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# Determining the effects of species, environmental conditions and tracking method on the detection efficiency of portable PIT telemetry

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The efficiency of portable passive integrated transponder (PIT) telemetry at detecting five fish species in a small river was evaluated under different environmental and tracking conditions. Significant differences between species were apparent, with detection efficiency varying between 0·7% (*Leuciscus leuciscus*) and 43·1% (*Salmo trutta*). Conditions of reduced flow and tracking in a downstream direction significantly increased detection efficiency for salmonids, while time of day had no significant effect for any species.


Key words: *Anguilla anguilla*; *Leuciscus leuciscus*; passive integrated transponder; portable antenna; tracking.

Passive integrated transponder (PIT) telemetry has recently emerged as an efficient alternative to conventional radio and acoustic telemetry. Compared with conventional telemetry tags, PIT tags can be a cost-effective alternative, as they are smaller, cheaper and remain active for a longer period. Initially, stationary antennae were designed to record the movements of tagged fishes and their habitat use (Prentice *et al*., 1990; Armstrong *et al*., 1996; Castro-Santos *et al*., 1996; Zydlewski *et al*., 2001). More recently, however, portable PIT detectors have been developed for actively locating small-bodied tagged fishes in shallow waters, and this has greatly contributed to understanding of ecology, behaviour and management of freshwater fishes (Roussel *et al*., 2004; Cunjak *et al*., 2005). The initial technical advances in portable PIT telemetry enabled effective detection of species of the Salmonidae family, *e.g. Salmo salar* L., *Oncorhynchus mykiss* (Walbaum) and *Salmo trutta* L., using PIT tags of 23 mm (Morhardt *et al*., 2000; Roussel *et al*., 2000) and 12 mm (Cucherousset *et al*., 2005). It has subsequently been used to study species of other

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families including Cottidae (Cucherousset *et al*., 2005; Keeler *et al*., 2007), Esocidae (Cucherousset *et al*., 2007, 2009), Petromyzontidae (Quintella *et al*., 2005) and Gobiidae (Cookingham & Ruetz, 2008; Breen *et al*., 2009).

The performance of portable PIT telemetry is a function of tag size and transmission type; the highest reported detection distance (tag orthogonal to the antenna) is 100 cm with 23 mm half-duplex PIT tags (Roussel *et al*., 2000; Linnansaari *et al*., 2007) but only 36 cm with 12 mm full-duplex PIT tags (Cucherousset *et al*., 2005). Notwithstanding, there are also many other factors that affect detection efficiency, including the presence of habitat features such as undercut banks, deep holes, boulder substrate and woody debris (Keeler *et al*., 2007; Cucherousset *et al*., 2008). Although these do not directly affect detection distance, they modify the ability of the operator to efficiently scan these habitats and enable the fishes to lie outside of the detection range (Linnansaari *et al*., 2007). Species behaviour has also been reported as potentially influencing detection efficiency (Cookingham & Ruetz, 2008). There is a lack of data, however, quantifying the influence on detection efficiency of species, tracking methodology, environmental factors and their combined effects. Therefore, the aim of this study was to assess the relative influence of flow, time of day and tracking direction on the detection efficiency of portable PIT telemetry across five different species.

