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Fisheries Research 77 (2006) 102–109

FISHERIES RESEARCH
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Development and evaluation of portable PIT tag detection units: PITpacks

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Received 2 April 2005; received in revised form 14 July 2005; accepted 4 August 2005

Abstract

Portable passive integrated transponder (PIT) technology has been used by biologists to study fish behavior non-invasively. However, the method's efficacy has not been evaluated rigorously. To address this, we evaluated the design and field application of three portable backpack PIT tag units (PITpacks) over three years in Abernathy Creek, Longview, WA. Specifically, we assessed options for PITpack design and construction, PIT tag loss and mortality in steelhead trout following the implantation of 23 mm PIT tags, field efficiency of PITpack surveys and the effect of approaching PITpacks on steelhead trout behavior. Our results indicate that antennas constructed of 14 gauge ribbon cable operated consistently when held at a 45° angle to the water surface. Design modifications reduced equipment weight and made PITpacks easier to use. Read range of optimized PITpacks approached 90 cm off the antenna plane when the antenna and tag were submerged in water. Mortality was higher in 23 mm PIT tagged (1.8%) than in non-PIT tagged (0.5%) fish maintained in the same raceways. Tag loss was estimated to be 7.2%, peaked 4 weeks after implantation, and continued at a lesser rate throughout the 4-month study. Instream use of PITpacks resulted in a consistent survey efficiency of 38% in three separate trials. In addition, behavioral observations of tagged fish revealed minimal disturbance to fish approached by PITpacks. Results show that PITpacks can be applied in small streams to study individual fish behavior with only one collection and handling event (for tagging) and minor further disruption.

Keywords: Passive integrated transponder; PIT; PIT tag; PITpack; Steelhead trout; Tag loss

1. Introduction

Passive integrated transponder (PIT) tags were first used in wild animal systems to monitor fish movement (Prentice et al., 1990). More recently, their use has expanded to study the behavior of small mammals, birds, invertebrates, reptiles and amphibians (reviewed by Gibbons and Andrews, 2004). PIT tags are advantageous for studying animal behavior because they are small (10–32+ mm), inexpensive, last indefinitely, and provide individual, unambiguous marks for tagged organisms.

PIT technology is comprised of three parts: the PIT tag, the transceiver and the antenna. The PIT tag consists of an antenna coil, capacitor and circuit board encased in a small glass capsule that is implanted internally (Roussel et al., 2000), or attached externally to animals. When a tagged animal comes within the read range of the antenna, which is attached to the transceiver, the individual code of the PIT tag is recorded. The transceiver energizes the tag by sending an electric current through the antenna; the antenna emits an electromagnetic signal, and a circuit board within the tag is energized and sends the individual code back to the transceiver (Gibbons and Andrews, 2004).

Traditional antennas are stationary and are used to monitor fish passage through hydroelectric facilities (Prentice et al., 1990), fishways (Castro-Santos et al., 1996) and small streams (Zydlewski et al., 2001, 2002). Portable PIT tag

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doi:10.1016/j.fishres.2005.08.001

detection systems were also developed to allow operators to scan wadable waters in search of fish (Morhardt et al., 2000; Roussel et al., 2000; Zydlewski et al., 2001; Cucherousset et al., 2005; Quintella et al., 2005). These portable PIT systems are advantageous because they provide a relatively non-invasive method to assess spatial distributions of local populations, fine-scale movement and microhabitat preferences of individuals, without repeat handling.

PIT tag detection systems, both stationary and portable, have been used extensively in Abernathy Creek, Longview, WA (Zydlewski et al., 2002). The size of Abernathy Creek (a third order tributary of the Columbia River) and the technology used in the construction of the portable backpack PIT units, PITpacks, differ markedly from those in previous studies utilizing portable PIT tag detection systems. The PITpacks described in this study utilize full duplex technology and 23 mm PIT tags. Previous studies used half duplex technology with 23 mm PIT tags (Morhardt et al., 2000; Roussel et al., 2000; Zydlewski et al., 2001) or full duplex technology with 12 mm PIT tags (Quintella et al., 2005; Cucherousset et al., 2005). Full duplex transceivers send and receive signals (from the tag) at the same time, while half duplex transceivers send a signal and shut off to receive the return signal, making half duplex an inherently slower system. Twenty-three millimeter PIT tags can be detected from farther distances with the same equipment, but there use is restricted to fish larger than 100 mm (Zydlewski et al., 2002).

