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Development and evaluation of a boat-mounted RFID antenna for monitoring freshwater mussels

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Abstract. Development of radio frequency identification (RFID) technology and passive integrated transponder (PIT) tags has substantially increased the ability of researchers and managers to monitor populations of aquatic organisms. However, use of transportable RFID antenna systems (i.e., backpack-mounted) is currently limited to wadeable aquatic environments (<1.4 m water depth). We describe the design, construction, and evaluation of a boat-mounted RFID antenna to detect individually PIT-tagged benthic aquatic organisms (mussels). We evaluated the effects of tag orientation on detection distances in water with a 32-mm half-duplex PIT tag. Detection distances up to 50 cm from the antenna coils were obtained, but detection distance was dependent on tag orientation. We also evaluated detection distance of PIT tags beneath the sediment to simulate detection of burrowing mussels with 23- and 32-mm tags. In sand substrate, the maximum detection distance varied from 3.5 cm and 4.5 cm (vertical tag orientation) to 24.7 cm and 39.4 cm (45° tag orientation) for the 23- and 32-mm PIT tags, respectively. Our results suggest a 1.4-m total detection width for tagged mussels on the substrate surface by the boat-mounted antenna system regardless of tag orientation. However, burrowed mussels may require multiple passes to increase detection that would be influenced by depth, tag orientation, and tag size. Construction of the boat-mounted antenna was relatively low in cost (<500 USD) and had several advantages (less labor and time intensive, increased safety) over traditional mussel sampling techniques (diving, snorkeling) in nonwadeable habitats.

Key words: RFID antenna, PIT tags, freshwater mussels.

Freshwater mussels are important contributors to biodiversity and have several unique functional roles (e.g., filter feeder, spawning beds, ecosystem engineers) in aquatic ecosystems (Pitlo 1989, Vaughn and Hakenkamp 2001, Vaughn and Spooner 2006). Despite their importance, native freshwater mussels are one of the most imperiled taxa in North America. Most (>70%) of species are considered endangered, threatened, or of conservation concern (Williams et al. 1993, Lydeard et al. 2004, Strayer et al. 2004). The poor status of freshwater mussels has been attributed to a number of factors, including habitat modifications (e.g., impoundment, channelization, siltation), overexploitation, interactions with exotic species (e.g., zebra mussels, *Dreissena polymorpha*), and degradation of water quality (Williams et al. 1993, Strayer 1999, Lydeard et al. 2004, Poole and Downing 2004). The decline of freshwater mussel populations in North America has created the need to monitor remaining and reintroduced mussel populations precisely and accurately.

One technique that may provide important information for the management and conservation of freshwater mussels is tagging. Tagging methods can

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be used to obtain estimates of population abundance, dynamic rate functions (i.e., growth, recruitment, and mortality), habitat use, and movement (Guy et al. 1996). In particular, use of radio frequency identification (RFID; also known as passive integrated transponder [PIT] tag) technology has increased steadily because of its advantages over traditional tagging methods (e.g., high retention, individual marks, low error rate; Gibbons and Andrews 2004). Thus, RFID technology has been used to monitor mammals (Harper and Batzli 1996), birds (Carver et al. 1999), reptiles (Reina et al. 2002), amphibians (Gunzburger and Guyer 1998), fish (Zydlewski et al. 2001), and invertebrates (Bubb et al. 2002), including freshwater mussels (Kurth et al. 2007).

Several mobile RFID antenna systems have been developed for detecting PIT-tagged organisms with little or no handling. These systems include small hand-held readers (i.e., encased antenna), larger backpack readers (Roussel et al. 2000, Zydlewski et al. 2001, Bubb et al. 2002), and modified surface trawls with pass-through antennas in the cod-end designed to study migratory fish (Ledgerwood et al. 2004). Backpack readers use an antenna (wand) that is passed over organisms in their natural habitat (e.g., under a log, in a burrow). Use of RFID technology to study mussels has been evaluated only in shallow aquatic environments with backpack readers and hand-held antennas (Kurth et al. 2007). However, many mussel populations can be sampled only by snorkeling or diving because they are in nonwadeable habitats (e.g., large rivers, lakes). Snorkeling and diving to locate benthic organisms may be necessary in specific situations, but these traditional techniques are often labor- and time-intensive, potentially dangerous, and frequently limited in the spatial extent surveyed. A boat-mounted RFID antenna system is one technique that would allow monitoring of mussel populations in nonwadeable habitats. A boat-mounted RFID system would overcome the limitations of traditional surveying techniques, and researchers would have the benefits associated with tagging methods (e.g., population density estimates, movement, mortality). Our objective was to describe the design and preliminary testing of a boat-mounted RFID antenna system that could be used to aid in the management and conservation of freshwater mussels.

