# Development and evaluation of a flat-bed passive integrated transponder detection system for recording movement of lowland river fishes through a baffled pass

Martyn C. Lucas[1,*], Tom Mercer[1], Shaun McGinty[2] and John D. Armstrong[3]

[1] *University of Durham, Department of Biological Sciences, South Road, Durham DH1 3LE, UK*

[2] *Environment Agency, North East Region, Coverdale House, Aviator Court, Amy Johnson Way, Clifton Moor, York YO30 4GZ, UK*

[3] *Freshwater Fisheries Laboratory, Faskally, Pitlochry, Perthshire PH16 5LB, UK*

* *Corresponding author.*

*Email: m.c.lucas@durham.ac.uk*

*Key words*: passive integrated transponder; fish pass; lowland river; Cyprinidae

## Abstract

The migratory behaviour of non-salmonid fishes in lowland rivers is still poorly understood, as is their success in using fish passes to allow upstream movement. The use of an automated flat-bed passive integrated transponder (PIT) detector array to study behaviour of fish at a baffled flume pass on the Yorkshire Derwent, North East England, is described. The array comprised four flat PIT detector plates, each connected to a control unit. Two detectors were positioned at the downstream end of the fish pass, and two at the upstream end. Control units sent interrogation signals, received transponded signals from tags, and stored the data. Efficiency of the upstream detectors was validated as near 100% using tagged brown trout (*Salmo trutta*) introduced below the detectors and observed to swim past them. Between 22 May 1998 and 9 April 1999 a total of 401 fish, comprising 11 species with a combined length range of 9-104 cm, were PIT tagged and released downstream of the fish pass. Near-continuous recording between 23 May 1998 and 31 May 1999 demonstrated the effectiveness of the PIT array at this site for recording entry to, and successful exit, of fishes from the pass. A total of 1271 records from 90 individual fish were recorded at the downstream detectors, and 20 tagged fish were recorded successfully exiting from the top of the pass, giving a pass efficiency of 22.2 %, based on the proportion of different fish which ascended. Overall 22.4 % of tagged fish entered the pass, comprising chub (*Leuciscus cephalus*), dace (*Leuciscus leuciscus*), roach (*Rutilus rutilus*), bleak (*Alburnus alburnus*), perch (*Perca fluviatilis*), pike (*Esox lucius*) and brown trout, with highest numbers in May and June.

## Introduction

There is increasing recognition that in lowland European rivers many non-salmonid fish species exhibit substantial ranging and migratory movements (e.g. Langford *et al.*, 1979; Baras & Cherry, 1990; Baras & Philippart, 1996; Lucas *et al.*, 1998a; Northcote, 1998; Baade & Fredrich, 1999; Clough *et al.*, 1999). Rheophilic cyprinids such as barbel (*Barbus barbus*), chub (*Leuciscus cephalus*), dace (*Leuciscus leuciscus*) and nase (*Chondrostoma nasus*) tend to move upstream in spring to find appropriate spawning habitat, and may travel tens of kilometres in the process (Lelek, 1987; Lucas & Batley, 1996; Lucas *et al.*, 1998b). In winter many fish, including juveniles, move downstream (Lucas *et al.*, 1998b) to seek refuge, or are displaced in high flows. Patterns of space use may also occur over shorter time scales, with species such as dace and roach often making regular diel migrations between distinct sites (Clough & Ladle, 1997; Baade & Fredrich, 1999). There is growing evidence that even very young fish, including cyprinids, exhibit diel and seasonal movements (Copp & Jurajda, 1993; Baras & Philippart, 1996).

Many of these advances in our knowledge have been made as a result of radio and acoustic tracking of these species. However, these techniques tend to be limited to fish larger than about 20 g (Martinelli *et al.*, 1998) while the logistics and economics of most projects normally means that fewer than 50 fish of one or two species are tracked in a study (Lucas, 2000). By contrast, passive integrated transponder (PIT) tags (Prentice *et al.*, 1990) are commercially available in sizes of < 0.1 g, enabling attachment to fish as small as 1 g (Prentice *et al.*, 1990) and certainly less than 5 g, with little ill effect (Baras *et al.*, in press). Intraperitoneal placement of PIT tags does not appear to have a major effect on very small fishes, although growth may be impaired until abdominal incisions have healed (Baras *et al.*, 1999). Passive integrated transponder tags contain a microchip but no battery, and are energised by a low frequency magnetic field emitted by the detector, triggering the tag to transmit its unique identity code. Since the number of different PIT codes is in the order of $3 \times 10^{10}$ and because the cost of a PIT tag is about 5% of that of a radio tag, it is easier to tag much larger samples of fish with PIT tags than with radio tags. The technique, therefore, has great potential for simultaneous study of the behaviour of a wide range of sizes and species of fish as typically occur in lowland rivers. Moreover, because PIT tags contain no battery they have, in practical terms, a near-infinite life. The principal disadvantage of the system is that it relies on electromagnetic induction and therefore range is extremely limited, and typically <0.3 m for tags of the size described above.

Although it is currently not feasible for automated PIT detection systems to log the presence and identity of fish across the full width of a river channel, it is possible to monitor movement through restricted routes. Passive integrated transponder systems have been used for several years to detect tagged fish passing through induction coils, typically with the coil housed around a cylindrical pipe (Prentice *et al.*, 1990) or rectangular frame (Adams and Schwevers, 1997). More recently, flat-bed PIT detectors (Armstrong *et al.*, 1996) have been used in behavioural studies on juvenile Atlantic salmon (*Salmo salar*) in narrow streams (Armstrong *et al.*, 1997; Armstrong *et al.*, 1998) and on stone loach (*Barbatula barbatulus*) in artificial streams (MacKenzie & Greenberg, 1998). They have also been used to monitor downstream movements of juvenile salmonids in the Columbia River system (Nunnallee *et al.*, 1998). In lowland rivers, fish passes present a restricted environment in which automated PIT detection may allow entry of tagged fish into the pass to be monitored as a measure of upstream-directed migration, as well as providing the possibility of measuring efficiency of passage. Castro-Santos *et al.* (1996) reported successful laboratory trials in measuring fish passage with a PIT detector array in an experimental baffle fish pass. Detection coils were formed on baffle plates placed at several positions, including baffles at the downstream and upstream ends of the pass. In order to assess effectiveness of bypass routes Adams & Schwevers (1997) have used mesh screens to force fish to swim through frame-shaped PIT detectors at the pass entrance and exit. Here we report on the development and use of a flat-bed PIT detector array installed in a fish pass in a lowland river.

