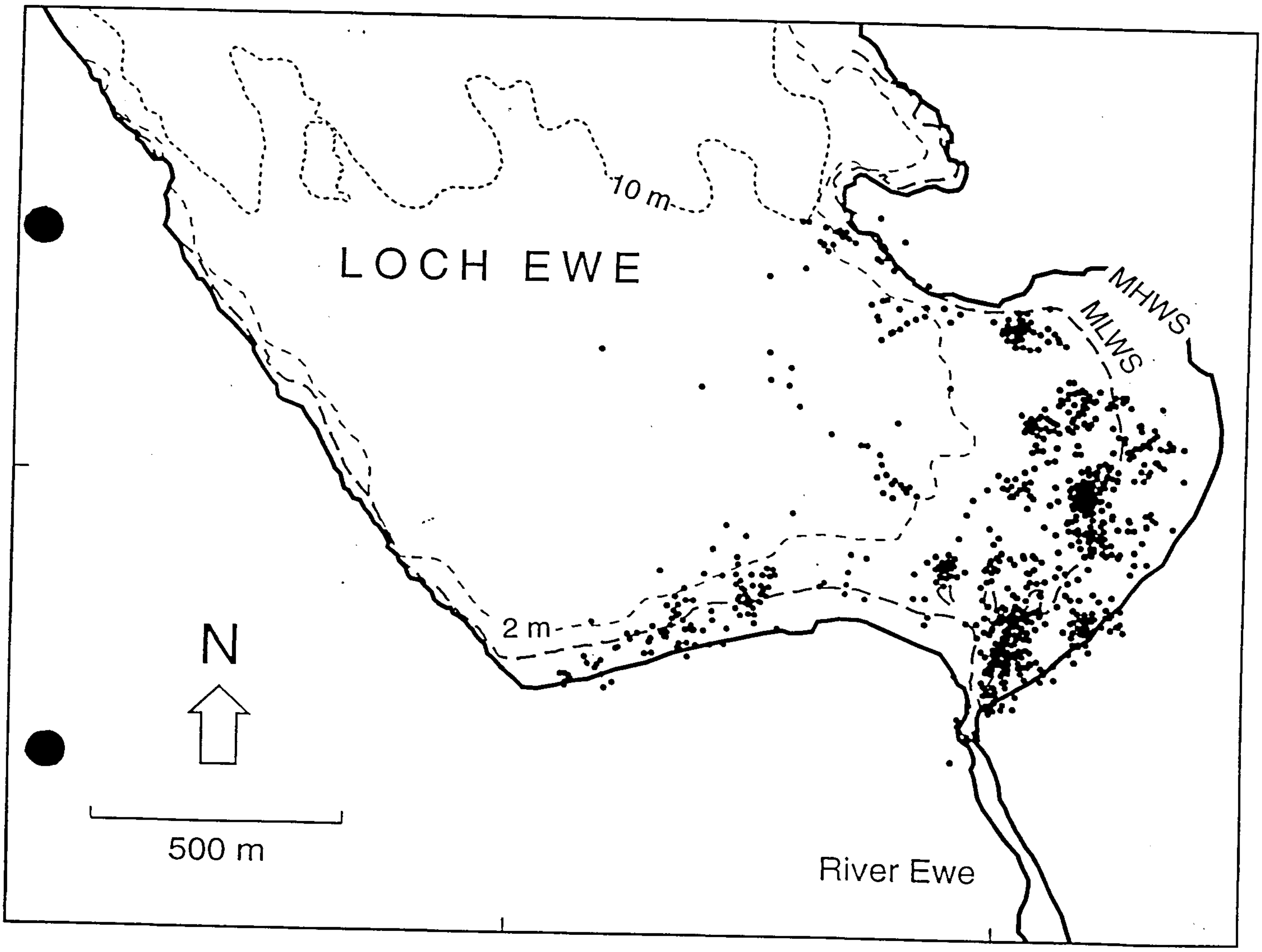

Figure 3 Boat positions, determined by GPS, representing the collective area of movements for five sea trout post-smolts, fitted with external acoustic tags. The fish were tracked at the head of Loch Ewe after release at the mouth of the River Ewe. Each point represents a position logged at 15 minute intervals.

