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A New Low-Cost Instream Antenna System for Tracking Passive Integrated Transponder (PIT)–Tagged Fish in Small Streams

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Abstract.—We present a new, low-cost, low-power, half/full-duplex passive integrated transponder (PIT) tag interrogation antenna for use in detecting fish movements in small streams. New technology by Allflex-USA allowed us to develop a reading system with an antenna 279.4 cm wide × 60.9 cm high that reads both common tag types used in fisheries today for about US$1,000. An instream antenna of this size and price makes high-resolution tracking of fish movement in small streams feasible where cost and tag-type restrictions were prohibitive. For evaluation, we placed the antenna upstream of a small estuary on the central California coast to observe the diel movements of juvenile steelhead *Oncorhynchus mykiss* between the estuary and upstream habitats in both spring and fall months.

For years, fisheries biologists have proven the potential of passive integrated transponder (PIT) tags to provide accurate measurements of the growth, survival, and movement of individual fish (Roussel et al. 2004). Because PIT tags are generally small, inert, and require no battery, they can easily last the life of the tagged animal. Several types of systems for monitoring fish with PIT tag technology have been developed. Handheld wand-type designs have been used to actively seek fish in specific habitats by moving through a stream to find fish (Roussel et al. 2000; Zydlewski et al. 2001; Cucherousset et al. 2005; Hill et al. 2006). In addition, as PIT tag technology has matured, the tags have been used in conjunction with automated instream readers to measure fish movement at larger spatial scales (Armstrong et al. 1996; Castro-Santos et al. 1996; Lucas et al. 1999). However, the high cost of these systems can be prohibitive when many reader installations are required to detect movement patterns with high resolution. In addition, low-cost readers are generally built with off-the-shelf components from Texas Instruments Radio Frequency Identification Systems (Texas Instruments, Dallas, Texas) designed to read only half-duplex (HDX) PIT tags. Half-duplex tags are 23.1 mm long, 3.9 mm in diameter, and 0.6 g in weight and are appropriate only for larger fish (e.g., salmonids >80 mm fork length [FL]) because the tag may harm or otherwise inhibit the movement of smaller fish. Full-duplex (FDX) tags are much smaller (11.5 mm long, 2.1 mm diameter, 0.09 g weight) and are appropriate for use in smaller fish (~65 mm FL). Similarly sized tags have been used in salmonids without observable effects on survival, growth, or swimming performance (Prentice et al. 1990). However, instream reading systems for these tag types are often far more expensive than those for HDX tags (US$5,000–$20,000; Hammer and Blankenship 2001; Riley et al. 2003). In the past, fish biologists have been forced to choose between employing FDX or HDX tag types and then to develop a reading system around the tag type of choice. This has also meant that if experimental design requires changing tag type (e.g., tagging smaller fish) then both types of reading systems would be required simultaneously, one to read historic tags and one for the new tagging protocol. In this study we developed a reading system for approximately $1,000 that is large enough to maintain adequate stream coverage during all but the highest flows in small streams. This low-power system simultaneously reads both FDX and HDX tags using Allflex-USA, Inc. (Dallas–Fort Worth Airport, Texas) technology to both power the antenna and communicate tag numbers to a logging device. The Allflex-USA circuitry utilized in this study conforms to International

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Standards Organization (ISO) animal tagging standards (11784/5), meaning that it reads both common 134.2-kHz tag types (HDX and FDX) in use today. This technology has been in use by the pet and livestock industry for years (Babot et al. 2006) but is almost unknown in fisheries (Zydlewski et al. 2006). This system was tested for reliability by placing it at the freshwater–estuary interface to monitor the timing of steelhead movement into and out of the estuary for several months.