## Materials and Methods

### *Study site*

The study site was a fish pass at Stamford Bridge weir on the Yorkshire Derwent, NE England (53° 59' N, 0° 55' W). Immediately downstream of the weir, the river is shallow (mostly < 1m, summer level), with patches of gravel bed, and luxuriant, submerged macrophyte growth (mainly *Ranunculus* sp.) in summer. This reach of the river is substantially impounded, with weirs 5 km below and 3 km above Stamford Bridge weir. These areas are characteristic of the middle and lower Derwent: 2-3 m deep with little in-stream habitat diversity (Whitton & Lucas, 1997). The fish community is dominated by riverine cyprinids; particularly chub and dace, which are lithophilic (gravel) spawners and often undergo spawning migrations (Lucas *et al.*, 1998b; Lucas *et al.*, in press a). These, and other species, aggregate and spawn in the weir pool in spring, but prior to the building of a fish pass in 1996, they could not move further upstream.

In order to aid fish migration within the Derwent several fish passes have been added by the Environment Agency in recent years, including one at Stamford

Bridge, built in 1996. The pass is sited on the west side of Stamford Bridge weir, which is impassable to non-salmonid species, and would also provide a substantial impediment to adult salmonids. A canal, ~300 m in length, bypasses the weir, but this has a vertical 1 m sluice, making upstream passage impossible by this route. The fish pass is of a Denil-type baffled flume design, 10 m long, 0.9 m wide and with a gradient of 1:5. At typical flows, the pass has a depth of 1.0 m in the downstream entrance area, and a depth of 0.60 m at the upstream exit. Catches of fish at the upstream exit in May 1997, made using a modified fyke net comprised 80 fish, mostly dace, confirming that some fish can ascend the pass.

*The PIT detector array*

The PIT detector array used in the fish-pass followed the principle of Castro-Santos *et al.* (1996) of placing detectors at several positions including the downstream and upstream ends of a fish pass, and was based upon the flat-bed design of Armstrong *et al.* (1996). The flat-bed design (UKID Systems, Preston, UK), using a coil embedded in a 2 cm thick plate, is capable of detecting small commercially available low-range PIT tags across the whole width of a typical baffled fish pass and operates at 125 kHz. Tags used were Trovan ID100 (11.7 mm x 1.9 mm, 0.10 g in air). Nominal peak range of detection in water of a typical tag over a single antenna, 0.90 m wide, was 0.18 m, occurring in the midline near each of the ends. In order to improve interrogation of the whole water column, pairs of vertically-spaced detectors were used. A multiplex phase-locking system (UKID Systems) was used to enable detectors to be placed in close proximity with minimal signal interference. Even so, position of detectors relative to each other influenced measured range by comparison to control measurements made from the same units independently. By placing the leading edge of one detector, with long axis spanning the fish pass, in line with the rear edge of another (Figure 1), ranges of individual detectors could be improved to 0.20+ m occurring at each end and 0.15 m in the middle. The depth coverage was therefore increased to 0.60+ m ([0.15 m x 2] x 2).

On 22/23 May 1998, pairs of detectors were installed at the downstream and upstream ends of the fish pass, using wooden battens to secure the units against the concrete walls of the pass. Detectors were placed at least 1.0 m from the nearest steel baffle to prevent interference. The vertical positions of detectors were adjusted to maximize effective monitoring of the full depth range (Figure 1). For the upstream pair of detectors (numbers 3 and 4), complete coverage of the pass cross section area was achieved. For the downstream pair (detectors 1 and 2), the top 0.3 m of water was not interrogated. However, the surface-water downstream of the baffles is extremely turbulent and likely to be avoided by non-salmonid fish. Water

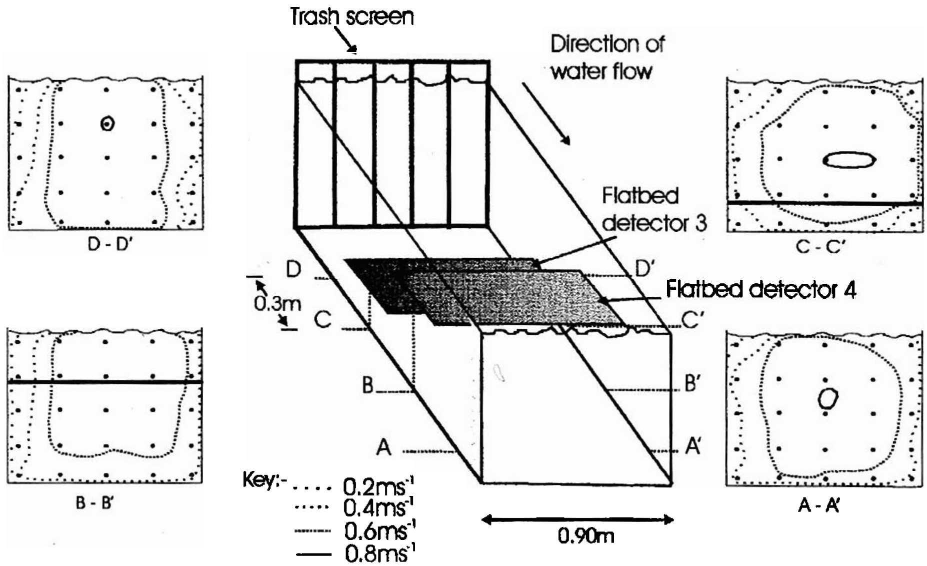


*Figure 1.* Orientation and relative position of the pair of flat-bed passive integrated transponder (PIT) detectors (numbers 3 and 4) at the upstream end of the fish pass, together with water velocity profiles around them.

velocities around the detectors were measured under summer flows using an Ott velocity meter. Cables carrying interrogation and detection signals were relayed into a mains-supplied weatherproof cabinet. Each detector was attached to a power supply and high-sensitivity decoder unit (UKID single point decoder). Records were stored by memory chips and were periodically downloaded onto a portable laptop computer. A coarse screen (0.3 x 0.2 m grid) at the upstream exit prevented large debris clogging the pass or damaging the PIT detectors.

