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The Use of Passive Integrated Transponder (PIT) Systems for Tracing Particles and Organisms in Rivers

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Passive Integrated Transponder (PIT) systems can be used to trace organisms and materials through Earth surface environments. Radio-tagging offers a number of benefits over traditional tracing techniques, particularly because it is a non-destructive method of repeatedly identifying tagged objects. The small size, long battery life and relatively low cost of PIT-tags are key advantages over other types of radio-tracking allowing for a large number of individuals to be repeatedly located over extended time periods (> years). PIT-tags can be detected with a hand-held portable antenna that is swept across an environment or by an automated system that continuously records when tags are in range of a fixed antenna or multiple antennae. Antennae usually have detection ranges of 0.01 m to 3 m which can be a practical disadvantage. However, the detection range also represents the spatial accuracy resulting in tags being located with greater precision than many other radio-tagging techniques. An automated detection system using an array of 16 antennae is described which has been used to continuously record the location of tagged signal crayfish in a small stream in the UK. Whilst PIT-tags are widely used in ecological studies to track organisms they are, as yet, only infrequently used in geomorphological studies despite their great potential for particle tracing studies.

KEYWORDS: passive integrated transponders; radio frequency identification; radio-telemetry, tracers

Introduction

The tracing of materials through Earth surface environments has led to many advances in our knowledge of both geomorphological and biological systems. For example, tracing sediment particles has led to a greater understanding of the spatial and temporal dynamics of sediment flux in fluvial and marine environments (Hassan and Ergenzinger, 2003) and the tracing of organisms has produced insights concerning the movement, migration and habitat use in a range of ecosystems (Gibbins and Andrews, 2004). Tracers vary widely between studies and can range in complexity from marking clasts with paint or dye through to using radio-telemetry. This technical note focuses on the use of Passive Integrated Transponder (PIT) tracing systems.

Passive and active radio-tags

Passive Integrated Transponder (PIT) tags are a type of radio-tag which are located using Radio Frequency Identification (RFID) technology. A distinction can be made between active and passive radio-tags with PIT tags belonging to the passive group. An active radio-tag sends a signal to an antenna array giving a continuous path of movement of the object being tracked (Habersack, 2001). Consequently, active radio-tags require an internal power source. PIT tags do not contain an internal power source. Instead, when an antenna is within range of a tag (usually ~ 1 m) an electromagnetic field is generated from which the tag derives power so that it can transmit information to the antenna and tag reader. This information is usually used to ascertain the point location of the tag at a specific time.

Both PIT tags and antennae are variable in size and design. However, the general principle is the same for all PIT systems. A PIT tag is a microchip which is usually encased in a glass tube approximately 2 mm wide and between 10 – 20 mm long (Figure 1). The range and efficiency of tag detection depends on the electromagnetic field created by the antenna and its attenuation by the object within which it is encased or buried. Consequently, the antenna design and tag size will influence the detection distance with most systems having detection ranges of 0.01 m to 3 m. PIT tags can be fixed onto or placed inside sediment particles and organisms (with virtually no negative impacts on animals; Gibbins and Andrews, 2004).

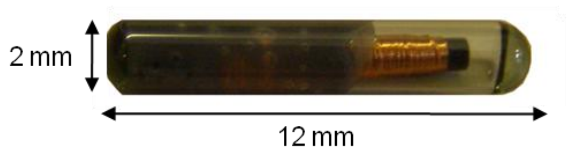

Figure 1: Photograph of a typical PIT-tag

Benefits and weaknesses

Radio-tags versus traditional techniques

Both active and passive radio-telemetry methods have a number of advantages over other forms of tracing. First, it is not necessary for an operator to be able to see the tagged object in order to locate it. This ensures that retrieval rates are typically higher than for visual marking techniques using painted or dyed objects which may be out of view (for example, they may be buried or in turbid water) or difficult to detect because markings have faded or otherwise degraded. Second, identifying an individual tagged object does not depend on an operator being able to physically retrieve it because electronic tags transmit a unique identification code. Again, this is advantageous in comparison to painted or similar identifiers, which are prone to become faded or illegible. It is also an advantage over magnetic tagging. With magnetic tags, locating an object using a magnetometer does not require that it is visible (e.g. buried clasts can be located), but identifying which particular object one has found requires that the object is recovered in order to examine its markings. Third, the use of traditional tracing techniques requires physically searching for the tagged object, so that retrieval becomes a destructive process, particularly if sediment particles are buried or if organisms are hiding. In contrast, because radio-tagged objects can be located and identified without physical disturbance (for example, they have been detected in buried sediments to a depth of approximately 1 m), radio-tagging can have little or no impact on the system being studied. The main limitation of radio-tagging is the expense in comparison to traditional techniques, which can limit the number of objects being traced. This is important in sediment transport studies where large numbers of observations are required to adequately characterise natural variability.