Methods

Antenna construction.—We designed an antenna with an inductance of about 250,000 nH using an antenna inductance calculator (UMR, EMC 2001). Our antenna was constructed as six turns of 10 American wire gauge (AWG) solid copper wire encased in 2.5-cm-diameter polyvinyl chloride (PVC) pipe. To do this, six pieces of wire, each cut to slightly more than the length of one turn (691 cm), were strung through the PVC housing as it was being assembled. Before final sealing of the housing, the six wires were trimmed to exact length and soldered together to form a six-turn loop with two free ends. A two-conductor 18 AWG antenna power cable was soldered to the remaining two free ends of wire and threaded through a watertight pass-through. The antenna assembly was then glued closed to keep water from coming into contact with any antenna wires. The PVC antenna pipe was cut to appropriate lengths to ensure the rectangular shape was constrained to 279.4 cm × 60.9 cm with little room for antenna movement. The bare version 1 Allflex International Standards of Operation (ISO) panel reader board (P/N 820018–004), which is quite small (25 cm × 3.5 cm × 3 cm), was encased in a 35-cm-long piece of 3.8-cm-diameter transparent PVC pipe with watertight connectors passing data and power wires through caps in each end. The sealed reader was placed in a larger (7.6-cm-diameter) PVC pipe attached to the antenna with a watertight cable pass-through on both the reader housing and antenna. The reader to antenna connection cannot exceed 60 cm or performance will suffer. Once enclosed in pipe, the Allflex reader unit was tuned and mounted on the antenna itself, and both were bolted to the downstream side of a sturdy wooden frame with stainless steel and plastic hardware (Figure 1a). The frame was constructed of 10.16-cm × 16.24-cm lumber to provide a structure that would be strong enough to maintain the antenna shape during high flows and protect the antenna and reader assembly from damage. The lumber was beveled on the upstream side to alleviate the effect of hydrodynamic forces on the structure. A small plate of 6-mm-thick aluminum was fixed to the top of the wooden frame to prevent reader damage from stream debris (Figure 1b). Flexible PVC conduit 1.9 cm in diameter was attached to the 7.6-cm PVC pipe housing for the Allflex reader unit to ensure watertight connection for both antenna power and communications. Conduit lengths of 23 m were achieved by using 12 AWG stranded copper wire for reader power and four-conductor, low-capacitance communications wire, which allowed the power and data logger to be placed safely on the stream bank. The shore end of the power and communications conduit was connected to a large waterproof case by watertight conduit connectors. Inside the case, two 225-amp–hour (AH), 6-V batteries arranged in parallel configuration powered the reader unit and a data logger (Figure 1c).

The ISO reader unit sent the tag number across a 9,600-baud serial port immediately after each tag reading but had no internal memory to store tags or a clock to record time stamps. We used a small logging device of our own design to capture fish tag numbers and record the date and time of each event; however, any device capable of reading an RS232 or RS422 serial port could log the data from the Allflex reader (e.g., Palm-type device, handheld computer, or laptop) with a simple terminal program. Our data logger is a simple device built on a small (6 cm × 10 cm) custom circuit board (expresspcb.com) around a PIC LF88 microcontroller (microEngineering Laboratories, Inc., Colorado Springs, Colorado). The device uses a watch battery and clock chip to log the time and date of each tag event, which are stored in flash memory capable of storing 2,000 tag events. A serial driver–receiver operates two serial ports, one to receive communication from the ISO reader and the other to download the data with a PDA or laptop computer. Total cost of each logger with printed circuit boards is less than $60. The total cost for the entire instream reading system with our data logger, was approximately $1,045. However, costs vary with installation type, and sites that have special requirements may require a larger investment to outfit properly (e.g., extreme debris load, poor streambed substrate, long power–communications cable, freezing temperatures).

Monitoring estuary movements of juvenile and adult steelhead.—In April of 2004, we placed the reader–antenna system at the head of the estuary of Scott Creek, a small stream in coastal central California (37°02′22″N, 122°13′44″W). The reader–antenna frame was bolted to the streambed with stainless steel cables and bolts, and a small-mesh blocking net was used to ensure that all fish moving through that section of stream would pass through the upright antenna window. The power and communications conduit was run up the stream bank and fixed onto the waterproof battery and data logger box. Once the reader–antenna