Efficiency of the upstream detectors was measured using twenty intraperitoneally PIT-tagged brown trout (*Salmo trutta*), 28-38 cm fork length, introduced below detectors 3 and 4, and observed to swim past them. The trout were externally marked with white streamer tags to enable observation. A mesh barrier prevented downstream escape of the experimental fish, and a temporary trap at the upstream exit enabled their recapture after passing the upstream detectors. All twenty fish were recorded by at least one of the detectors, giving an efficiency of detection of 100%. While acknowledging that this was a small sample, the true efficiency under similar conditions can reasonably be expected to be close to this figure. It was logistically impossible to introduce PIT tagged fish to the deep, turbulent downstream section of the fish pass and observe their movements in order to calibrate detection efficiency of detectors 1 and 2. Records of entry by PIT tagged fish must therefore be regarded as conservative. For the duration of the study, the effectiveness of each detector was periodically tested using a tag mounted on the tip of a wooden pole or using a tagged dead fish attached to a line.

*Fish tagging and data collection*

Between 22 May 1998 and 9 April 1999 a total of 401 fish, comprising 11 species and a length range of 9-104 cm, were PIT tagged and released downstream of the fish pass (Table 1). Species tagged were chub, dace, barbel, brown trout, grayling (*Thymallus thymallus*), roach (*Rutilus rutilus*), bleak (*Alburnus alburnus*), gudgeon (*Gobio gobio*), pike (*Esox lucius*), perch (*Perca fluviatilis*) and ruffe (*Gymnocephalus cernua*). Most of the fish tagged were cyprinids, chub, dace and roach. Fish mostly larger than 20 cm were tagged intraperitoneally from the ventral surface, using a tagging gun and tags pre-mounted in sterile hypodermic syringe needles. Smaller fish were tagged by making a 3 mm incision through the abdominal wall using a sterile scalpel, and inserting the tag into the abdominal

Table 1. *Details of the species, numbers, sizes (fork length, FL) and sources of fish to which PIT tags were attached in this study.*

| Species | Source | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Downstream of weir, 22/05/98 ($n$ = 117) 23/06/98 ($n$ = 91) 15/01/99 ($n$ = 2) 09/04/99 ($n$ = 31) | | | Hatchery reared, 29/05/98 ($n$ = 71) 30/09/98 ($n$ = 31) | | | Upstream of weir, 23/06/98 ($n$ = 10) 16/09/98 ($n$ = 48) | | | |
| | $n$ | FL (cm) | | $n$ | FL (cm) | | $n$ | FL (cm) | | Total no |
| | | $\bar{x}$ | range | | $\bar{x}$ | range | | $\bar{x}$ | range | |
| Brown trout | 3 | 18.3 | 17-21 | 31 | 33.1 | 29-41 | 1 | 18 | 18 | 35 |
| Grayling | 2 | 22.0 | 21-23 | - | - | | 1 | 30 | 30 | 3 |
| Pike | 20 | 73.5 | 52-104 | - | - | - | - | - | - | 20 |
| Chub | 63 | 37.5 | 10-58 | 23 | 13.7 | 11-19 | 18 | 38.2 | 30-46 | 104 |
| Dace | 37 | 15.3 | 10-19 | 47 | 12.3 | 12-14 | 21 | 15.7 | 11-18 | 105 |
| Roach | 59 | 17.9 | 10-30 | 1 | 12 | 12 | 13 | 16.4 | 12-24 | 73 |
| Barbel | 7 | 44.4 | 16-60 | - | - | - | - | | - | 7 |
| Bleak | 17 | 12.5 | 11-14 | - | - | | - | - | - | 17 |
| Gudgeon | 14 | 11.0 | 9-13 | - | - | | 1 | 12 | 12 | 15 |
| Perch | 14 | 18.9 | 12-26 | - | - | | 3 | 27.3 | 19-32 | 17 |
| Ruffe | 5 | 11.2 | 9-13 | - | - | | | | | 5 |
| Total no. / FL | 241 | 27.2 | 9-104 | 102 | 19.0 | 11-41 | 58 | 23.7 | 11-46 | 401 |

cavity using a sterile plunger, formed from a modified seeker. All tagging was carried out under light anaesthesia, using a 0.1 g $l^{-1}$ solution of buffered MS222. Fish were also measured and, to enable future external recognition of PIT tagged fish, were dye-marked with alcian blue on the ventral surface using a Panjet marker with soft spring. Three treatment groups of fish were used (Table 1): first, 241 fish of mixed sizes and species, captured by electric-fishing < 0.5 km downstream of the weir; second, 102 hatchery-reared fish (71 juvenile cyprinids, 31 adult brown trout); and third, 58 fish, mostly chub, dace and roach, captured 0-3 km upstream of the weir. All fish were released 100 m below Stamford Bridge weir. Based on other studies of cyprinid displacement (Stott *et al.*, 1963; Lucas *et al.*, 2000), it was expected that the displaced fish would have a tendency to attempt to home upstream. A subsample of pike ($n$ = 9, FL 45-79 cm), chub ($n$ = 4, FL 40-47 cm) and barbel ($n$ = 1, FL 56 cm) captured below the weir in 1999 were also radio-tagged to enable their movements to be tracked and to provide independent information on entry to the fish pass. Tags (Biotrack TW-3, 173 MHz) enclosed in polycarbonate cases were surgically implanted following the procedures described by Lucas & Batley (1996). A programmable scanning-receiver (Mariner M58 prototype) and low-gain dipole antenna positioned above water level in the fish pass were used to log radio-tagged fish entering the fish pass. Tests showed that because of the screening effect of the concrete pass, radio tags present in the fish pass outflow were not detected whereas those in the fish pass were recorded in > 95% of tests.