Methods

Antenna design

The antenna design included 2 flexible droppers, each with a flat-plate antenna coil housing (Nunnallee et al. 1998), which could be pulled effectively over the substrate from the bow of a boat (Fig. 1). The system was powered by a 12-V lead acid battery and had a commercially available low-frequency half-duplex RFID reader (Oregon RFID, Portland, Oregon; Fig. 1). The reader was connected to a remote antenna tuner (Oregon RFID; Fig. 1) by 4.4 m of twinax cable (P/N 9207; Belden, Richmond, Indiana). The remote antenna tuner also was connected to the antenna, which was constructed of 32.4 m of 12-gauge insulated stranded (19 strands) copper wire that created a continuous loop through both droppers and antenna coils (Fig. 1). The antenna wire exiting the antenna tuner ran along the outside of each dropper and was wrapped in a downward direction (i.e., toward the bottom side of the coil encasement), which resulted in alternating wrapping directions for each antenna coil (i.e., 1 counterclockwise- and 1 clockwise-wrapped coil). Each antenna coil was 18.5 cm in diameter and consisted of 11 wraps. The antenna coils were wrapped tightly around a high-density polypropylene (HDPE) cylinder constructed on two 19.1-mm-thick discs that were 18.5 cm in diameter (Fig. 2A, B). The wire exiting each coil ran along the inside of each dropper to complete a

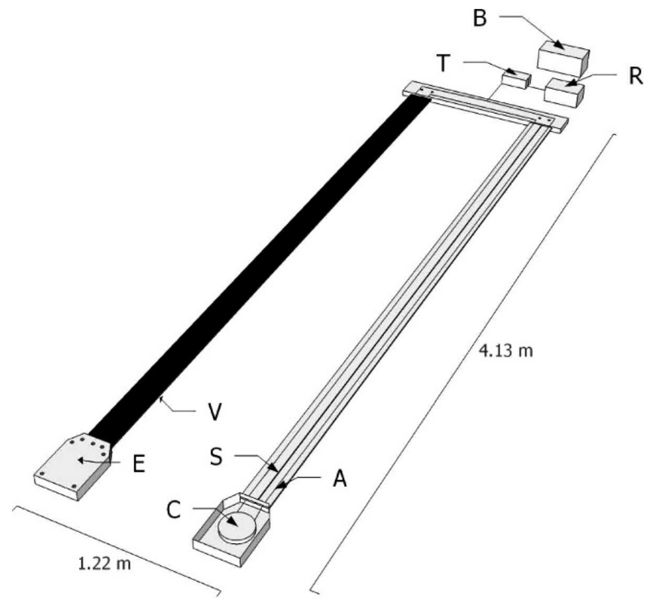

FIG. 1. Schematic representation of a boat-mounted radio frequency identification (RFID) antenna system consisting of an antenna with a single continuous 12-gauge stranded copper wire (A) with 2 antenna coils (C) encased in a protective high-density polypropylene housing (E) and 2 flexible vinyl-coated polyester droppers (V) with a 9-mm-diameter Spectra® rope (S). The antenna was connected to a low-frequency half-duplex RFID reader (R) via the antenna tuner (T) and was powered by a 12-V direct-current battery (B).