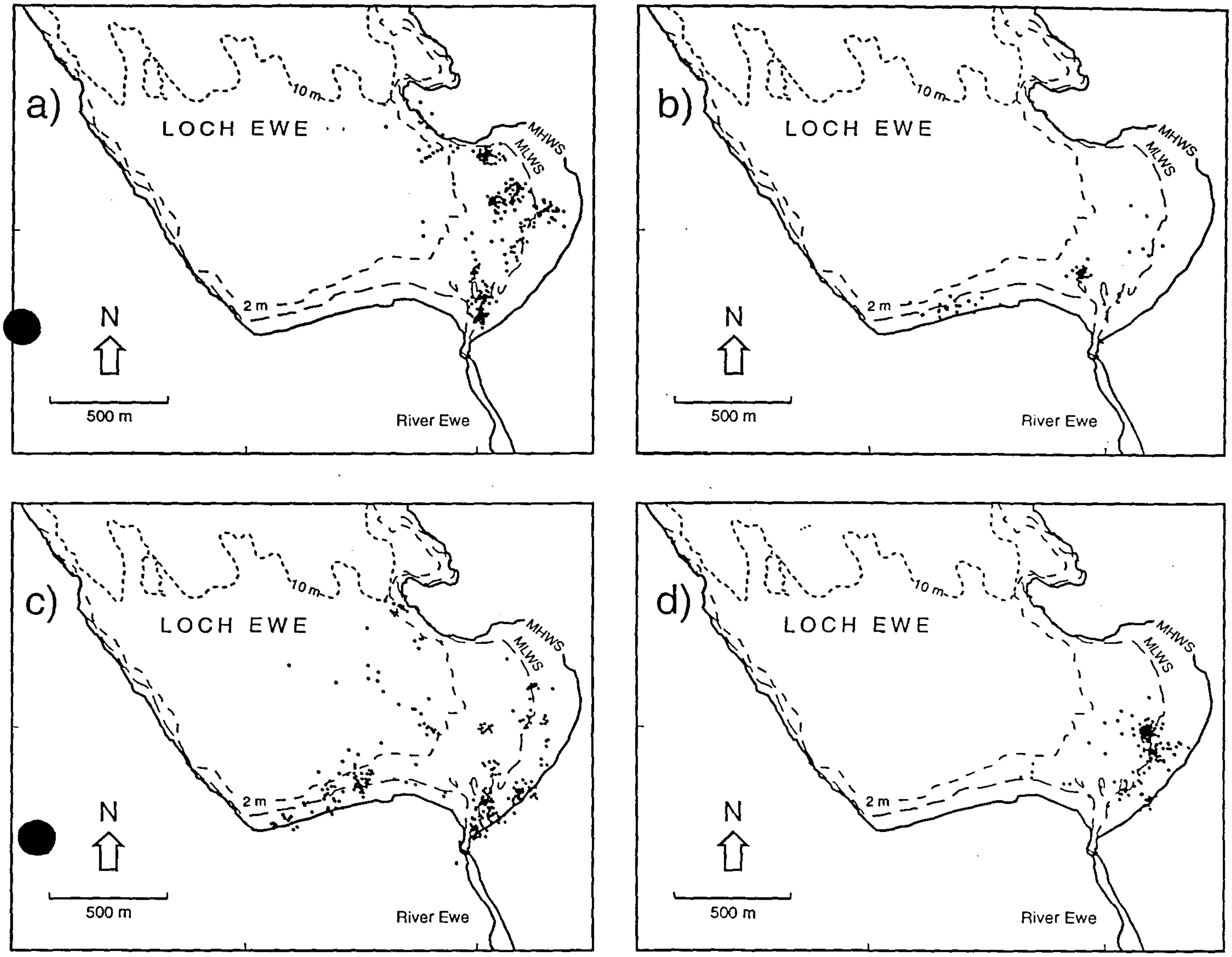

Figure 4 Boat positions, determined by GPS, for sea trout smolts fitted with external acoustic tags tracked at the head of Loch Ewe. a) STS5; b) STS6; c) STS9; d) Two smolts (STS11 and STS12) were followed simultaneously for part of the track.