Common to all tagging studies is a concern about tag loss and mortality associated with tagging. Fish can lose their tag and live. It is also possible for fish to die from anesthesia, handling or the tagging process itself. Finally, it is possible for fish to lose their tag and die from other causes. Unlike radio tags, PIT tags do not rely on a battery for power and therefore remain active in the stream indefinitely. Tag loss is less of an issue for stationary PIT tag arrays because they require fish to swim through or by to be detected (Zydlewski et al., 2001). In contrast, PITpacks move to the tags, and therefore do not require the tag to move to be detected. As a result, it is especially important to distinguish between tags in stationary live fish and tags lying on or slightly below the substrate.

Due to the limited testing of portable PIT tag detection systems used in previous and current studies, we address several technical and biological aspects of portable PIT technology. First, PITpack design was examined and refined. In addition to technical design, PITpack technology is dependent on the successful implantation and retention of a PIT tag. Therefore, our second objective was to quantify tag loss and survival of PIT tagged hatchery steelhead trout over a 4-month period. Third we documented the transition of a technology from design-level to field application by examining detection efficiency in a third order tributary. Finally, integrating technology and fish biology, we examined fish behavior upon the approach of an antenna.

2. Materials and methods

2.1. PITpack design and construction

All PITpacks utilized Destron Fearing[1] FS1001A DC powered full duplex transceivers and custom designed portable antennas. When a Destron Fearing PIT tag was within range of an antenna it emitted a 134.2 kHz (ISO standard frequency) radio frequency, which was transmitted back to the transceiver for decoding. All antennas consisted of several wraps of 12–18 gauge wire, with inductance values from 325 to 375 μH, and a set of capacitors. The capacitors were attached to an antenna lead cable from the transceiver fixing the capacitance between 33 and 44 nF. The fixed capacitance was used in conjunction with the adjustable capacitance within the transceiver to tune the resonance frequency of the system to the desired 134.2 kHz. The tuning of the adjustable capacitor was performed while antennas were submerged in water. The antennas were enclosed in an airtight PVC wand and attached to the transceiver. All tests and field experiments were conducted with PITpack systems tuned to phase 0–2%, signal 1–20%, current 2.5–5.0 A. PITpacks were designed for use with Destron Fearing PIT tags (23 mm long, 3.4 mm wide and 0.6 g in air). The transceiver was modified to allow the use of an external buzzer to alert the operator of a tag detection.

The 2002 PITpack was designed and built by Destron Fearing. A FS1001A transceiver and battery packs (two 12 V 0.5 AH rechargeable batteries) were enclosed in the standard transceiver housing and attached to an aluminum framepack. In 2003, the transceiver and battery pack were enclosed in a Pelican™ case attached to a framepack. In 2004, to reduce the overall dimensions and weight of the PITpack, the transceiver components were removed from their original housing and mounted directly inside a smaller and lighter watertight case attached to a framepack. This reduced the weight of the backpack component from 17 kg in 2003 to 12 kg in 2004.

The antenna design was also improved over the duration of the evaluation. The 2002 antenna was a 46 cm^2 square antenna attached to a 2 m PVC wand. The read range was approximately 30 cm off the plane of the antenna and the antenna weighed 2.3 kg. Several tests were conducted in 2003 to improve the performance of the 2002 antenna. Different gauge wire, and antenna angle were evaluated according to their read range.

Three antenna designs were tested (Fig. 1). A ribbon cable antenna was constructed of several wraps of 14 gauge ribbon cable so that wires were stacked perpendicular to the antenna plane. A tubular antenna was constructed of several wraps of 12 gauge wire loosely bound together. A third “flat plate” design was built with several wraps of 12 gauge wire lying side by side horizontally (so that no wires were overlapping).

[1] Mention of trade names or commercial products does not constitute endorsement or recommendation by the US Government.

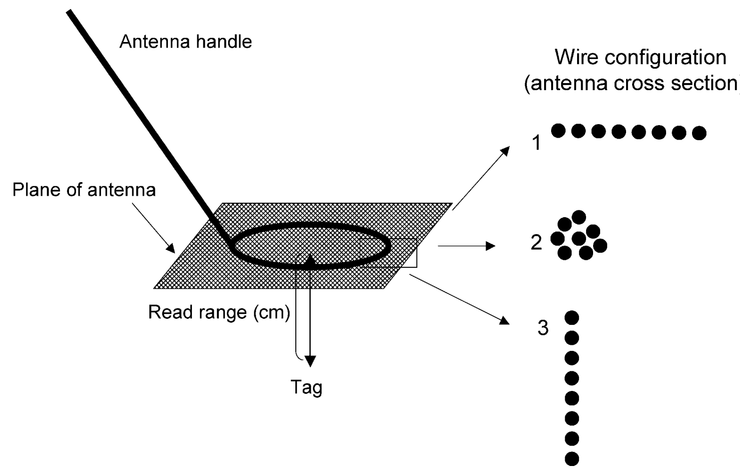

Fig. 1. Evaluation of antenna design. Three antennas were constructed with differing wire configurations: (1) 14 gauge non-overlapping ribbon cable inside of 1 inch PVC; (2) several wraps of overlapping 12 gauge wire bound loosely together inside of 1 inch PVC; and (3) several wraps of 12 gauge wire lying side-by-side horizontally. Read range, the distance between the antenna and the tag when the tag is read at a consistent rate, was measured at eight points around the antenna. This was conducted for the three antenna designs held at different orientations to the PIT tag (0°, 45° and 90°).