Water temperature and river discharge were recorded throughout the study. Temperature was recorded every 30 minutes using a programmable, submersible logger (Tinytalk, Orion Instruments). River discharge data were obtained from Environment Agency hydrographic records collected at Buttercrambe, 3 km upstream. Passive integrated transponder data were logged continuously between 23 May 1998 and 7 March 1999. A large flood on 6 March 1999 cut power and prevented access to the site until 20 March 1999. Some damage to the equipment occurred, requiring servicing of two decoders. However continuous monitoring of detectors 1, 3 and 4 recommenced on 24 March 1999 and monitoring of detector 2 resumed on 30 April 1999. Thus although monitoring of the fish pass entrance was reduced, the exit was fully monitored, providing complete information on the successful passage of tagged fish for all but the period 6-24 March 1999. Moreover, because preliminary data showed that most records were obtained at the detectors lowest in the water column (Lucas *et al.*, 1999), detector 1 can be expected to have recorded a high proportion of entries over the period during which only three detectors were operating. Range and sensitivity of the detectors did not appear to be significantly altered following the March 1999 flood.

## Results

During the period 23 May 1998 – 31 May 1999 a total of 1271 records were obtained in the fish pass from 90 tagged fish, comprising chub, roach, dace, bleak, perch, pike and brown trout. However, some 601 records (47.3% of total) were recorded from two adult brown trout, for which many detections occurred as a result of persistent presence in the lower part of the fish pass (Figure 2). However, no other fish species was recorded in the fish pass for extended periods and typically records were relatively discrete. Figure 3 provides a comparison between the record of presence in the lower part of the fish pass as indicated by radio-telemetry records and PIT records on 13 April 1999 for a female pike of 68 cm FL. In all cases where the fish was logged as present by the radio receiver PIT records were also obtained. Additionally, 19 out of 20 PIT tagged fish that were recorded at the upstream detectors were also recorded at the downstream detectors one or more times. Overall, 1.7 % of records were made from detectors 3 and 4 at the upstream exit (3.1% of records if data for the two trout described above are removed), reflecting the relatively high frequency of fish entry into the pass by comparison to successful ascents. This is a maximum figure because it is likely that some records of PIT tagged fish were missed at the downstream detectors, particularly during March and April 1999.

Records of tagged fish in the lower part of the fish pass (at detectors 1 and 2) reflect the intensity of upstream-directed activity, both in terms of the numbers of different fish recorded, and as repeat records made of the same fish. However, a substantial number of PIT records made in the lower part of the fish pass were recorded at intervals of seconds or tens of seconds, reflecting multiple records associated with localized movements within the fish pass (Figure 3). On the basis of the frequency distribution of these data Lucas *et al* (1999) argued that intervals of > 10 minutes between records normally reflect genuine repeat entries into the

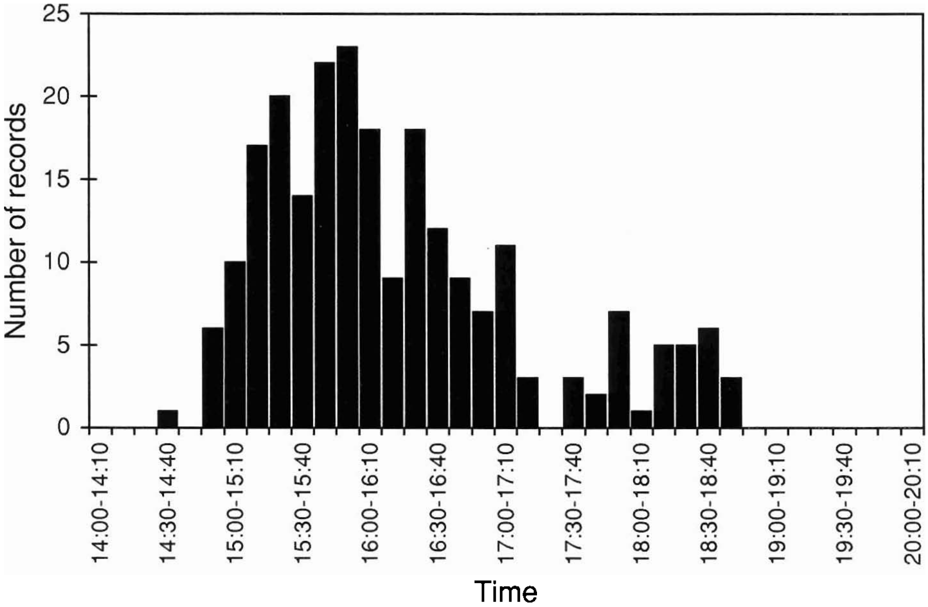


*Figure 2.* An example of the frequencies of PIT tag records at detectors 1 and 2 (fish pass entrance) for a brown trout (FL, 35 cm) released on 30 September 1998, which persistently remained in the fish pass over several hours on 1 December 1998 and lingered near the downstream detectors. Similar behaviour was recorded for this fish on several other dates.