The study site was the lower reach of a millstream of the River Frome (Dorset, U.K.; 50° 40′ 4″ N; 2° 10′ 42″ W). The site length was 520 m, mean ± S.E. width 6·25 ± 0·19 m and habitat features (measured in low flow) ranged from shallow rifles (mean ± S.E. 15·1 ± 1·7 cm) to deep pools (83·5 ± 4·2 cm, maximal depth = 104 cm). There were no barriers to prevent fishes leaving the study area. The species present in the study area, which were studied, were young-of-the-year (YOY) *S. salar* and *Esox lucius* L., and several age-classes of *S. trutta*, *Anguilla anguilla* (L.) and *Leuciscus leuciscus* (L.) The site was divided into 50 m reaches with stop-nets, and the fishes sampled by electrofishing (50 Hz pulsed DC) using two successive passes. Captured fishes were anaesthetized with 2-phenoxyethanol, measured (fork length, $L_F$, nearest mm) and weighed (nearest 0·1 g), and a PIT tag (11·5 mm × 2·1 mm; ID 100, Dorset Identification b.v.; www.dorset.nu) inserted into the peritoneal cavity using a sterile scalpel. Small PIT tags were used to allow the monitoring of all individuals, including YOY individuals, with the same device. After recovery in oxygenated water, fishes were released from the area where they were sampled. Tagging was performed on two occasions, 16 June and 17 July 2008, and then, using the same sampling protocol, electrofishing was conducted on 19 August, 23 September and 10 October 2008. This was completed to determine fish presence in the study area through recapture and to tag new *E. lucius*, as few were captured in the initial samples. A total of 341 fishes were tagged (*S. salar*: mean ± S.E. $L_F$ 74·5 ± 0·7 mm, $n = 89$; *S. trutta*: 119·25 ± 5·5 mm, $n = 86$; *E. lucius*: 149·6 ± 6·9 mm, $n = 17$; *A. anguilla*: 397·1 ± 8 mm, $n = 94$; *L. leuciscus*: 123·3 ± 3·7 mm, $n = 55$).

A portable PIT detector working with 12 mm PIT tags (Cucherousset *et al*., 2005) was used to track the tagged fishes. A tracking session consisted of the same operator, moving the antenna just above the stream surface to detect the fishes (sweeping technique). When water depth was higher than the maximal detection distance (*i.e.* 36 cm), the antenna was submerged to scan all available habitats. A total of 18 tracking surveys were performed. They were conducted on a regular basis (approximately twice per week) from 23 July to 9 October 2008 by wading upstream ($n = 12$) or downstream ($n = 6$). On average, a tracking lasted for 3·5 h and started at dawn (0600 to 0800 hours, $n = 6$), day (1000 to 1400 hours, $n = 5$) or dusk (1600 to 1700 hours, $n = 7$). Stream flow was automatically recorded each 15 min during the tracking surveys.

The detection efficiency ($E_{ij}$) of each species was calculated by: $E_{ij} = 100N_{di}N_{pi}^{-1}$, where $N_{di}$ is the number of tagged individuals of the species$_i$ detected with the antenna during tracking$_j$ and $N_{pi}$ is the number of tagged individuals of the species present in the study area during tracking$_j$. Individuals were considered present in the i study area at a given tracking if they were subsequently recaptured during one of the following electrofishing episodes. Specifically, only the data collected between tagging and the last recapture of a given individual were used in the calculation of detection efficiency. This allows taking into account the potential occurrence of tag loss, mortality and emigration without biasing the calculation of $E_{ij}$. Differences in detection efficiency between species were tested using a one-way ANOVA followed by *post hoc* HSD Tukey's tests. Since species identity might also influence the effects of environmental conditions and tracking methodology, general linear models (GLM) were then performed for each species, with the detection efficiency as the response variable and flow (continuous), time of day (categorical: dawn, day and dusk) and tracking methodology (categorical: upstream and downstream) as explanatory variables. The models were run with the three-way interaction terms. All statistical analyses were performed using R (version 2.8.0; R Development Core Team; www.r-project.org).

The number of tagged individuals of a given species present in the study area at a given tracking ($N_{pi}$) ranged from five to 25 for *L. leuciscus*, 18 to 35 for *A. anguilla*, four to 13 for *E. lucius*, 30 to 60 for *S. salar* and 44 to 67 for *S. trutta*. During the 18 tracking surveys, a mean ± S.E. of 34·0 ± 11·5% (range 15·7–51·4%) of all the tagged fishes present in the study area was detected. Detection efficiency differed significantly between species (ANOVA, $F_{4,85}$, $P < 0{\cdot}001$; Fig. 1). The lowest detection efficiency was measured with *L. leuciscus* (mean ± S.E. 0·7 ± 0·4%); as a result it has not been used for further analyses. For *A. anguilla* and *E. lucius*, mean ± S.E. detection efficiencies were 20·4 ± 2·7 and 31·2 ± 4·3%. *Salmo salar* and *S. trutta* had the highest detection efficiency, mean ± S.E. 39·2 ± 3·7 and 43·1 ± 3·5% (Fig. 1).