Read range (the distance between the antenna and the tag when the tag is read at a consistent rapid rate) was measured at eight points around the antenna at three orientations (0°, 45° and 90°).

All initial antenna design tests were conducted in air; the best performing model was then tested in the stream. The stream testing resulted in several modifications to the antenna to allow it to withstand prolonged use in the stream without malfunction. Loose wires and breaks in the waterproof seals were the most common problems. These tests resulted in the construction of a ribbon cable wire (14 gauge) antenna enclosed in a 0.55 m × 0.40 m PVC oval and attached to a 2 m PVC antenna wand. Design improvements increased read range to 45 cm off the plane of the oval loop; the antennas weighed 4 kg. The design was further improved in 2004 by better matching the inductance and capacitance; the antenna shape and size remained the same as those reported for 2003. Read range increased to between 60 and 91 cm with the antenna submerged in water. In addition, the antenna was attached to an adjustable fiberglass wand (ranging from 1.8 to 2.5 m). The fiberglass wand was more rigid than the previously used PVC material, and this made it easier to push the antenna through the water.

2.2. *Tagging: loss and mortality*

Hatchery steelhead trout from a native broodstock program established at the US Fish and Wildlife Service Abernathy Fish Technology Center (AFTC), Longview, WA were PIT tagged in January of 2003 ($n = 1000$) and 2004 ($n = 1392$) when they were 163 ± 40 mm fork length (mean ± S.D.), and weighed 43 ± 26 g. Over a 3-day period all fish were removed from crowded sections of three raceways to troughs for coded wire tagging (CWT) and PIT tagging. Steelhead to be PIT tagged were anaesthetized with MS-222 (100 mg l^{-1}, buffered with sodium bicarbonate to pH 7.0) and a 23 mm PIT tag was inserted into the fish via an incision into the peritoneal cavity (suturing was not required for fish of this size, as per Zydlewski et al., 2001). After tagging, fish were allowed to recover in a different trough for up to 3 h. After recovery, fish were netted and bucketed back to their original raceway. In 2003, approximately every 25th fish to be CWT'ed was given a PIT tag rather than a CWT. In 2004, all fish were CWT'ed, adipose fin clipped, and approximately every 25th fish received a PIT tag (Table 1).

In both years, all three raceways were checked daily for mortalities. All mortalities were scanned with a 2002 Destron Fearing FS 2001 reader to detect the presence of a PIT tag. The proportion of tagged and untagged fish that died in each raceway was compared using χ^2 analysis. The lengths and weights of tagged and untagged mortalities were compared using *t*-tests. To assess tag loss, a large rolling magnet (length = 0.9 m) was pushed along the raceway bottom prior to weekly cleanings. Tags removed with the magnet were assumed to be the result of tag loss, not fish mortality. To reduce the chance of underestimating tag mortality and overestimating tag loss, an attempt was made to remove mortalities from the raceway with the fish and PIT tag intact (within 24 h). In 2004, to reduce stress to the steelhead, magnets were installed on the raceway bottom next to the outflow screen. These magnets collected lost tags that were swept to the end of the raceway. Additionally, the raceways were walked through monthly with the rolling magnet to retrieve any additional lost tags. The lengths and weights of fish that lost and retained their tags were compared using *t*-tests.

A blind efficiency test of the rolling magnet was conducted on 3 February 2003. Tags were scattered along the bottom of an unused raceway with similar water flow (0.01 cm/s) to the raceways containing the steelhead. The magnet was systematically rolled over the raceway bottom by a person who was unaware of the number or location of tags. The

Table 1
Number of passive integrated transponder (PIT) and coded wire (CWT) tagged hatchery steelhead tagged per raceway (RW) in 2003 and 2004

	RW 3		RW 4		RW 5	
	PIT	CWT	PIT	CWT	PIT	CWT
2003						
Steelhead	321	10130	348	10058	331	10886
Mortality	6	67	12	204	9	90
Tag loss	34	na	32	na	34	na
Total released	281	10063	304	9854	288	10796
2004						
Steelhead	457	9811	466	9711	469	10522
Mortality	14	70	10	43	0	21
Tag loss	38	na	25	na	7	na
Total released	405	9741	431	9668	462	10501

Total released = total tagged − mortality (PIT and CWT) − tag loss (PIT) between 23 January and 17 April 2003.

procedure was then repeated. In both trials 23 tags were distributed throughout the raceway, and all 23 PIT tags were recovered.