Passive versus active radio-tags

The key advantage of PIT-tags over active tags is their relatively low cost, although this cost remains greater than more traditional techniques. The antenna array is the largest expense, the PIT tags themselves costing approximately £2 each (2009 prices; see practical issues below for full pricings) allowing for numerous individual clasts or organisms to be tagged once an antenna system has been purchased. Further advantages of PIT tags over active tags are their small size and the fact that tracing is not limited by onboard battery life. A weakness relative to active tags is the small detection range which requires the antenna to be within approximately 1 m of the tag. However, detection distances are increasing with technological advancements and for many applications short-range detection can be viewed as a benefit because it means that the spatial error in locating the tag is small (centimetres) relative to active tags (metres) and errors associated with recording several tags simultaneously are minimised.

Perhaps the greatest benefit of PIT tags is the very high reliability in tag detection (95 – 100%) and reading accuracy (100%) (Gibbins and Andrews, 2004). However, this efficiency can be affected by the speed at which tags are moving, tag angle relative to the antenna, and the number of tags simultaneously within range of an antenna (Castro-Santos *et al*., 1996). Errors associated with these issues tend to be infrequent and limited, for instance, PIT tags attached to fish have been detected when travelling at 3.6 m s^{-1} (Prentice *et al*., 1990) and were detected while moving at up to 8 m s^{-1} in the system used by Downing *et al* (2001). Errors are also small relative to the large quantity of data obtained using this technique and can be minimised with careful experimental design. However, tag readers cannot register through some substances such as metal (Freeland and Fry, 1995) and not all PIT tags can be read by all readers because they need to be on the same radio frequency for codes to be received.

Specific examples of use

PIT tags were initially used to identify individual animals using handheld tag readers that are held directly over the tags attached to or inserted into the animal, for example in agriculture (Freeland and Fry 1995). Subsequently, many of the advancements in PIT tag usage have been associated with ecological studies. However, PIT tags have been used in some geomorphological studies and they offer significant potential for geomorphic applications.

Portable detectors

Portable detectors are swept across an environment, much like a metal detector (Roussel *et al*., 2000; Morhardt *et al*., 2000). These tend to consist of a circular antenna mounted on a pole. Bubb *et al.* (2006) were able to successfully track the movement of tagged signal crayfish through the River Wharfe, UK using such antenna and they have been widely used to locate tagged fish (Roussel *et al*., 2000; Zydlewski *et al*., 2001; Hill *et al*., 2006), including fish in ice covered streams (Limnansaari *et al*., 2007). More recently, this technique has been used to identify and trace sediment particles in marine, hill-slope, and fluvial environments (Nichols, 2004; Allan *et al*., 2006; Carré *et al*., 2007; Lamarre *et al*., 2008). Nichols (2004) was able to locate 96% of cobble tracers after four major run-off events from hillslopes, whereas only 63% would have been located without radio-tags. A similar technique was used by Allan *et al*., (2006) to study the transport of cobbles across beaches with a 90% recovery rate after 8 months. After flood events, 87 – 96% of tagged particles (*b* axis 40 – 250 mm) were recovered from Moras Creek, Québec, including those buried up to 0.25 m (Lamarre *et al*., 2005). Rollet *et al*. (2008) were able to recover 87 – 90% of PIT-tagged particles after two years in a small river (6 m wide) but recovery was reduced to only 36% after one year in a large river (100 m wide). Despite this reduction, most likely due to the inability to locate tags in deep pools and when buried at depths greater than 0.25 m, the recovery rate was still substantially greater than other tracing techniques (Rollet *et al*., 2008). This highlights that in fluvial environments the use of hand-held antennae is particularly well suited to small-moderate sized streams. The main weakness of using hand-held antennae is that the spatial and temporal extent and resolution of the data obtained is dependent on intensive surveying effort, making it a labour intensive approach.

Automated detection of objects

Rather than sweeping an environment with an antenna, automated detection systems can be used. In this case, one or more antennae are distributed in space (for example, across the river bed) and a record is made every time a tag is within range of an antenna. When using multiple antennae it is necessary for them to be connected to a Multi-Point Decoder (MPD) that sequentially interrogates each antenna in turn. If a tag is detected, its identification number, the antenna number and a time and date is logged and recorded by the MPD. Automated systems are an effective, non-destructive way of monitoring the passage of particles or organisms or for establishing residence times at points within the sampling frame. The main limitation of using automated systems is that antennae must be placed in locations where the tagged objects will come into range of them. This assumes some knowledge of the future location of tagged particles. Consequently, automated tracking is also particularly well suited to the fluvial environment.