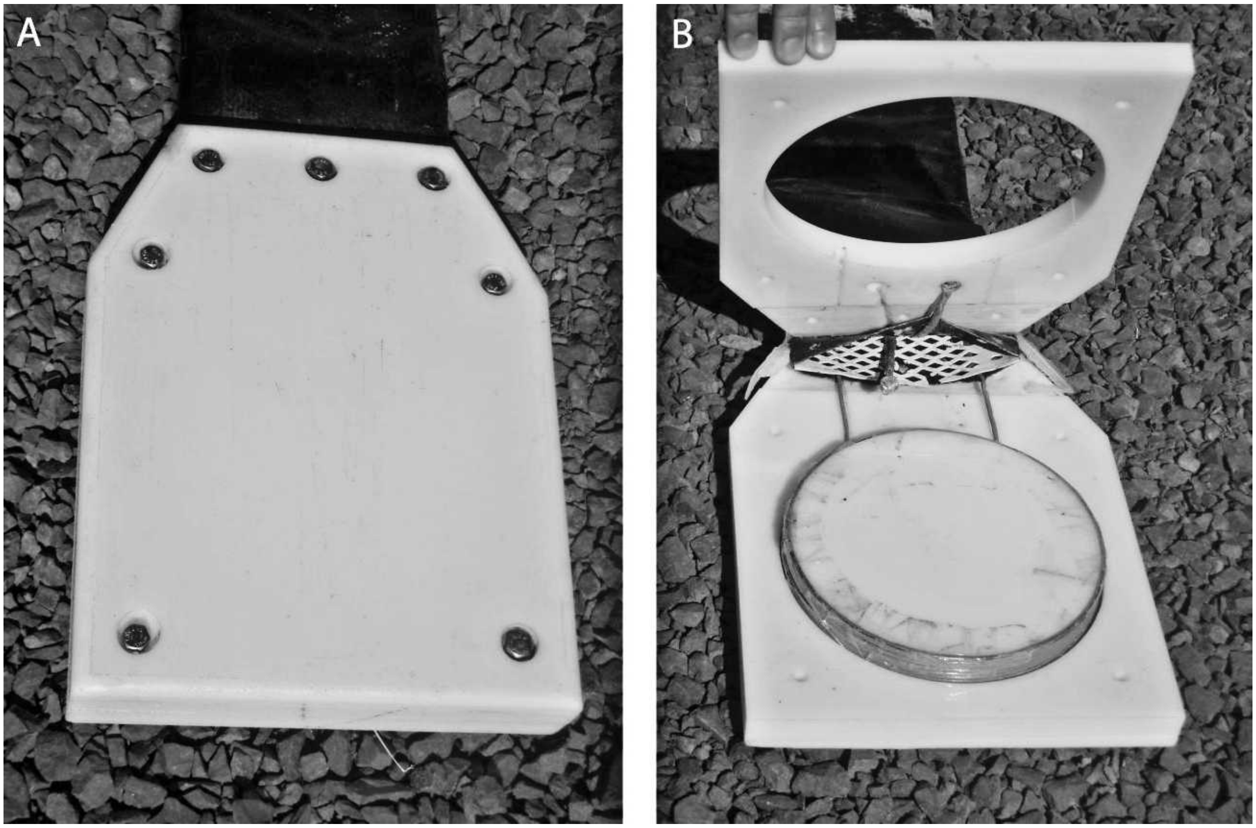

FIG. 2. Photographs of protective housing consisting of 4 high-density polypropylene sheets held to together by stainless-steel bolts (A) and the protective housing interior with exposed antenna coil (B).

continuous wire loop to and from the antenna tuner. The coils were housed in rectangular HDPE encasements (33.0 cm long × 25.4 cm wide × 6.4 cm tall) for protection. The encasements consisted of 2 layers of 19.1-mm-thick HDPE between 2 layers of 12.7-mm-thick HDPE (Fig. 2B). Each antenna coil encasement was held together by 7 stainless-steel bolts (5.1 cm long × 7.9 mm diameter; Fig. 2A). The antenna dropper wires were secured (8.3 cm apart) to polyvinyl chloride (PVC) mesh (15.2 cm wide × 3.8 m long) by small nylon cable ties. A single 9-mm-diameter Spectra® rope (12 strand) was attached to the PVC mesh between the antenna wires to reduce stress from possible snagging of the antenna coil encasements. Each dropper was encased in a 1.2-kg, vinyl-coated polyester sleeve for protection, while providing flexibility. The PVC mesh, with attached wires, Spectra® rope, and vinyl-coated polyester, was inserted between the 2 pieces of 19.1-mm-thick HDPE on the antenna coil encasement (Fig. 1) and 2 pieces of 19.1-mm-thick HDPE that were 1.2 m long and 15.2 cm wide (boat attachment; Fig. 2A). The boat attachment was held together with 4 stainless-steel eyebolts (7.6 cm long × 7.9 mm diameter). The final antenna inductance was 97 μH, and the antenna tuner fixed capacitance to 15 nF and inductance to 93.8 μH.