2.3. Efficiency

PITpack efficiency was determined in representative 50 m section(s) of Abernathy Creek, WA in 2002, 2003 and two sections in 2004. Abernathy Creek has a mean summer channel width of 7 m and mean spring channel width of 10 m. Habitat surveys have been conducted in two intensively studied sections of the creek (river km 3 and 7.5). In the spring, these sections have a mean depth of 2.7 and 2.4 dm respectively (ranging between 0.1 and 5.8 dm) and mean flow of 0.42 and 0.44 m s^{-1} (ranging between 0.00 and 1.43 m s^{-1}); the substrate is predominately cobble-boulder (Hill, 2004). In all years efficiency tests were conducted between (08:00 and 17:00 h) on dry days in the summer. Blocknets were stretched across the upstream and downstream boundaries of the sites to prevent fish from escaping the study sections. A backpack electrofisher (Smith Root LR-24) was used to elicit taxis from juvenile steelhead trout. Reacting steelhead (≥100 mm) were captured by netters and placed in a recovery bucket. After the survey, all fish captured were interrogated for PIT tags. Fish not previously PIT tagged were implanted with 23 mm PIT tags and released throughout the blocknetted section (Table 2). The operators were unaware of the number of tagged fish in the section at the onset of the trial.

Table 2
Number of PIT tagged fish released into blocknetted sections and recaptured by single pass PITpacking surveys

Year	PIT tagged fish	Recaptured	Efficiency (%)
2002*	19	5, 5	25
2003	21	8	38
2004	20	7	38
2004	8	3	38

* In 2002, two trials were conducted by an individual operator. Both operators recovered five fish.

After an acclimation period (at least 1 h), operators(s) scanned the section for PIT tagged fish. The PITpack capacitance was matched to the daily water conditions (tuning) before each trial. The operators(s) then slowly moved upstream through the section scanning all available habitats. The antenna was held at a 45° angle perpendicular to water flow. In 2002 one operator worked back and forth through the stream scanning the entire stream width (mean stream width 7–11 m). In 2003 and 2004, two operators worked through the sections, walking side-by-side each scanning half the creek. In 2002, the blocknets were maintained through the night, and the trials were repeated 24 h post-tagging (Zydlewski et al., 2002). In 2003 and 2004, the sections were electrofished to depletion after PITpacking.

2.4. Fish response: PITpack avoidance

In summer 2003 an experiment was conducted to evaluate the behavior of steelhead trout approached by antennas in a semi-natural stream, an outdoor stream channel with vegetation, substrate and cover that received constant flow from AFTC to Abernathy Creek. Fish were not allowed to leave the system; the inflow pipe to the stream was blocked with screening and two blocknets were placed 18 m downstream. The average width of the semi-natural stream was 2.5 m. Substrate ranged from fines to cobble. The stream was heavily shaded by overhanging vegetation and contained high levels of aquatic vegetation. Habitat units within the study included three pools and two riffles.

Steelhead trout (fork length: 183 ± 19 mm, weight: 69 ± 20 g) from Big Creek Hatchery (Washington Department of Fish and Wildlife, WDFW) were marked externally with neon streamer tags and internally with PIT tags. Commercially available streamer tags were not readily available for small fish; therefore a 5 cm long neon monofilament streamer was tied to a size 12 snap swivel. Fish were anaesthetized with MS-222 (100 mg l^{-1}, buffered with sodium bicarbonate to pH 7.0). A small hole was made through the tissue behind the dorsal fin with a suture needle and a 1 cm loop was then tied with the 3.0 metric silk suture thread. The streamer was then attached to the suture loop with the snap swivel. Fish recovered in a tank with flow through water at 11 °C for 2 weeks before they were used in behavioral trials. All fish survived tagging and the behavioral trials.

Two fish were placed in the semi-natural stream at a time. The fish were allowed 24 h to acclimate to the stream. A operator then started at the downstream blocknet and proceeded upstream to the inflow pipe. An observer watched the fish response to the approaching antenna and video taped the trials. The procedure was repeated with eight different fish (four pairs).