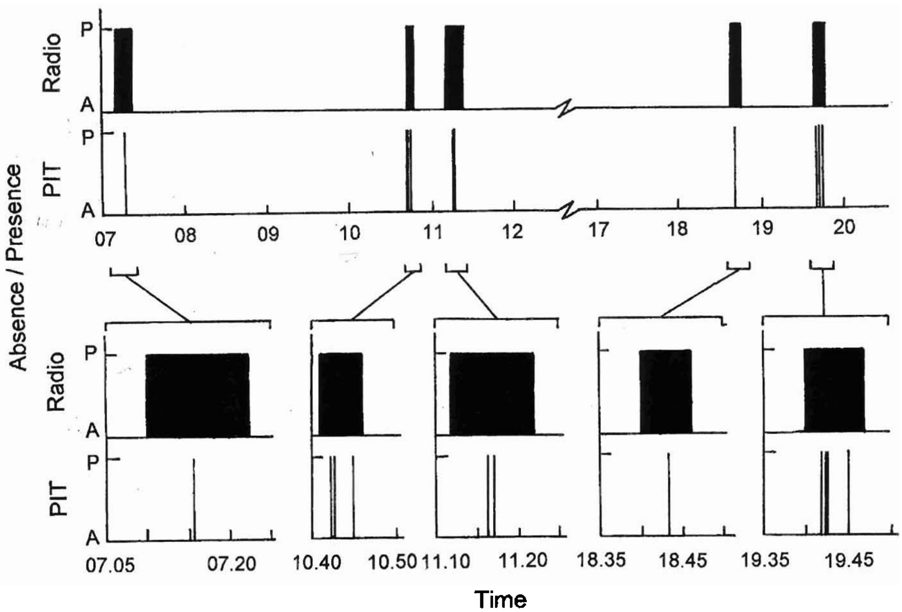


*Figure 3.* Comparison between timings of PIT and radio records of pike (FL, 68 cm) released on 9 April 1999 which entered the fish pass on five different occasions on 13 April 1999. Fish presence is recorded as P, and absence as A.

pass for pike and this appears to be confirmed by radio-tracking data (Figure 3). An exception to this may be for large salmonids such as adult brown which can maintain position in the turbulent pass for long periods (Figure 2), although this behaviour was observed only for 2 trout out of 13 recorded entering the pass. This behaviour was most evident on several days in October and November 1998 when activity by non-salmonid fishes was low. The seasonal variation in numbers of tagged fish recorded entering the fish pass is displayed in Figure 4, and repeat records (interval > 10 minutes) are also presented for non-salmonid species. Highest levels of activity occurred in late spring and early summer, with another peak in early autumn mostly from fish that were moved from upstream to below the weir in September 1998.

From a total of 401 fish tagged and released by 9 April 1999 a total of 90 fish (22.4 %) had entered the pass, exhibiting upstream-directed movement, by 31 May 1999. This calculation assumes 100% tag retention, and zero mortality of tagged fish due to handling or natural mortality, and in reality the proportion of available tagged fish entering the fish pass is likely to have been higher. The incidence of records of tagged fish entering the pass varied between species (Table 2) and was highest for brown trout, pike, chub and perch and zero for barbel,

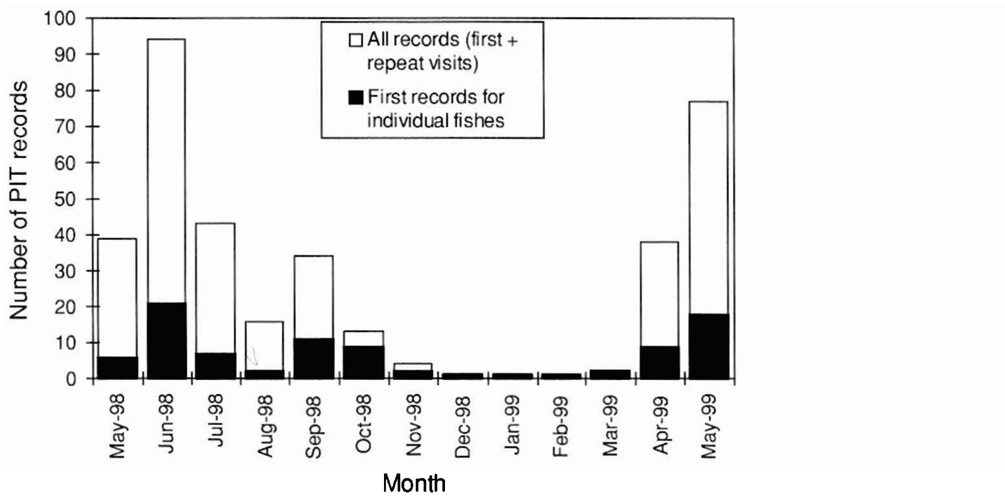


*Figure 4.* Seasonal variations in first entries by all fish and repeat entries (intervals between records > 10 minutes) for non-salmonid fishes between May 1998 and May 1999. Data for May 1998 are incomplete since recording started on 23 May 1998. No recording was possible between 8-20 March 1999 due to equipment failure during flood conditions (see text).

*Table 2.* Numbers of PIT tagged fish of different species recorded entering the fish pass at Stamford Bridge.

| Species | Number tagged | Number recorded | % entering pass |
|---|---|---|---|
| Brown trout | 35 | 13 | 37.1 |
| Pike | 20 | 7 | 35.0 |
| Chub | 104 | 31 | 29.8 |
| Perch | 17 | 5 | 29.4 |
| Dace | 105 | 20 | 19.1 |
| Roach | 73 | 12 | 16.4 |
| Bleak | 17 | 2 | 11.8 |
| Gudgeon | 15 | 0 | 0 |
| Barbel | 7 | 0 | 0 |
| Ruffe | 5 | 0 | 0 |
| Grayling | 3 | 0 | 0 |
| Total | 401 | 90 | 22.4 |

*Table 3.* Measured efficiencies of passage through Stamford Bridge fish pass by PIT tagged fish of different species and sizes. Efficiencies are calculated as the percentage of tagged fish that entered the pass and were ultimately recorded at the exit, irrespective of number of attempts or duration between entry and exit.

