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A Modified Downrigger for Detecting Radio Transmitters in Deep Water

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Abstract.—The advantages and disadvantages of aerial (i.e., through the air–water interface) and underwater tracking of radio-tagged free-swimming fish are compared. A novel device is described that can be used to detect radio signals from depths exceeding the detection range of aerial antennas. This device can be used in small, confined bodies of water to track seasonal movements of fish into deep water, to identify locations of lost or expelled transmitters, to monitor relatively immobile benthic species, and to determine swimming or suspended depth while retaining several other advantages associated with the use of radio (versus ultrasonic) transmitters. The device is inexpensive, simple to construct, and easy to use with any commercially available telemetry receiver.

Telemetry is a useful tool for remotely monitoring the movement and activity of free-swimming fish in their natural environment. Three types of transmitters are generally used in fisheries biology to track fish movements. For short-range applications in small streams (Morhardt et al. 2000) or at dams (Prentice et al. 1990), passive integrated transponder tags may be appropriate for identifying movement patterns of individual fish. In deep freshwater or high-conductivity water (e.g., marine environments), ultrasonic transmitters are necessary (Stasko and Pincock 1977). Because signal transmission is blocked at the air–water interface, however, detection of ultrasonic signals requires the use of a submerged hydrophone that must be moved relatively slowly to prevent currents and bubbles from producing interference (Stasko and Polar 1973). In freshwater systems, fish movements in the majority of shallow to moderately deep (<10 m) environments have been studied with radio transmitters (e.g., Bunt et al. 1999a, 2000; Cooke et al. 2000; Bunt and Cooke 2001). Advantages of radiotelemetry include good signal propagation through the air–water interface, even in turbulent systems or in systems with low to moderate water conductivity. Signals can also be detected from rapidly moving watercraft or aircraft (Bunt et al. 1999b) or through ice cover (Winter 1996). Radiotelemetry permits use of shore-based receivers and antennas, which is not possible with acoustic telemetry systems. Disadvantages of radio transmission include potential complications (e.g., tangling, negative behavioral impacts, and esthetic and ethical considerations) with a transmitter's external whip antenna (Cooke and Bunt 2001) and, more importantly, signal attenuation by deep water (Winter 1996). Periodically, fish tagged with radio transmitters may unexpectedly move into deep water (as discussed below), beyond the range of aerial radio antennas. Propagation and reception of radio signals in water are generally affected by transmitter power, transmitter antenna configuration (Cooke and Bunt 2001), and water conductivity (Winter 1996). Radio transmitter signals become increasingly difficult to detect with aerial antennas when transmitter depths are greater than approximately 15 m in moderately conductive (>350 μS/cm) bodies of water. In this paper, we describe the construction and efficacy of a device that we used to detect radio signals from tagged fish that had unexpectedly moved to deep overwintering areas in a small lake.

Methods

Construction.—The device consists of a modified downrigger, coaxial cable, and a protected antenna. With the appropriate connectors (e.g.,

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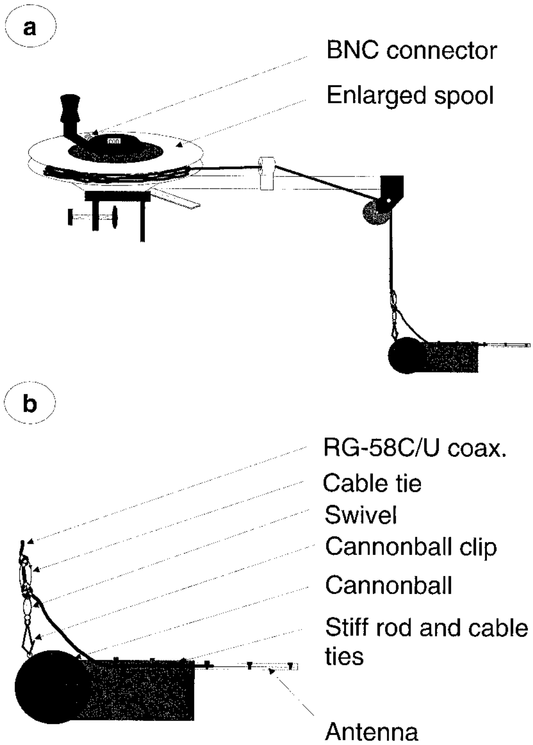

FIGURE 1.—**(a)** Configuration and details of the modified downrigger and **(b)** details of the modified cannonball and antenna. See text for details.

BNC), the device is compatible with any commercially available telemetry receiver. The prototype was constructed from an inexpensive commercially available downrigger (Scotty model 1080; Scotty Fishing, Marine and Outdoor Products, Sidney, British Columbia, Canada). The downrigger was disassembled so that the spool could be enlarged to carry 33 m of RG-58 C/U coaxial cable (Figure 1a). The diameter of the coaxial cable had to be less than the diameter of the guide at the end of the downrigger arm. Two flat plastic lids from 20-L buckets were cut into 28-cm-diameter discs. Circular holes with a diameter of 11 cm (i.e., diameter of the drum of the original spool) were cut into the center of each disk, and the outer edges of each disk were smoothed with sandpaper. Each disk was then glued onto the inside of each half of the drum of the original spool with epoxy. After the epoxy cured, the edges where the spool contacts the discs were filled in with clear, flexible silicone. The modified spool was then reassembled, and a 6-mm-diameter hole was drilled from the top through to the base of the drum. One end of the 33-m-long coaxial cable was passed through the end pulley and the cable guide of the downrigger and then out the hole in the base of the spool. This end was trimmed, and a BNC connector was permanently attached as near to the spool as possible. The cable was then wound onto the downrigger, and 5–6 cm of the free end was stripped of insulation down to the center conductor. The bare conductor was twisted, and the end was knotted to prevent fraying. To stiffen this end, a fine layer of solder was then applied with flux and a soldering iron. Plastidip (Plastidip Corporation) sealing compound was thinly applied with a small paintbrush to waterproof the cable where the bare conductor exited from the coaxial bundle. A square knot was then tied approximately 60 cm from the end of the cable, which was then threaded through the swivel above the cannonball clip. A second square knot was used to tie the cable to the swivel so that the first and second knots were separated by 4 cm (center to center). A cable tie was then threaded between the first knot and the swivel, tightened to carry most of the weight of the cannonball, and then trimmed (Figure 1b).