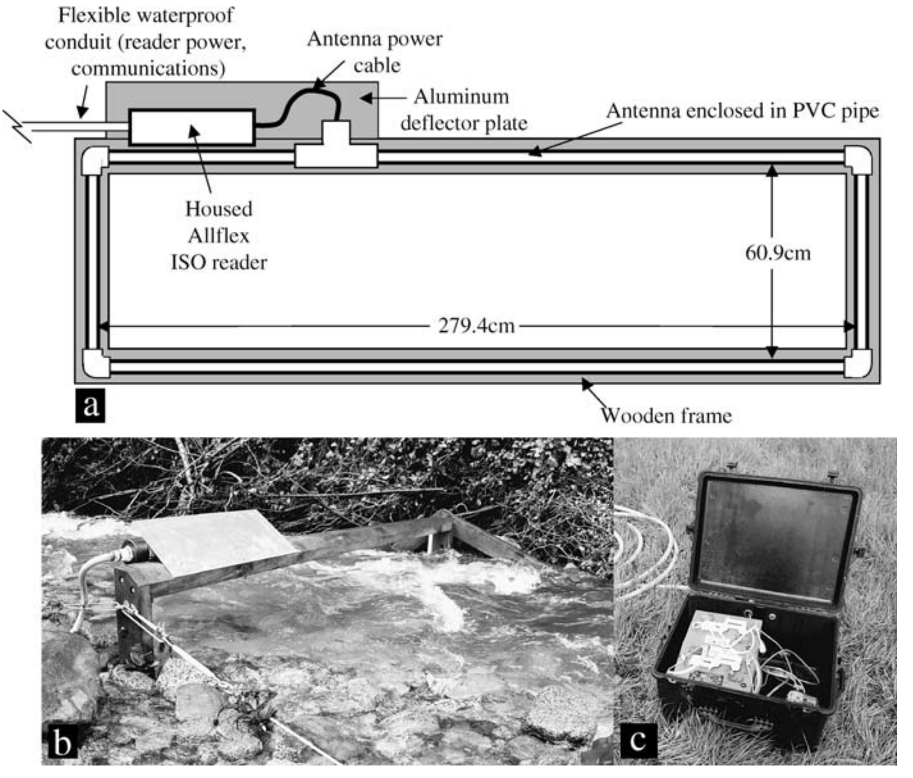

FIGURE 1.—Panel **(a)** shows the antenna assembly from the downstream side. The PVC housings for the antenna wire and the reader are bolted to a wooden frame with plastic conduit clamps and stainless steel screws. A small aluminum plate mounted on the upstream side of the antenna frame protects the reader unit from debris. Flexible PVC conduit carries power and communications lines to the reader. Panel **(b)** shows instream antenna installation in moderate flows, in which the wooden frame with beveled face and aluminum debris shield are visible. Panel **(c)** shows the power supply box with two batteries and conduit for power distribution and communications. A small data logger (not pictured) also resides in the box.

was in place, we tagged wild steelhead (>63 mm FL) with Allflex-USA FDX tags at the tail of the estuary near the ocean, approximately 1,000 m downstream from the reader–antenna. Fish were handled as detailed in Hayes et al. (2004). PIT tags were injected into the peritoneal cavity of each fish with a 12-gauge needle and syringe. We then monitored PIT tag detections to identify when steelhead tagged in the lower stretches of the estuary moved into upstream freshwater habitats.

Results and Discussion

Reader Operation

We tested the operation of the reader–antenna with Allflex FDX-B tags and Texas Instruments HDX tags. We evaluated a variety of antenna shapes and sizes and found that the smaller FDX-B tags limited the size of the antenna. Larger antennas may be capable of reading the HDX tags, but performance with FDX-B tags suffers. We found the 279.4 cm × 60.9 cm antenna shape was the largest antenna capable of reliably reading both tag types at any location within the antenna window. In this configuration, all tags were read when passed through the reading window perpendicular to the antenna at speeds no greater than 1 m/s. In addition, any tag passed perpendicular to the antenna within 8 cm of the outside of the reading window on any side was also read. Tag detection probability decreased when tags were passed at deviations from perpendicular. The antenna can also be placed flat on the stream bottom, where it will read tags moving within 20 cm of the antenna plane. For any orientation it is necessary that the antenna be kept in a very flat plane: even slight deformations from the specified shape will result in reduced reading range.