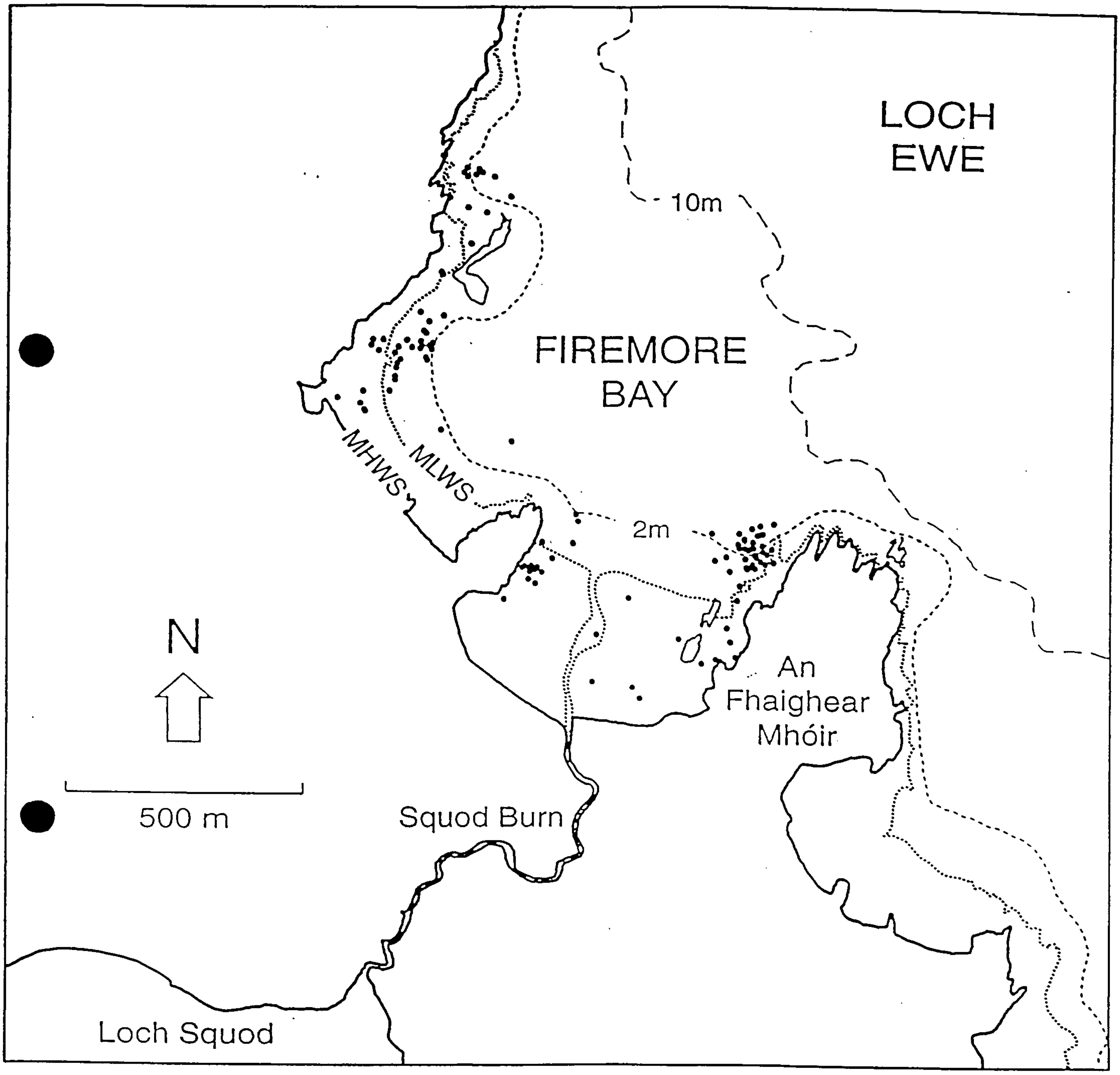

Figure 5 The boat track obtained for a tagged sea trout smolt released at the mouth of the Sguod Burn in Firemore Bay, Loch Ewe. The track duration during this period of inshore movement was 50 h 37 min.