3. Results

3.1. PITpack design and construction

The longest read range in any one direction off the antenna plane was recorded when antennas were held at 90° to the tag, regardless of wire configuration. However, the field was not evenly distributed around the antenna; the antennas had long detection distances in one direction but were short in all other directions. In contrast, antennas held at 45° to the water surface performed consistently in all directions with a mean read range similar to the 90° antennas. The tubular design had the shortest read range compared to the flat plate and the ribbon cable designs. The range of the flat plate antenna was slightly greater than the ribbon cable design (Fig. 2).

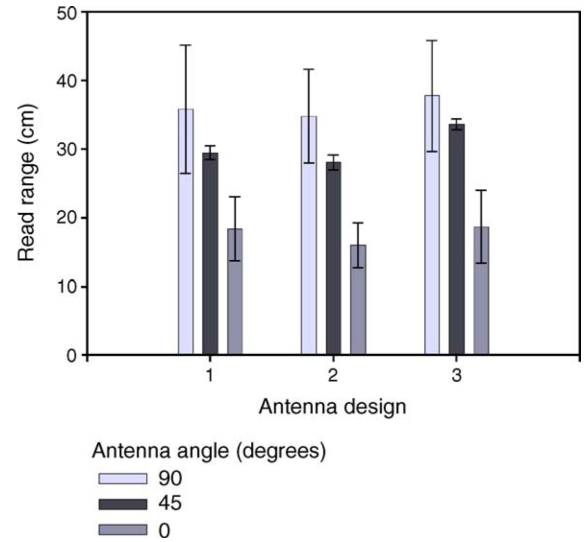

Fig. 2. 2003 antenna design comparison several wraps of: (1) 14 gauge ribbon cable to fit inside of 1 inch PVC pipe; (2) 12 gauge wire loosely gathered together to fit inside of 1 inch PVC pipe; and (3) 12 gauge wire laid side-by-side (non-overlapping) to lie flat in sheet PVC. Read range was measured at eight equally spaced intervals around the antenna at 0°, 45° and 90° (in air) for the three models. Mean read range and standard deviation (error bars) are displayed.

3.2. Tagging: loss and mortality

Daily tag recovery revealed a low incidence of tagging mortality (Table 1). In 2003 and 2004, PIT tagged fish had slightly higher mortality (2003: 1.97%, 2004: 1.70%) than non-PIT tagged fish (2003: 0.49%, 2004: 0.50%) (Table 1). In 2003, PIT tagged fish had significantly higher mortality that non-PIT tagged fish in raceway 3 and raceway 5 ($p < 0.01$). However, mortality in raceway 4 was similar for PIT tagged and non-PIT tagged fish ($p = 0.08$). In 2004, PIT tagged fish had significantly higher mortality than non-PIT tagged fish in raceway 3 and raceway 4 ($p < 0.01$). In contrast, mortality in raceway 5 was similar for PIT tagged and non-PIT tagged fish. Fish that died following tagging were significantly smaller at tagging than survivors (Fig. 3; $p < 0.01$). The average weight of tagged fish was 48 ± 24 g, the average weight of fish that died was 20 ± 7 g, none of the larger fish (>35 g) died.

In 2003, 81 tags were retrieved from the raceways; 72 were retrieved in 2004. Known tag loss in 2003 was 7.2 and 5.0% in 2004. Tag loss peaked at week 4 in 2003; however, fish lost tags at a slower rate through the remainder of the study. Fish that lost their tags were significantly smaller, 27 ± 17 g, than those that retained their tags, 48 ± 24 g ($p < 0.01$).

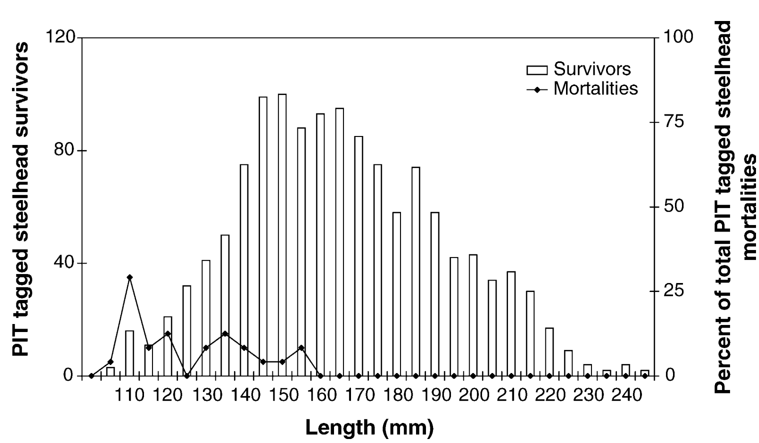

Fig. 3. Fork lengths of PIT tagged hatchery steelhead trout that survived to release (bars) and those that died (line) in the months following PIT tagging.