| Species | < 20 cm | | | > 20 cm | | | All |
|---|---|---|---|---|---|---|---|
| | Entered | Success | % success | Entered | Success | % success | % success |
| Br. trout | 1 | 0 | 0 | 12 | 6 | 50.0 | 46.2 |
| Chub | 6 | 0 | 0 | 25 | 8 | 32.0 | 25.8 |
| Roach | 7 | 1 | 14.3 | 5 | 2 | 40.0 | 16.7 |
| Pike | - | - | - | 7 | 1 | 14.3 | 14.3 |
| Dace | 20 | 2 | 10.0 | - | - | - | 10.0 |
| Perch | 1 | 0 | 0 | 4 | 0 | 0 | 0 |
| Bleak | 2 | 0 | 0 | - | - | - | 0 |
| Total | 37 | 3 | 8.1 | 53 | 17 | 32.1 | 22.2 |

gudgeon, ruffe and grayling, although low numbers of several of these species were tagged. There was significant variation in the relative frequency of different species entering the fish pass ($\chi^2 = 16.96$, 7 d.f., $P < 0.05$; all species in separate categories, except gudgeon, barbel, ruffe and grayling grouped together). There were significant variations between treatment groups in proportions of tagged fish which were recorded entering the pass (stocked cyprinids, 16.9%; stocked trout, 35.5%; wild fish - home site, 17.4%; wild fish - displaced, 43.1%; $\chi^2 = 17.05$, 3 d.f., $P < 0.001$). The displaced and home site wild fish treatments were relatively well matched in terms of species composition and size range (Table I) and a comparison between these showed that fish which were displaced downstream exhibited a significantly greater tendency to enter the fish pass ($\chi^2$ with Yates' correction = 12.63, 1 d.f., $P < 0.001$) than home-site wild fish.

Overall, out of 90 PIT tagged fishes which were recorded entering the fish pass, a total of 20 were recorded as having successfully ascended, giving an overall efficiency of passage of 22.2%. However, efficiency of passage varied greatly between species, being highest in brown trout (46.2%) and lowest in dace (10%) perch (0%) and bleak (0%), although sample sizes were low (Table 3). Chi square analysis (2 x 2 contingency) was used to analyse the influence of fish size on the relative success of passage for all species combined. In this analysis no consideration was given to the number of attempts at passage for an individual fish, only whether those fish which entered the pass were ultimately successful. Length had a significant effect on the frequency of successful and unsuccessful passage ($\chi^2$ with Yates' correction = 5.92, 1 d.f., $P < 0.05$), with 8.1% of fish less than 20 cm successfully passing and 32.1% of fish 20 cm or larger successfully passing. However, 41% of all tagged fish that entered the pass were less than 20 cm in length.

## Discussion

This study demonstrates the effectiveness of automated PIT apparatus for examining the behaviour of a wide range of sizes and species of fish in a narrow fish pass, and for estimating pass efficiency. We believe that the number of tagged fish recorded as successfully ascending the pass represents a good estimate of the true numbers, since the cross section of the pass at the upstream exit was fully interrogated. Regular checks of the detection and logging equipment showed that continuous monitoring was achieved over all but the flood period in March 1999. Validation measurements at the upstream detectors gave an efficiency of detection of 100%, and it is therefore reasonable to assume detection efficiencies of greater than 90% for the upstream detectors. This is likely to hold under most conditions since water depth in the pass varies little and increases substantially only at the highest flows when entry into the fish pass ceases (Lucas *et al.*,1999). Although the efficiency of the downstream PIT detectors could not be calibrated experimentally with observations of live fish, data from PIT and radio-tagged fish suggest that detection was relatively effective. Additionally 95% of fish that were recorded at the upstream antennae were also recorded at the downstream antennae one or more times. The PIT array provided a wealth of information concerning the behaviour of fish entering the pass that would have been difficult to gather in any other way. Water clarity was mostly too poor for successful operation of CCTV and was not attempted.

Our field trials demonstrated that the PIT detection system described here is robust. The detectors remained in position throughout several periods of high flow, including the largest floods on the Derwent this century. The decoding equipment performed well over a wide range of environmental temperatures. Flat-bed PIT detectors are able to detect the smallest commercially available tags across greater channel widths than coils formed on plastic baffle plates. Our results suggest that planar detectors do not deter fish from movement through the pass. Water velocities within the pass were only slightly affected by the presence of the detectors (Figure 1), and much less so than by the presence of the baffles. Also, of the pair of downstream detectors, detector 1 was upstream relative to detector 2, but the majority of PIT records were at the former. Therefore those fish recorded at detector 1 had passed below detector 2, without being deterred by its presence (Lucas *et al.*, 1999). Armstrong *et al.* (1996) presented evidence for Atlantic salmon (*Salmo salar*) parr that neither flat-bed PIT detectors, nor their magnetic field, have a significant influence on the fishes' responses to them. Nevertheless, further information including visual stimuli of detectors of various types and orientations is required for a wider range of species to determine whether fish could be deterred from passing PIT detectors. We recorded only two examples of tagged fish lingering near detectors which, in other studies, has been shown to cause inhibition of signal detection from other tagged fish (e.g. Armstrong *et al.*, 1996). Both cases involved brown trout and occurred in late autumn when entry of other fish species was low, so that the effects of blockage on recording entries by other fish species are likely to have been very limited. Therefore although PIT detection can be used effectively to record repeat entries of most typical lowland fish species, care must be used in assessing the frequency of entry by taxa such as salmonids.

The relative frequency of entry to the pass by different species showed that upstream-directed movement was frequent in several rheophilic species including brown trout, chub and dace, as expected. These species are commonly found in traps at the exits of fish passes on European rivers (Baras *et al.*, 1994; Travade *et al.*, 1998). Some rheophilic species such as barbel were not recorded despite their migratory behaviour being well established (Baras *et al.*, 1994; Lucas & Batley, 1996), although the sample size for this species was very low. It should also be noted that gravel spawning habitat and abundant summer macrophyte was available for 300 m immediately below the weir. While barbel did not enter the pass, dace, another lithophilic species, were recorded only from May onwards, after spawning. Chub were frequently recorded in May and June, prior to and during their spawning season. Surprisingly, pike and perch, both limnophilic species, were among the most frequently recorded entrants, with most entering in April and early May. Radiotracking data for pike shows that these fish entered the pass for periods of several minutes at a time, reflecting their sustained swimming capabilities (Jones *et al.*, 1974). Such entries may be local foraging movements, but the successful passage of a PIT tagged fish and the trapping of pike at the pass exit in May 1998 (McGinty, unpubl. data) suggests that entries of pike are associated with migration.