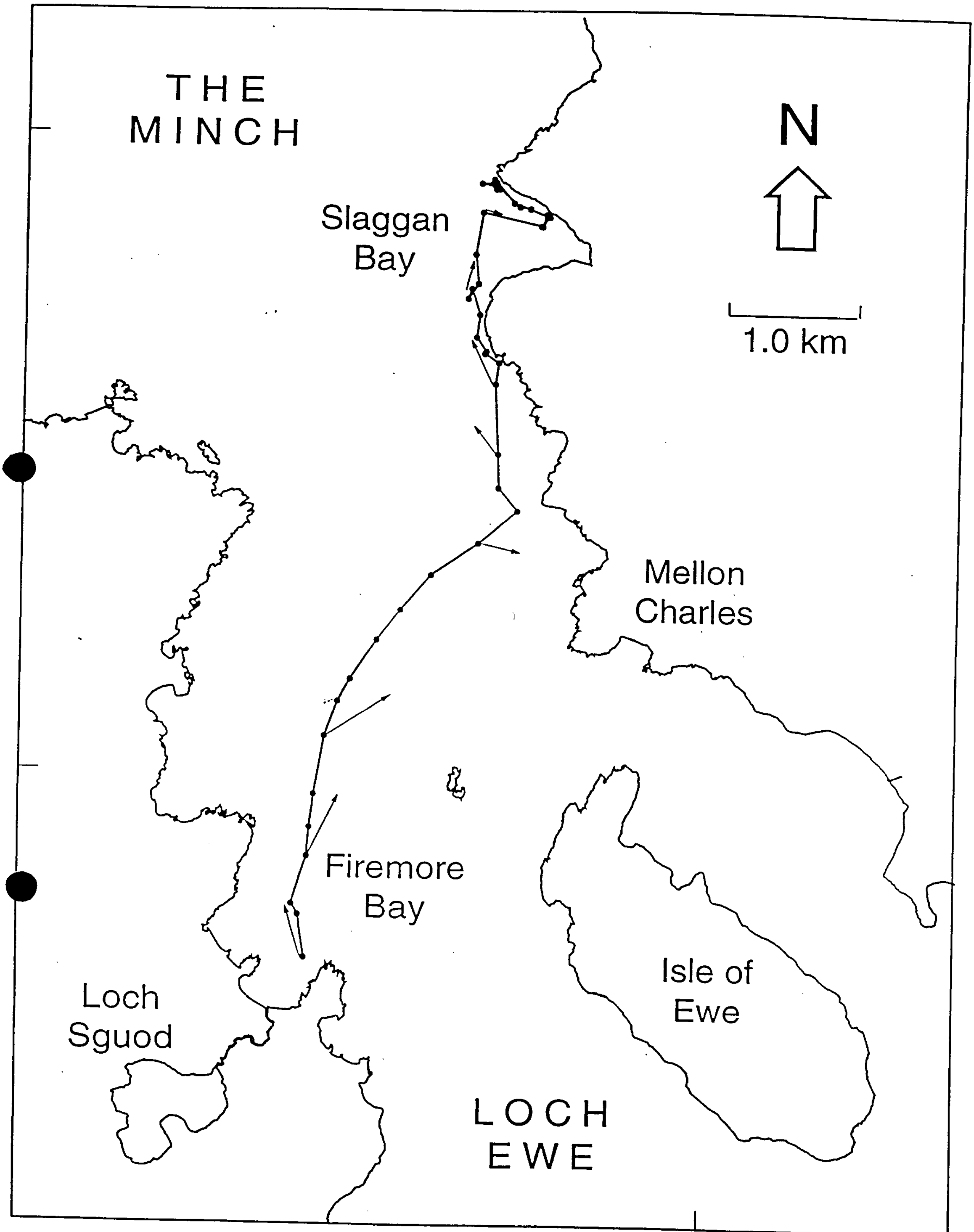

Figure 6 The boat track showing the movement of a tagged sea trout smolt (STS4) across Loch Ewe to Slaggan Bay during the period 21:49 on 13 May to 17:33 on 14 May 1994. The arrows indicate corrected course vectors for the fish at intervals during the track. The length of each arrow is proportional to estimated swimming speed through water which varied from a minimum of 5.9 cm s^{-1} to a maximum value of 25.4 cm s^{-1} .