Detection-distance testing

We tested detection distance underwater with a 2-m × 2-m PVC frame adjustable to 10-cm incremental heights (10, 20, 30, 40, 50, 60 cm) above the antenna to create a 3-dimensional grid. We placed a PIT tag in the frame at each 10-cm interval in each dimension to measure detection distances. We recorded detection distance if the tag was detected by the RFID reader. We tested maximum below-substrate detection distance by driving wooden stakes into the substrate with PIT tags inserted at known locations on each stake. We centered an individual antenna dropper aside the antenna coil to test the maximum below-substrate detection distance perpendicular to the wooden stake (i.e., directly below). We tested 3 tag orientations (horizontal, vertical, 45°) in relation to the antenna coil in water and substrate. Water detection distance was tested with a 32-mm half-duplex PIT tag (P/N RI-TRP-RE2B-30; ISO 11784/11785; Oregon RFID), and substrate detection distance was tested with 23-mm (P/N RI-TRP-REHP-30; ISO 11784/11785; Oregon RFID) and 32-mm half-duplex PIT tags.

Results

Effective underwater detection distances with a 32-mm PIT tag differed among tag orientations. The largest detection distances (1.8-m-wide path) were obtained with a vertical orientation (i.e., tag orientated parallel to antenna coils) at the 10-cm detection height (Fig. 3A). All 3 tag orientations had a maximum detection distance of ~50 cm directly over the antenna coils (Fig. 3A–C). The maximum detection distance in sand substrate was tested directly below the coils of the antenna and differed among tag orientations and sizes. Detection distance below substrate was greater with the larger (i.e., 32 mm) PIT tag. Detection distance for the 23- and 32-mm tags were 4 and 5 cm for the vertical orientation, 17 and 25 cm for the horizontal orientation, and 25 and 40 cm for the 45° tag orientation, respectively. Therefore, knowledge of mussel orientation while burrowed beneath the substrate–water interface should be used, when available, when attaching PIT tags to maximize potential detections with the current antenna system.

Discussion

A boat-mounted RFID antenna system would allow researchers to monitor mussel populations in non-wadeable habitats more efficiently, would overcome the limitations of snorkeling and diving (e.g., labor), and would have the benefits associated with tagging methods with a minimally destructive detection technique. PIT tags also would be useful to determine the fate of hatchery-reared mussels, as is done with fishes (Cucherousset et al. 2007).

Our goal was to design a durable antenna system of manageable size with maximum detection distance. We selected a continuous antenna system because it used more than one antenna coil (i.e., multiple droppers). We designed easy-to-repair protective coil housings capable of withstanding continuous contact with the substrate (e.g., replaceable HDPE sheets). Metallic objects are known to interfere with tag detection (Hill et al. 2006) and are not recommended in the construction RFID antennas, but we did not observe noticeable differences in detection distances during the construction and tuning of the antenna with or without the stainless-steel bolts used in the protective coil housings. Nevertheless, other designs (e.g., epoxy coil encasements, nylon nuts and bolts) that do not use inductive materials could be used. We used widely available and low-cost materials to reduce the expense often associated with RFID technology. The initial cost to construct a boat-mounted RFID antenna (i.e., low-frequency half-duplex RFID reader, construction materials, battery) was relatively low (2500 USD) and the cost of antenna construction was <500 USD.