Irrespective of species, detection efficiency generally increased when tracking was completed in a downstream direction compared with upstream (Fig. 2). This difference, however, was only significant for *S. salar* and *S. trutta* (Table I). Increased flow significantly decreased the detection efficiency of *S. salar* and *S. trutta* by *c*. 16% (Fig. 2). Although the detection efficiency of *A. anguilla* tended to be higher in high flow than low flow, these differences were not significant (Fig. 2). There was no significant effect of time of day for any species (Fig. 2 and Table I).

Previous studies have been unable to quantify the influence of species identity on the detection efficiency of portable PIT telemetry as they were conducted on single species (or family) and in different ecosystems. *Leuciscus leuciscus* is a shoaling rheophilic species, highly mobile and capable of rapid displacements (Clough & Beaumont, 1998). *Esox lucius* is an ambush predator with a more sedentary behaviour, which usually hides in the submerged vegetation (Craig, 2008; Cucherousset *et al*., 2009). Although inhabiting similar habitats (*i.e.* deep pool), their

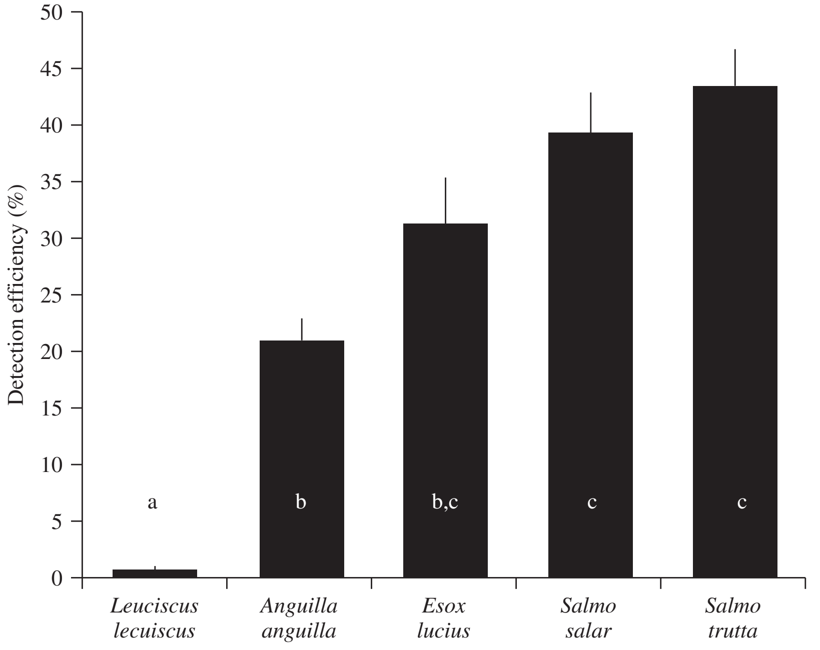


Fig. 1. Mean + s.e. detection efficiency of five species studied during the 18 tracking surveys. Different lowercase letters indicate significant differences (ANOVA followed by *post hoc* HSD Tukey's tests, $P < 0.05$).

contrasted fleeing behaviour, notably when the antenna was submerged, is likely to explain the differences in detection efficiency. Conversely, salmonids species inhabited the shallowest parts of the stretch and the territorial behaviour of salmonids, coupled with their tendency to hide in beds of macrophytes, is known to be particularly suitable for portable PIT telemetry (Roussel *et al*., 2000). *Anguilla anguilla* is a more cryptic species demonstrating a sedentary behaviour, which uses undercut bank, woody debris and burrows and this can decrease the detection efficiency (Roussel *et al*., 2000; Linnansaari *et al*., 2007).