3.3. Efficiency

Average detection efficiency in 2002 with one operator for one pass was 25% (Table 2). In the first trial, both operators detected five tags of 19 tags available. Only one of the 10 tags was common between the operators. During the second trial (24 h post-tagging), each operator detected four tags. Two tags were detected by both operators (for six original detections) (Zydlewski et al., 2002).

Average detection efficiency in 2003 with two operators was conservatively estimated to be 38% in a single pass. Of the 21 fish tagged and released into the blocknetted section, two operators recovered eight fish during their first pass, one on the second pass and five during the third pass. Due to water in the antenna, resulting in reduced read range, all but one fish was detected by a single PITpack. Due to blocknet failure (two fish were detected outside the nets), only eight of the 19 fish released were recovered by multipass electrofishing (three of those eight were detected by the PITpacks). This leads to a conservative efficiency estimate of 38% with two operators working through a section once.

In 2004, PITpacking occurred before and after electrofishing. In the first section, one PIT tagged fish (from another study) was detected with the PITpack prior to electrofishing. This same fish was captured during the electrofishing survey. Twenty additional fish were implanted with 23 mm tags and released back into the blocknetted sections for a total of 21 PIT tagged fish. Seven tagged fish were detected in the post-electrofishing PITpack survey. In addition, one PIT tagged fish (from another study) that was missed during the initial PITpacking and electrofishing was detected. A conservative estimate of efficiency of this trial is 38%; this excludes the one additional fish and the pre-electrofishing PITpack detections.

This same procedure was conducted in a second blocknetted section with a lower natural abundance of fish. No PIT tagged fish were detected with the PITpack prior to electrofishing. However, one PIT tagged fish was recovered during electrofishing of the same site. Of the eight fish tagged and released in the section, three were detected in the post-electrofishing PITpack survey. Based on this, efficiency is estimated to be 38% with two operators.

3.4. Fish response: PITpack avoidance

In the semi-natural stream, seven of the eight fish remained near the substrate and did not move upon detection. The eighth fish scared within the pool it was detected in, and it returned to its original location within 45 s of detection.

4. Discussion

The optimal PITpack system is lightweight, waterproof and operates for a continuous time period (no less than 8 h) without changing battery packs. The antenna is pushed through the water with as little effort as possible to avoid fatigue to the operator, but it is sturdy enough so that it does not break during transport or use. Through formal evaluation of antenna design and field testing, our PITpacks better meet these criteria. The 2004 PITpacks weighed less, had adjustable wands and handles, and were more durable than previous models. The wand and antenna components were separated with a water-tight connector so that antennas and wands could be exchanged quickly if one part malfunctioned. PITpack batteries lasted for 8 h of continuous use and could be quickly exchanged if more time were necessary. In addition, an adjustable handle was added to the pole. This made the antenna easier to hold and more stable in high water. The adjustable wand allowed operators to extend the pole in deep waters or to reach into rootwads and logjams. Conversely, the wand could be shortened in high flows for increased stability.

Although laboratory results suggested that flat plate antennas have a greater read range, a tubular design was chosen because it created less drag in the water thereby decreasing noise and increasing usability in the field. In this way, the read range of the PITpack was improved, without negatively affecting the usability, from an average of 30 cm in 2002 to 90 cm in 2004. In air, the antenna performed consistently when held at a 45° angle. In the stream, this orientation also resulted in a consistent efficiency (38%). However, this orientation is only optimal when the tag is parallel to the water surface. Although, this will not always be the case, the use of 23 mm tags in relatively small fish increases this probability. These advances have allowed portable PIT technology to be used in streams larger than reported in previous studies (Morhardt et al., 2000; Roussel et al., 2000; Zydlewski et al., 2001).

However, these design improvements are only valuable if PIT tags are successfully implanted and retained by the tagged animal. Mortality of PIT tagged fish was significantly higher compared to untagged fish in the same raceways in most cases. Fish were reared in outdoor raceways that operated on creek water and were subjected to CWT tagging, high turbidity events, predation and disease outbreaks uncharacteristic to tank studies. In contrast, Zydlewski et al. (2002) reported no significant difference in mortality of PIT tagged and control steelhead that were tagged using the same surgical procedure but held in tanks. The slightly higher mortality in this study possibly resulted from the added stress of handling for CWT and adipose fin clipping and different environmental conditions (raceway) than other studies (tanks or natural environment).