Although the data are preliminary, the low passage efficiencies for non-salmonid fish found in this study may be related to their relatively poor swimming performance (Beamish, 1978). The effect of size on swimming performance is well established (Beamish, 1978) but empirical data concerning efficiency of passage by non-salmonid fish through fishways are relatively scarce. Our data showed that 41% of all fish which attempted to ascend the pass were < 20 cm, but of this category only 8% succeeded. Many of these small fish were juveniles and we interpret these upstream-directed movements as redistribution behaviour following displacement by winter floods (Axford, 1991), or following experimental displacement. The efficiencies of passage of brown trout were quite low, but these were mostly hatchery-reared fish, and for salmonids there is wide evidence of reduced swimming performance and altered behaviour by comparison to wild fish (e.g. Duthie, 1987). Maintenance of river connectivity for fish migration is generally approached through the provision of fish passage facilities at obstructions. Despite recent efforts to introduce fish pass designs that are more appropriate for non-salmonid species with poorer swimming performances (Larinier, 1983; Jungwirth, 1996) the behaviour of these fish in relation to the passes is largely unknown. Effectiveness of fish passes has mostly been studied using traps or CCTV at the upstream exits of fish passes to enable identification, enumeration and measurement of fishes which have successfully ascended (Travade *et al.*, 1998). However, the efficiency of passage, and the behaviour of fish attempting to use the pass are more effectively measured by radio-tracking for larger species (e.g. Lucas & Frear, 1997) and for a wide range of sizes by PIT telemetry.

Automated PIT telemetry has substantial potential for use in examining the migratory behaviour of lowland-river fish through restricted routes of passage such as fish passes, culverts and streams. The method is highly appropriate for assessment of efficiency of passage through fish passes and should enable a clearer understanding of the effects of environmental factors, such as temperature and discharge on the passage of freshwater fish of different species and sizes. In the near future it should also be possible to monitor wider channels by multiplexing several planar antennae positioned in series, although the technical difficulties of securing antennae above the bed of wide channels are acknowledged.

## Acknowledgements

This work was funded in part by the Natural Environment Research Council (Grant no. GR9/0C081 to MCL). We are grateful to Mr. D. Hines for site access and to Environment Agency fisheries staff and C. West for assistance with fieldwork.

## References

Adams, B. & Schwevers, U. (1997). Funktionsüberprüfung von fischwegen. Einsatz automatischer kontrollstationen unter anwendung der transponder-technologie. Bonn, Germany: *Deutscher Verband für Wasserwitschaft und Kulturbau* (DVWK) **119**, 100 pp.

Armstrong, J.D., Braithwaite, V.A. & Rycroft, P. (1996). A flat-bed passive integrated transponder array for monitoring the behaviour of Atlantic salmon parr and other fish. *Journal of Fish Biology*, **48**, 539-541.

Armstrong, J.D., Braithwaite, V.A. & Huntingford, F.A. (1997). Spatial strategies of wild Atlantic salmon parr: exploration and settlement in unfamiliar areas. *Journal of Animal Ecology*, **66**, 203-211.

Armstrong, J.D., Braithwaite, V.A. & Fox, M. (1998). The response of wild Atlantic salmon to acute reduction in water flow. *Journal of Animal Ecology*, **67**, 292-297.

Axford, S.N. (1991). Some factors affecting catches in Yorkshire rivers. In: *Catch Effort Sampling Strategies* (ed. Cowx, I.G.). Oxford: Fishing News Books, Blackwell Scientific Publications. pp. 143-153.

Baade, U. & Fredrich, F. (1999). Movement and pattern of activity of the roach in the River Spree, Germany. *Journal of Fish Biology*, **52**, 1165-1174.

Baras, E. & Cherry, B. (1990). Seasonal activities of female barbel *Barbus barbus* (L.) in the River Ourthe (Southern Belgium) as revealed by radio-tracking. *Aquatic Living Resources*, **3**, 283-294.

Baras, E. & Philippart, J.C. (eds.) (1996). *Underwater Biotelemetry.* Proceedings of the First Conference and Workshop on Fish Telemetry in Europe. University of Liege, Belgium, vi + 257pp.

Baras, E., Lambert, H. & Philippart, J.C. (1994). A comprehensive assessment of the failure of *Barbus barbus* (L.) spawning migrations through a fish pass in the canalized River Meuse (Belgium). *Aquatic Living Resources*, **7**, 181-189.

Baras, E., Malbrouck, C., Houbart, M., Kestemont, P. & Mélard, C. (2000). The effect of PIT tags on growth and some physiological factors of age-0 cultured Eurasian perch *Perca fluviatilis* of variable size. *Aquaculture*, **185**, 159-173.

Baras, E., Westerloppe, L., Mélard, C., Philippart, J.C. & Bénech, V. (1999). Evaluation of implantation procedures for PIT tagging juvenile Nile tilapia. *North American Journal of Aquaculture*, **61**, 246-251.

Beamish, F.W.H. (1978). Fish swimming capacity. In *Fish Physiology*, Vol. VII (eds. Hoar, W.H. & Randall, D.J.). New York: Academic Press. pp.101-187.

Castro-Santos, T., Haro, A. & Walk, S. (1996). A passive integrated transponder (PIT) tag system for monitoring fishways. *Fisheries Research*, **28**, 253-261.

Clough, S. & Ladle, M. (1997). Diel migration and site fidelity in a stream-dwelling cyprinid, *Leuciscus leuciscus*. *Journal of Fish Biology*, **50**, 1117-1119.

Clough, S., Garner, P., Deans, D. & Ladle, M. (1999). Post-spawning movements and habitat selection of dace in the River Frome, Dorset, southern England. *Journal of Fish Biology*, **53**, 1060-1070.

Copp, G.H. & Jurajda, P. (1993). Do small riverine fish move inshore at night? *Journal of Fish Biology*, **43** (Suppl. A), 229-241.