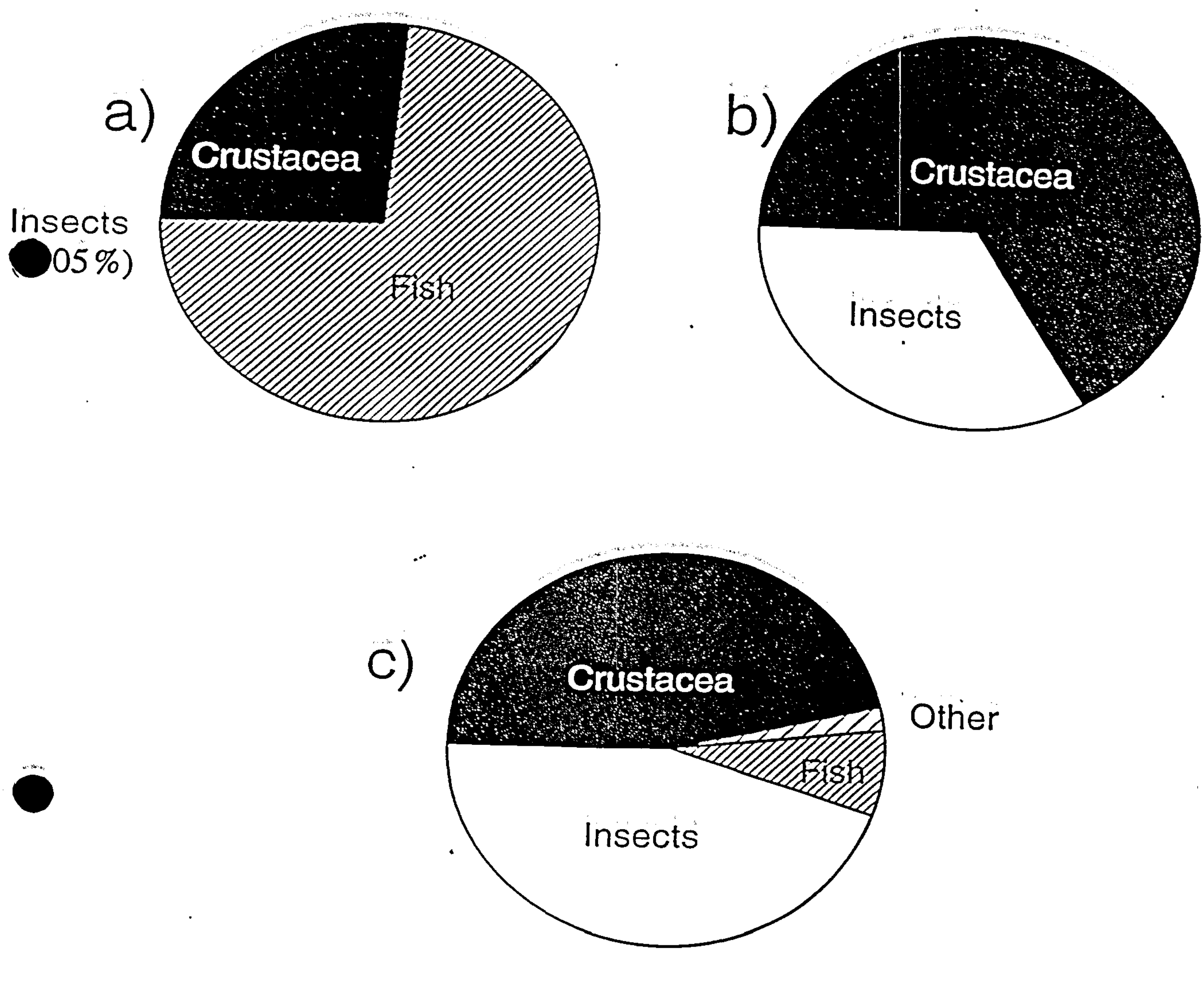

Figure 7 A comparison of the stomach contents of sea trout post-smolts sampled from the head of Loch Ewe. Two fish with acoustic tags were deliberately recaptured during the sampling exercise for physical examination and to determine whether they had been feeding. The proportion by weight of the main food components in the stomach contents are shown for each of the tagged post-smolts, a) STS6; b) STS9, and the control group c), (n = 29).