Tag loss fell within the range reported by other researchers. Prentice et al. (1990) reported tag loss of less than 1% in chinook salmon tagged with 12 mm tags. In contrast, Roussel et al. (2000) reported tag losses of 15.2% for unsutured atlantic salmon tagged with 23 mm tags. Tag loss was slightly lower than previous studies in hatchery steelhead trout (Zydlewski et al., 2002). Tag loss recorded in 2003, 7.2%, is probably a more accurate estimate than that recorded in 2004, 5%, due to the regular and active retrieval of tags with the rolling magnet in 2003. Tag loss peaked 4 weeks after the tagging event. In this instance an estimate of tag loss 2 weeks after tagging would only have accounted for 4% of the overall tag loss. This suggests the duration of tag loss studies may need to be extended for accurate estimates of tag retention. Tagging environment, tag size, species, and fish size are likely to affect the magnitude and timing of tag loss and mortality.

Likewise, stream characteristics are likely to affect the field application and efficiency of PITpacks. Due to Abernathy Creek's width, depth and high flows, it is likely at the upper end of streams where PITpacks would be efficient. During high water, the creek becomes unwadable, and during low flows several pools are too deep to wade through without submerging the PITpacks. Even with the addition of a second operator it is difficult for the operators to obtain the optimal antenna orientation and depth. The operators often must move back and forth several times to scan the entire stream width. Roussel et al. (2000) reported an efficiency of 87.3% in a similarly sized stream, Catamaran Brook. These difference in efficiencies may exists because of differing PITpack technology (Roussel et al. used Texas Instruments equipment), survey technique or stream characteristics. We scanned stream sections with a consistent effort (0.58 m/min); all habitats were scanned equally and no areas were resampled. This protocol was chosen to be consistent with other field studies ongoing in Abernathy Creek (Hill, 2004). These survey method details were not reported by Roussel et al. (2000) and may partially account for the differing efficiencies. Although the streams are similarly sized, Abernathy Creek has several undercut banks, deep holes and woody debris jams which in some instances allow fish to reach areas beyond the detection range. In contrast, the study reach in Catamaran Brook did not have any obstacles for the operators to work around (Roussel et al., 2000).

Thirty-eight percent falls within the range of previous portable PIT detection units, 25–85% (Morhardt et al., 2000; Roussel et al., 2000; Zydlewski et al., 2001; Cucherousset et al., 2005). The range in efficiencies is most likely due to tag size, equipment read range, species of fish and size of stream. Most notably, most of these efficiencies were recorded in streams much smaller than Abernathy Creek (Morhardt et al., 2000; Zydlewski et al., 2001; Cucherousset et al., 2005). PITpack efficiency also falls within the lower range of electrofishing survey efficiencies (33–65%, Pratt, 1952; Webster et al., 1955; Lennon and Parker, 1957). However, electrofishing surveys, especially repeat surveys, have the disadvantage of injury (Ainslie et al., 1998) and behavioral changes (Mesa and Schreck, 1989) that can result from exposing fish to electricity. In addition to direct effects of electricity, fish handling for data collection is a source of stress associated with electrofishing.

PITpacks also have minimal effect on fish location. When a tag was detected in the creek, the operators usually repeatedly scanned the area, gently disturbing the substrate. If the tag remained in the detection field throughout the data collection procedure, the fish was recorded as "stationary." These stationary detections could either represent a stationary fish, a rejected tag, or a tag remaining after the mortality of the fish. One-hundred and eleven of the fish detected in PITpack surveys were detected later in the season at two stationary swim-through antennas located on Abernathy Creek. During the PITpacking surveys, 54 of 111 dual detections were recorded as "moving." Fifty-seven remained stationary at the time of detection; yet, these tags are known to be in live fish because of their subsequent downstream detection at stationary sites. These results indicate that stationary tags could likely be live fish and should not be ignored. Although these results indicate that many steelhead were not disturbed by PITpacking, it does not indicate the number of fish that swam away before the PITpack got close enough to register the tag code.

Behavioral observations can be used to assess pre-detection disturbance. Streamer tagged fish observations indicated that few steelhead were displaced as PITpacks approached. The majority of fish did not scare during the artificial stream trials, and the one that did quickly resumed its territory following disturbance. However, fish tended to stay near the upstream boundary of the artificial stream, and this may have decreased their ability to swim away when approached by the antenna. Therefore, in 2004 observations were made in the main channel of Abernathy Creek. Several wild steelhead of different age classes (at least 0+ and 1+, probably some 2+; size range was 80–140 mm FL) were observed by snorkel in the main channel of Abernathy Creek on 17 August. Two snorkelers watched fish as they were approached by a PITpack. The snorkelers observed that some of the fish moved lower in the water column, and some of the larger fish moved approximately 50 cm upstream of the PIT tag antenna. None of the observed steelhead moved out of range of antenna detection, and steelhead quickly resumed their positions in the pool (Riley pers. comm.). All three methods of assessing steelhead response to PITpacks indicate that disturbance is minimal. These are the first observations of fish behavioral responses to portable PIT tag detection systems and will hopefully trigger more rigorous evaluations. This is especially important as fish response to portable detection units likely vary by species, age class, environmental conditions and the unit's construction and operation.