When portable PIT telemetry has been previously conducted in running waters (Roussel *et al*., 2000; Cucherousset *et al*., 2005; Hill *et al*., 2006; Enders *et al*., 2007), the tracking surveys were always performed in an upstream direction, as it was considered to minimize disturbance. Here, tracking in a downstream direction actually resulted in significantly increased detection efficiency of salmonids, perhaps through the operator increasing the water turbidity where the antenna was being manoeuvred and so reducing salmonid fleeing behaviour. In the present study, no relationship between time of day and detection efficiency was observed, which is in contrast to other studies that report slight increases at night-time compared to daytime (Roussel *et al*., 2000; Breen *et al*., 2009) although Cookingham & Ruetz (2008) provide somewhat different results. Increased flow adversely affected the detection efficiency of the salmonids, probably through the consequent increased water depth affecting detection efficiency. This could also explain why the detection efficiencies measured in the present study for *E. lucius*, *S. salar* and *S. trutta* were within the

 

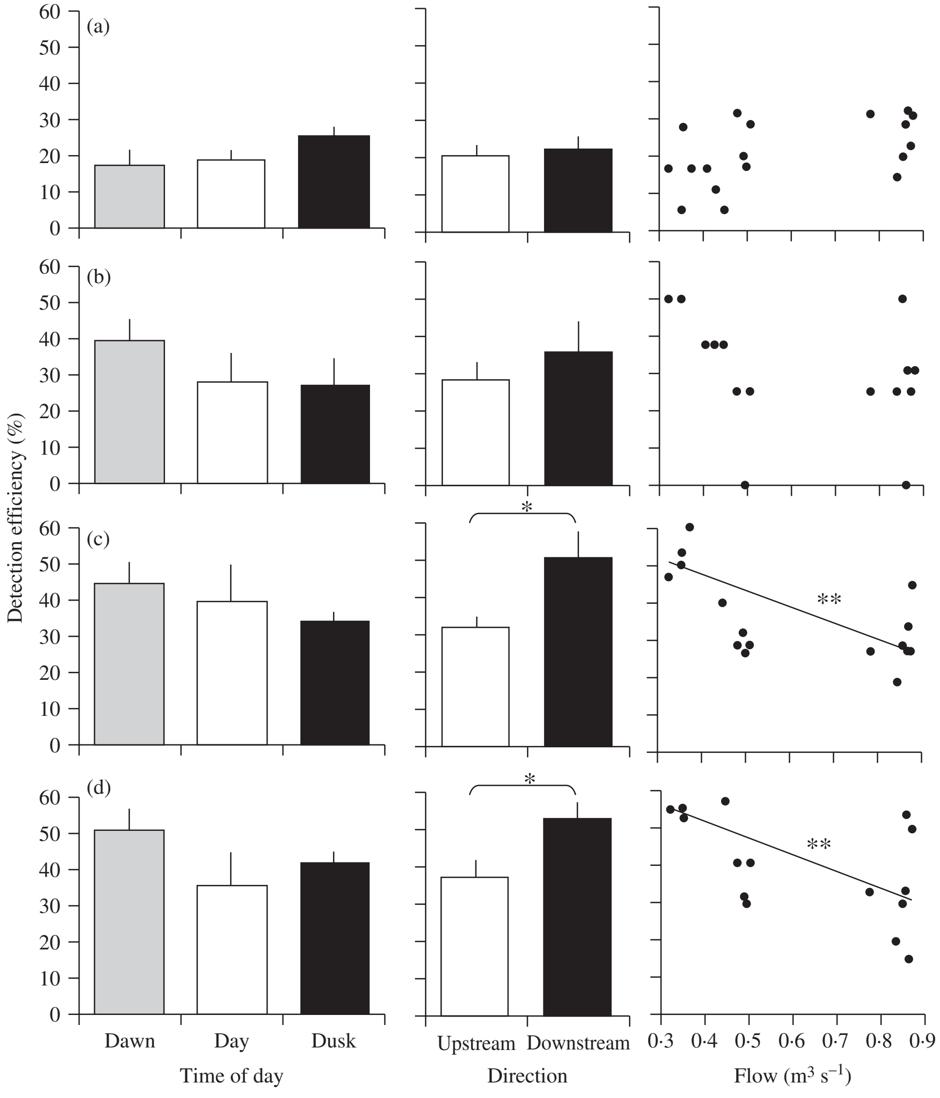


FIG. 2. Effects of time of day, tracking direction and flow on the detection efficiency of (a) *Anguilla anguilla*, (b) *Esox lucius*, (c) *Salmo salar* and (d) *Salmo trutta*. Statistical details are provided in Table I (*, $P < 0{\cdot}05$; **, $P < 0{\cdot}01$).

lower range of the values reported (19·6–81·7%; Roussel *et al*., 2000; Cucherousset *et al*., 2005, 2007; Enders *et al*., 2007), for these studies were conducted in shallower habitats (9–32 cm).