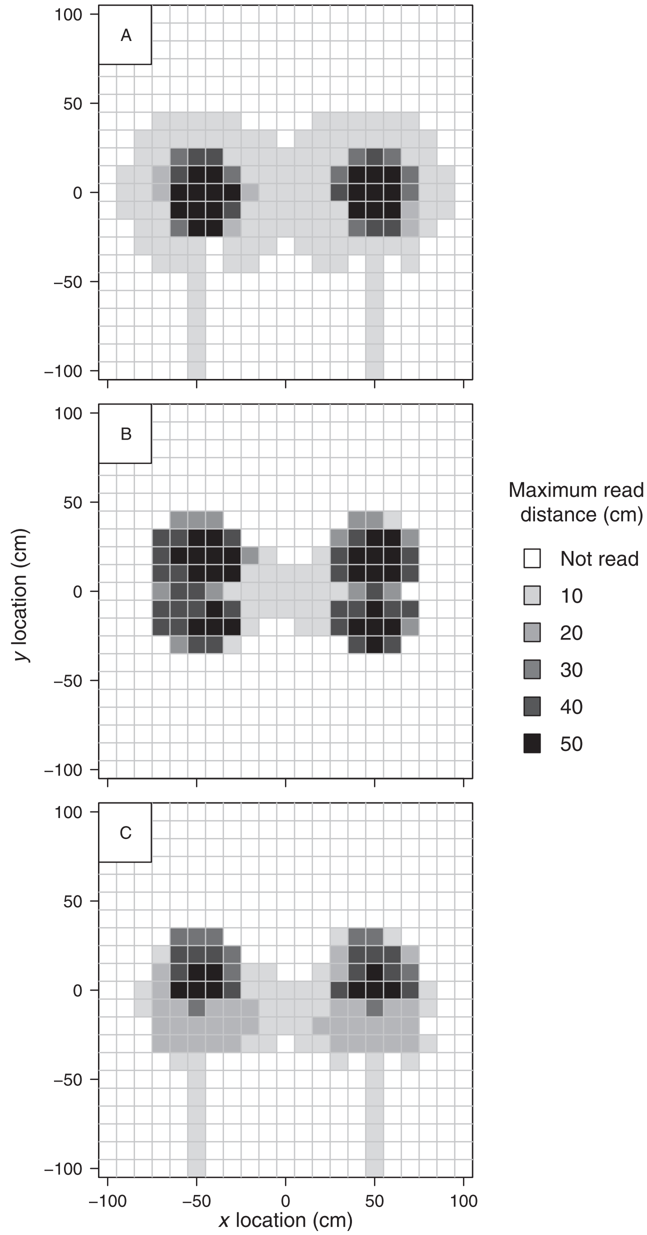

FIG. 3. Maximum detection distance tested underwater with a 32-mm half-duplex passive integrated transponder (PIT) tag for vertical (A), horizontal (B), and 45° (C) tag orientations in relation to the antenna coil. The origin of the grid (0,0) represents the midpoint of the *x*-axis between the antenna coils that was centered on the coils in the *y*-axis orientation.

Our preliminary evaluation of a boat-mounted RFID antenna system for monitoring mussels and other benthic fauna was successful, but several potential drawbacks and improvements to the current system should be considered. Results from the preliminary evaluation indicated that 1.4-m pass width would detect PIT tags regardless of tag orientation on the substrate–water interface. Increased sampling area could potentially be obtained with multiple antennas (e.g., multiple-antenna reader). For example, 4 antennas of similar design mounted in parallel (0.3 m apart) would have a substantially greater effective detection field (i.e., up to 6.5 m wide for tagged mussels on or near the substrate–water interface). In lieu of multiple antennas, increased effective detection distances might be obtained with modifications to the current reader antenna system (e.g., increasing voltage from 12 to 24 V, higher quality antenna wire). However, increased detection distance could increase the frequency of tag collision, wherein no tags are detected because of the simultaneous presence of multiple tags in the detection field of the antenna (Axel et al. 2005). In this case, multiple passes would be necessary to increase detection efficiency.

Our objective was to design and conduct preliminary laboratory tests of a boat-mounted RFID antenna system capable of furthering understanding of mussel populations in nonwadeable systems (e.g., federally-endangered Higgins eye pearlymussel *Lampsilis higginsii*). Our design may provide benefits over traditional sampling methods (e.g., snorkeling or diving), but we did not test the antenna system in the field. We encourage researchers to use similar antenna designs in the field to determine limitations and potential improvements on the current design (see Kurth et al. 2007 and Hill et al. 2006 for a description of mobile-RFID antenna evaluations). In addition, evaluations are needed of tag saturation and new RFID technology that uses anticollision readers with PIT-tagged mussels. Future technological advances in RFID systems probably will reduce the limitations of the current boat-mounted antenna design. However, mussels often use both wadeable and nonwadeable habitat, and a boat-mounted RFID antenna cannot be used in areas inaccessible by boat (e.g., shallow, rapids). Use of wadeable RFID antennas systems (e.g., backpack readers) may be necessary to prevent habitat-specific bias in detection methods.

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