These results yield a field protocol for the use of PITpacks in wadable streams. Two operators working upstream with antennas held 45° to the water flow resulted in consistent efficiencies in Abernathy Creek. When PITpacks are employed in this manner, there is minimal disturbance to fish behavior and habitat use.

Acknowledgements

Data collection and reporting for 2003 were funded through the Bonneville Power Administration and the US Fish and Wildlife Service SCEP program. Data collection and reporting for 2004 were funded by the US Fish and Wildlife Service Oregon State Office.

We would like to thank Don Campton, Jeff Poole, Michele Grooms, Paul Larson, and John Holmes for spawning, handling, and maintaining hatchery brood stock and their progeny. We would like to thank the US Fish and Wildlife Service Columbia River Fisheries Program Office for coded wire tagging the hatchery fish. We thank Sean Casey, Roger Clarke, Jeff Johnson, and Dee McClanahan for helping in the development of the PITpacks. We thank many people for helping in efficiency and behavioral testing of the PIT-pack equipment: Bill Gale, Jeff Hogle, John Brunzell, Casey Jackson, John Holmes, Dee McClanahan, Christiane Winter, Steve Riley, Chris Tatara, and others. We thank Brian Tissot, Cheryl Schultz and Judy Gordon for reviewing the manuscript.

References

Ainslie, B.J., Post, J.R., Paul, A.J., 1998. Effects of pulsed and continuous DC electrofishing on juvenile rainbow trout. N. Am. J. Fish. Manage. 18, 905–918.

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

Cucherousset, J., Roussel, J.M., Keeler, R., Cunjak, R.A., Stump, R., 2005. The use of two new portable 12 mm PIT tag detectors to track small fish in shallow streams. N. Am. J. Fish. Manage. 25, 270–274.

Gibbons, J.W., Andrews, K.M., 2004. PIT tagging: Simple technology at its best. Bioscience 54, 447–454.

Hill, M.S., 2004. Habitat use and physiology of PIT-tagged hatchery and wild steelhead trout smolts. Master's thesis. Washington State University, Vancouver.

Lennon, R.E., Parker, P.S., 1957. Electric shocker developments on south-eastern trout waters. Trans. Am. Fish. Soc. 85, 234–240.

Mesa, M.G., Schreck, C.B., 1989. Electrofishing mark-recapture and depletion methodologies evoke behavioral and physiological changes in cutthroat trout. Trans. Am. Fish. Soc. 118, 644–658.

Morhardt, J.E., Bishir, D., Handlin, C.I., Mulder, S.D., 2000. A portable system for reading large passive integrated transponder tags from wild trout. N. Am. J. Fish. Manage. 20, 276–283.

Pratt, V.S., 1952. A measure of efficiency of alternating and direct current fish shockers. Trans. Am. Fish. Soc. 81, 63–68.

Prentice, E.F., Flagg, T.A., McCutcheon, C.S., Brastow, D.F., 1990. PIT-tag monitoring systems for hydroelectric dams and fish hatcheries, Am. Fish. Soc. Symp. 7, pp. 317–322.

Quintella, B.R., Andrade, N.O., Espanhol, R., Almeida, P.R., 2005. The use of PIT telemetry to study movements of ammocoetes and meta-morphosing sea lampreys in river beds. J. Fish Biol. 66, 97–106.

Roussel, J.-M., Haro, A., Cunjak, R.A., 2000. Field test of a new method for tracking small fishes in shallow rivers using passive integrated transponder (PIT) technology. Can. J. Fish. Aquat. Sci. 57, 1326–1329.

Webster, D.A., Forney, J.L., Gibbs Jr., R.H., Severns, J.H., Van Woert, W.F., 1955. A comparison of alternating and direct electric currents in fishery work. N. Y. Fish Game J..

Zydlewski, G.B., Haro, A., Whalen, G., McCormick, S.D., 2001. Performance of stationary and portable passive transponder detection systems for monitoring of fish movements. J. Fish Biol. 58, 1471–1475.

Zydlewski, G.B., Winter, C., McClanahan, D., Johnson, J., Zydlewski, J., 2002. Evaluation of fish movements, migration patterns, and population abundances with Streamwidth PIT tag Interrogation systems. Bonneville Power Administration Report # 2001-012-00.