Automated systems have been used for a variety of ecological studies but there are no published accounts of use in geomorphic studies. For example, Riley *et al*. (2003; 2006) used an automated system consisting of two MPD connected to 31 antennae placed on the substrate surface to monitor the location of different fish species within a river channel. A similar technique was used by Johnston *et al*. (2009) who used a grid of 242 buried antennae to detect the location of tagged fish. Large, flat antennae can be constructed across entire channel widths to record every time a tagged fish enters or exits a particular channel reach (Lucas *et al*., 1999; Greenburg and Giller, 2000). In the Columbia River Basin over 12 million fish have been PIT tagged and monitored since 1987 (www.psmfc.org/PIT_Tag_Information_System_PTAGIS).

With careful consideration of antennae placement, the automated approach has the potential to be used to study the dynamics of tagged particles in rivers and other geomorphological settings. As well as being able to relate high resolution temporal and spatial point locations of sediment grains to hydraulic conditions, it could provide valuable information on the storage of bed material by continuously recording where grains come to rest and how long they remain stationary.

Practical issues

The author used PIT tags to continuously trace the location of signal crayfish in relation to substrate and flow conditions in a small English stream for a period of 150 days in 2009. Multiple antennae were used and each was buried below the surface of discrete habitat units in a meander bend with sites selected to reflect combinations of substrate and hydraulic conditions. This information was used to relate experimental laboratory studies on the reworking of fluvial substrates (Johnson *et al*., 2010) to a field environment; in essence to show that substrates comprising those gravel sizes which crayfish activity can alter, were occupied by crayfish in the field.

We used 16 circular, 0.25 m diameter antennae (ANT-SP-DISC-250) connected to a Multi-Point Decoder (DEC-MPD-16) with 10 m coaxial cables (figure 2). Tags (12 x 2.2 mm) and all equipment were purchased in the UK from Wyre Micro Design Ltd. The 16 antennae were interrogated over a three second period, with each antenna in turn being activated for 300 milliseconds. This rapid interrogation removed potential

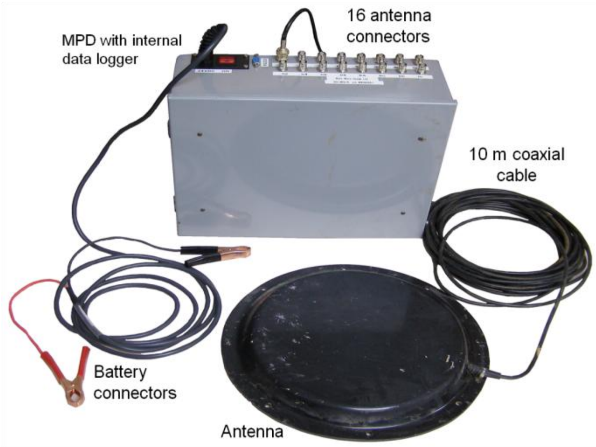

Figure 2: Photograph of the equipment used by the author to track signal crayfish in an English river.

problems of multiple tags being recorded at the same time or interference between antennae positioned close together. Each antennae cost approximately £175 (2009 price) and the MPD cost £1450 (2009 price). Over the tracking period, we successfully recorded over 10,000 point locations of a total of 65 PIT-tagged crayfish. Therefore, we obtained a continuous record of every time a PIT-tagged crayfish was present in a predefined habitat unit over the 150 day study.

Figure 3: Tracking equipment in situ at the field site used by the author. The MPD and two 12V batteries were housed in the black box and antennae were buried under the substrate of the river.

Conclusions

PIT tags are a relatively inexpensive way of accurately tracking large numbers of individual particles or organisms over extended periods. The small size and mass of the tags (< 10 mm, 0.1 grams) means that relatively small clasts or organisms (crayfish, juvenile fish) can be tracked, and their long life makes them ideal for tracking over extended periods (> years). The relatively small detection range between tags and antenna may be seen as a weakness as it necessitates some knowledge of the future location of the individuals being tracked. However, the short detection range makes the technique ideally suited to fluvial environments where the location of sediments and organisms tend to be limited to within the channel. The small detection range also results in a greater spatial accuracy when locating objects. The flexibility of the approach holds great promise for geomorphological studies of particle dynamics.

Links

AVID, Inc. (American Veterinary Identification Devices): *www.avidid.com*
Biomark, Inc.: *www.biomark.com*
Lotek Wireless, Inc.: *www.lotek.com/index.htm*
Trovan, Ltd.: *www.trovan.com*
Wyre Micro Design, Ltd: *www.wyremicrodesign.co.uk/*

References

Allen JC, Hart R, Tranquili JV. 2006. The use of Passive Integrated Transponder (PIT) tags to trace cobble transport in a mixed sand-and-gravel beach on the high-energy Oregon coast, USA. *Marine Geology* **232**: 63–86.