The antenna has a maximum reading frame of 40 cm for FDX tags, meaning that fish are read from 20 cm before to 20 cm after their passage through the loop. Reading of HDX tags is far more effective, having a

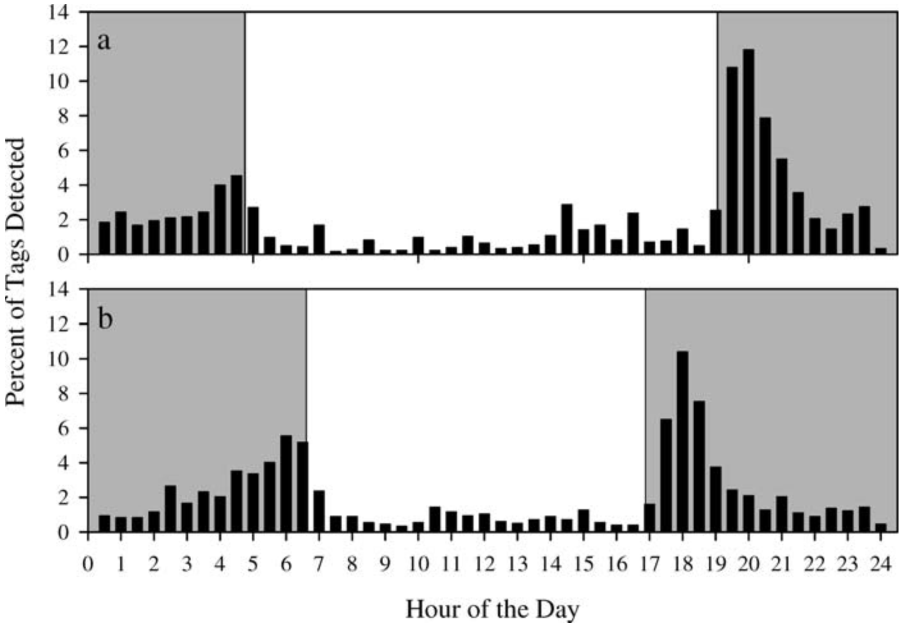

FIGURE 2.—Percent of estuary-tagged fish moving into and out of the estuary by hour of the day. The shaded area indicates the mean time of darkness (before sunrise and after sunset) for **(a)** spring (April 16–June 30) and **(b)** fall (October 1–December 6).

maximum reading frame of 152 cm. Alternating tag types (HDX and FDX) can be read in rapid succession as long as both tags do not occupy their respective reading frames simultaneously. The manufacturer advised that metals (even nonferrous) absorb the energy created by the antenna and will result in a reduced tag read range or a de-tuning of the antenna if any are placed within the reading frame. However, small amounts of metal, such as the stainless steel fasteners used in our installation, did not affect the reading performance in any measurable way. The reader is also susceptible to electromagnetic and radio interference, and sites should be checked to be free of outside noise before installation.

Using two large (225 AH lead–acid) 6-V batteries, we were able to sustain continuous reading for 12–20 d between battery changes. The reader unit and antenna typically draw between 400 and 900 mA at 6 V DC. Variations in power draw are due to slight deviations in the antenna shape from the ideal 279.4-cm × 60.9-cm shape, differences between readers, or both. These deviations are accounted for in the variable tuning capability of the ISO reader unit and do not seem to affect tag-reading performance. Additionally, we found that the small size of the reader package, low-power draw, and flexible antenna configuration may make this device particularly conducive to being configured as a handheld wand-type reader, which is becoming widely used in fisheries, for stream surveys.

Steelhead Movement from Estuary to Freshwater Habitats

Our original prototype antenna ran continuously from April 2004 to December 2004 with only minimal interruption to accommodate battery changes. Of the 231 steelhead tagged in the estuary, 146 steelhead were observed moving through the reader at least once throughout the summer and fall, for a total of 4,658 independent reads. These preliminary results indicate that in general, movement patterns were diel in nature, similar to what others have observed for salmonids (Greenberg and Giller 2000; Bradford and Higgins 2001), the vast majority of movement activity occurring just before dawn and immediately after sunset (Figure 2). We observed a shift in the time of the movement as the months progressed, the peak movement in fall occurring later in the morning and earlier in the evening than during spring months. This pattern is best explained by the change in timing of sunrise and sunset by season (Figure 2). It is unclear why the fish are making the transition from estuarine waters to upstream habitat and back. With only one reading station in place, we were unable to unambiguously determine the direction of movement for each event. However, trapping of fish just before or immediately following detection events has allowed us to determine that the bulk of upstream movement is occurring after dusk, indicating that fish are leaving the estuary in the evening and returning in the morning hours. A strategic placement of two readers, one upstream of the other, would allow us to definitively determine the direction of movement. Coupling of the movement data with environmental characteristics (e.g., food resources, flow, temperature, dissolved oxygen) may also help determine the motivation behind these movements.

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