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TABLE I. Output of the general linear models on the effects of flow, tracking direction (direction) and time of day (time) on detection efficiency

| Source of variation | d.f. | Dev. | *F* | *P* |
|---|---|---|---|---|
| *Anguilla anguilla* | | | | |
| Flow | 1,16 | 990·3 | 4·591 | >0·05 |
| Direction | 1,15 | 954·4 | 0·534 | >0·05 |
| Time | 2,13 | 831·1 | 0·916 | >0·05 |
| Flow × direction | 1,12 | 817·9 | 0·196 | >0·05 |
| Flow × time | 2,10 | 560·0 | 1·914 | >0·05 |
| Direction × time | 2,8 | 428·2 | 0·979 | >0·05 |
| Flow × direction × time | 2,6 | 404·1 | 0·179 | >0·05 |
| Error | 17 | | | |
| *Esox lucius* | | | | |
| Flow | 1,16 | 4874·2 | 2·459 | >0·05 |
| Direction | 1,15 | 4731·6 | 0·467 | >0·05 |
| Time | 2,13 | 4439·4 | 0·478 | >0·05 |
| Flow × direction | 1,12 | 3379·0 | 3·471 | >0·05 |
| Flow × time | 2,10 | 3116·9 | 0·429 | >0·05 |
| Direction × time | 2,8 | 2412·0 | 1·154 | >0·05 |
| Flow × direction × time | 2,6 | 1833·2 | 0·947 | >0·05 |
| Error | 17 | | | |
| *Salmo salar* | | | | |
| Flow | 1,16 | 2520·4 | 20·189 | <0·01 |
| Direction | 1,15 | 1480·6 | 13·379 | <0·05 |
| Time | 2,13 | 1465·1 | 0·100 | >0·05 |
| Flow × direction | 1,12 | 1045·4 | 5·400 | >0·05 |
| Flow × time | 2,10 | 952·6 | 0·597 | >0·05 |
| Direction × time | 2,8 | 495·6 | 2·940 | >0·05 |
| Flow × direction × time | 2,6 | 466·3 | 0·188 | >0·05 |
| Error | 17 | | | |
| *Salmo trutta* | | | | |
| Flow | 1,16 | 2255·3 | 17·129 | <0·01 |
| Direction | 1,15 | 1539·8 | 8·275 | <0·05 |
| Time | 2,13 | 1074·5 | 2·691 | >0·05 |
| Flow × direction | 1,12 | 1051·2 | 0·269 | >0·05 |
| Flow × time | 2,10 | 891·3 | 0·925 | >0·05 |
| Direction × time | 2,8 | 717·9 | 1·003 | >0·05 |
| Flow × direction × time | 2,6 | 518·7 | 1·152 | >0·05 |
| Error | 17 | | | |

Dev., deviation.

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