Duthie, G.G. (1987). Observations of poor swimming performance among hatchery-reared rainbow trout. *Environmental Biology of Fishes*, **18**, 309-311.

Jones, D.R., Kiceniuk, J.W. & Bamford, O.S. (1974). Evaluation of the swimming performance of several fish species from the Mackenzie River. *Journal of the Fisheries Research Board of Canada*, **31**, 1641-1647.

Jungwirth, M. (1996). Bypass channels at weirs as appropriate aids for fish migration in rhithral rivers. *Regulated Rivers: Research and Management*, **12**, 483-492.

Langford, T.E., Milner, A.G.P., Foster, D.J. & Fleming, J.M. (1979). The movements and distribution of some common bream (*Abramis brama* L) in the vicinity of power station intakes and outfalls in British rivers as observed by ultra-sonic tracking. Central Electricity Generating Board Laboratory Note RD/L/N 145/78, 24 pp. + appendices.

Larinier, M. (1983). Guide pour la conception des dispositifs de franchissement des barrages pour les poissons migrateurs. Bulletin Français de la Pisciculture, numero special.

Lelek, A. (1987). Threatened Fishes of Europe, *The Freshwater Fishes of Europe Vol. 9*. Wiesbaden: AULA-Verlag.

Lucas, M.C. (in press). Recent advances in the application of tracking and telemetry to the study of freshwater fishes. In *Proceedings of the Fifth European Wildlife Telemetry Conference* (ed. Le Mayo, Y.) Strasbourg, Aug. 1996.

Lucas, M.C. & Batley, E. (1996). Seasonal movements and behaviour of adult barbel *Barbus barbus*, a riverine cyprinid fish: implications for river management. *Journal of Applied Ecology*, **33**, 1345-1358.

Lucas, M.C. & Frear, P.A. (1997). Effects of a flow-gauging weir on the migratory behaviour of adult barbel, a riverine cyprinid. *Journal of Fish Biology*, **50**, 382-396.

Lucas, M.C., Thom, T.J., Duncan, A. & Slavík, O. (1998a). Coarse Fish Migration: Occurrence, Causes and Implications. Research and Development Technical Report W152. Environment Agency, UK.

Lucas, M.C., Mercer, T., Batley, E., Frear, P.A., Peirson, G., Duncan, A & Kubecka, J. (1998b). Spatio-temporal variations in the distribution and abundance of fishes in the Yorkshire Ouse system. *Science of the Total Environment*, **210/211**, 437-455.

Lucas, M.C., Mercer, T., Armstrong, J.D., McGinty, S. & Rycroft, P. (1999). Use of a flat-bed passive integrated transponder antenna array to study the migration and behaviour of lowland river fishes at a fish pass. *Fisheries Research*, **44**,183-191.

Lucas, M.C., Mercer, T., Peirson, G. & Frear, P.A. (2000). Seasonal movements of coarse fish in lowland rivers and their relevance to fisheries management. In: *Ecology and Management of River Fisheries* (ed. Cowx, I.G.). Oxford: Fishing News Books, Blackwell Science. pp.87-100.

MacKenzie, A.R. & Greenberg, L. (1998). The influence of instream cover and predation risk on microhabitat selection of stone loach *Barbatula barbatulus* (L.). *Ecology of Freshwater Fish*, **7**, 87-94.

Martinelli, T.L., Hansel, H.S. & Shively, R.S. (1998). Growth and physiological responses to surgical and gastric radio transmitter implantation techniques in subyearling Chinook salmon (*Oncorhynchus tshawytscha*). *Hydrobiologia*, **371/372**, 79-87.

Northcote, T.G. (1998). Migratory behaviour of fish and its significance to movement through riverine fish passage facilities. In *Fish Migration and Fish Bypass Channels* (eds. Jungwirth, M., Schmutz, S. & Weiss, S.). Oxford: Fishing News Books, Blackwell Science. pp.3-18.

Nunnallee, E.P., Prentice, E.F., Jonasson, B.F. & Patten, W. (1998). Evaluation of a flat-plate PIT tag interrogation system at Bonneville Dam. *Aquacultural Engineering*, **17**, 261-272.

Prentice, E.F., Flagg, T.A. & McCutcheon, S. (1990). Feasibility of using implantable passive integrated tranponder (PIT) tags in salmonids. In: *Fish Marking Techniques* (eds. Parker, N.C., Giorgi, A.E., Heidimger, R.C., Jester, D.B. Jr, Prince, E.D. & Winans, G.A. *American Fisheries Society Symposia*, **7**, 317-322.

Stott, B., Elsdon, J.W.V. & Johnston, J.A.A. (1963). Homing behaviour in gudgeon (*Gobio gobio* (L.)). *Animal Behaviour*, **11**, 93-96.

Travade, F., Larinier, M., Boyer-Bernard, S. & Dartiguelongue, J. (1998). Performance of four fish pass installations recently built on two rivers in south-west France. In: *Fish Migration and Fish Bypass Channels*, (eds. Jungwirth, M., Schmutz, S. & Weiss, S.). Oxford: Fishing News Books, Blackwell Science. pp.146-170.

Whitton, B.A.W. & Lucas, M.C. (1997). Biology of the Humber rivers. *Science of the Total Environment*, **194/195**, 247-262.

# Advances in Fish Telemetry

Proceedings of the Third Conference on Fish Telemetry in Europe, held in Norwich, England, 20-25 June 1999

*Edited by*

Andrew Moore and Ian Russell

CEFAS

*The Centre for Environment, Fisheries & Aquaculture Science*

Lucas, M. C., Mercer, T., McGinty, S. and Armstrong, J. D. (2000). Development and evaluation of a flat-bed passive integrated transponder detection system for recording movement of lowland river fishes through a baffle pass. In *Advances in Fish Telemetry* (Moore, A. & Russel, I., eds), pp. 117-127. Lowerstoft: CEFAS, Lowerstoft Laboratory.

CEFAS

Lowestoft