Bubb DH, Thom TJ, Lucas MC. 2006. Movement patterns of the invasive signal crayfish determined by PIT telemetry. *Canadian Journal of Zoology* **84**: 1202–1209.

Carré DM, Biron PM, Gaskin SJ. 2007. Flow dynamics and bedload transport around paired deflectors for fish habitat enhancement: a field study in the Nicolet River. *Canadian Journal of Civil Engineering* **34**: 761–769.

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

Downing SL, Prentice EF, Frazier RW, Simonson JE, Nunnallee EP. 2001. Technology developed for diverting passive integrated transponder (PIT) tagged fish at hydroelectric dams in the Columbia River Basin. *Aquacultural Engineering* **25**: 149–164.

Freeland WJ, Fry K. 1995. Suitability of passive integrated transponder tags for marking live animals for trade. *Wildlife Research* **22**: 767–773.

Gibbons JW, Andrews KM. 2004. PIT Tagging: Simple Technology at Its Best. *Bioscience* **54**: 447–454.

Greenberg LA, Giller PS. 2000. The potential of flat-bed passive integrated transponder antennae for studying habitat use by stream fishes. *Ecology of Freshwater Fish* **9**: 74–80.

Habersack HM. 2001. Radio-tracking gravel particles in a large braided river in New Zealand: a field test of the stochastic theory of bed load transport proposed by Einstein. *Hydrological Processes* **15**, 377–391.

Hassan MA, Ergenziner P. 2003. Use of tracers in fluvial geomorphology. In *Tools in fluvial Geomorphology*, Kondolf GM, Piegay H. (eds). John Wiley and Sons, Chichester, UK; 397–424.

Hill MS, Zydlewski GB, Zydlewski JD, Gasvoda JM. 2006. Development and evaluation of portable PIT tag detection units: PIT packs. *Fisheries Research* **77**: 102–109.

Johnson MF, Rice SP, Reid, I. 2010. Topographic disturbance of subaqueous gravel substrates by signal crayfish (*Pacifastacus leniusculus*). *Geomorphology* **123**: 269–278.

Johnston P, Bérubé F, Bergeron NE. 2009. Development of a flatbed passive integrated transponder antenna grid antenna grid for continuous monitoring of fishes in natural streams. *Journal of Fish Biology* **74**: 1651–1661.

Lamarre H, MacVicar B, Roy AG. 2005. Using passive integrated transponder (PIT) tags to investigate sediment transport in gravel-bed rivers. *Journal of Sediment Research* **75**: 736–741.

Lamarre H, Roy AG. 2008. The role of morphology on the displacement of particles in a step-pool river system. *Geomorphology* **99**: 270–279.

Limnansaari T, Roussel J-M, Cunjak RA, Halleraker JH. 2007. Efficacy and accuracy of portable PIT-antennae when locating fish in ice-covered streams. *Hydrobiologia* **582:** 281–287.

Lucas MC, Mercer T, Armstrong JD, 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.

Morhardt JE, Bishir D, Handlin CI, Mulder SD. 2000. A portable system for reading large passive integrated transponder tags from wild trout. *North American Journal of Fish Management* **20**: 276–283.

Nichols MH. 2004. A radio frequency identification system for monitoring coarse sediment particle displacement. *Applied Engineering Agriculture* **20**: 783–787.

Prentice EF, Flagg TA, McCutcheon CS. 1990. Feasibility of using implantable passive integrated transponder (PIT) tags in salmonids. *American Fisheries Society Symposium* **7**: 317–322.

Riley WD, Eagle MO, Ives MJ, Rycroft P, Wilkinson A. 2003. A portable passive integrated transponder multi-point decoder system for monitoring habitat use and behaviour of freshwater fish in small streams. *Fisheries Management and Ecology* **10**: 265–268.

Riley WD, Ives MJ, Pawson MG, Maxwell DL. 2006. Seasonal variation in habitat use by salmon, *Salmo sala*, trout, *Salmo trutta* and grayling, *Thymallus thymallus*, in a chalk stream. *Fisheries Management and Ecology* **13** : 221–236.

Rollet AJ, Macvicar B, Piegay H, Roy A. 2008. L'utilisation de transpondeurs passif pour l'estimation du transport sédimentaire: premiers retours d'experimence. *La Houille Blanche* **4**: 110–116.

Roussel J-M, Haro A, Cunjak RA. 2000. Field test of a new method for tracking small fishes in shallow rivers usig passive integrated transponder (PIT) technology. *Canadian Journal of Fisheries and Aquatic Science* **57**: 1326–1329.

Zydlewski GB, Haro A, Whalen KG, McCormick SD. 2001. Performance of stationary and portable passive transponder detection systems for monitoring of fish movements. *Journal of Fish Biology* **58**: 1471–1475.