For the prototype, we used a Tru Trac disk-shaped cannonball weight (3.18 kg) with a vertical keel (Figure 1b). One hole was at the end of the keel, and two more 5-mm-diameter holes were drilled at equal intervals along the top of the keel. The free end of the cable was attached to the top of the keel with three trimmed cable ties, leaving 17 cm of cable, including the bare conductor, trailing from the keel. There must be enough free cable between the keel and the swivel of the cannonball connector to allow for flexibility and a complete range of movement. To protect the bare conductor, a 32-cm-long stiff but flexible plastic rod (from a plastic coat hanger) was attached to the opposite side of the keel from the cable side with two trimmed cable ties. The cable and the bare conductor were also attached to the plastic rod with three more trimmed cable ties.

The downrigger meter was calibrated so that the cannonball antenna could be lowered to known depths. For the calibration, we removed all of the cable from the spool and laid it in a straight line beside a long tape measure. The downrigger was then moved along the tape measure while the cable was rewound, and the corresponding meter reading was recorded. Because the relationship between meter readings and cable length may change if the cable stretches, one may need to repeat the calibration after extensive use of the device.

Field calibration.—Reception ranges were mapped out in the Regional Municipality of Waterloo clean water reservoir (nominal conductivity, 200–300 μS/cm) in Kitchener, Ontario. The rectangular reservoir, constructed from concrete with a plastic liner, measured approximately 30 m × 30 m and was 9 m deep. For all tests, the transmitter and antenna were positioned as far from the reservoir walls as possible to minimize signal bounce. After the cannonball had been lowered to preset depths, we used a Lotek SRX_400 receiver attached to the modified downrigger with a barrel connector and BNC patch cable. Coded test transmitters with whip antennas (Lotek MBFT-6a, 149.520 MHz) were moved throughout the test area perpendicular to a linear transect, and the signal strengths from decoded pulses received were recorded. This process required two boats—one with the downrigger and receiver, the other with the transmitter on a graduated tape measure—and a control line to ensure consistent orientation of the transmitter relative to the receiving antenna. A second tape measure was used to measure lateral distance between the boats carrying the transmitter and the receiving antenna. Signal strengths measured with the SRX_400 receiver were converted into decibels from dimensionless units of signal strength, which ranged from 0 to 235, the strongest possible signal (235) being equivalent to approximately 40 dB of dynamic range (Cooke and Bunt 2001). Reception profiles were generated by nonlinear regression analysis of antenna depth, transmitter depth, and received power strengths.

Field comparisons with an aerial receiving antenna were conducted at Miller's Lake in eastern Ontario. With the receiver gain set to 99 (maximum), the test transmitter was lowered to a depth of 9 m in approximately 10 m of water. Maximum detection ranges were determined for the downrigger device, and differences between that and a three-element aerial Yagi antenna were determined.

Depth determination.—To measure the accuracy of estimates of vertical position (depth) of transmitters in the water column, we conducted blind experiments in which transmitters were lowered to various depths by one researcher while a second researcher varied the depth of the receiving antenna until maximum power strength was achieved. We then compared actual depth versus predicted depth within the water column. The device was subsequently used to track free-swimming smallmouth bass *Micropterus dolomieu* that had been surgically implanted with coded transmitters similar to the test transmitters for a previously designed study in Miller's Lake. On 21 November 2000, using a three-element aerial Yagi antenna, we located a winter aggregation of smallmouth bass in approximately 10 m of water. Using the downrigger, we then estimated the depth of fish in the water column by varying the depth of the antenna until transmitters were decoded with the lowest possible antenna gain. We also used the device to laterally estimate fish locations to within 10 m.

Results and Discussion

Field Calibration

Reception profiles of the test transmitter used with the modified downrigger are shown in Figure 2 ($r^2 = 0.99$, analysis of variance [ANOVA] $P < 0.05$ for each regression). Reception cell size was greatest when the transmitter and cannonball were at similar depths (Figure 2a, b). In addition, reception appeared to increase marginally when the transmitter and cannonball were both positioned near the surface. This suggests that radio waves may have been reflecting off the air–water interface, thereby alternately reinforcing and diminishing the direct wave. Reception diminished when the cannonball and transmitter were high and low in the water column, respectively (Figure 2c). This illustrates the inverse relationship between area for aerial reception and transmitter depth: that is, at some depth detecting signals from the surface becomes impossible without a submerged antenna similar to the one described in this paper. The coded telemetry system used in these tests relied on pulse-code discrimination software to decipher transmitter identification numbers, a process successfully triggered above a factory-preset power strength, which eliminates the subjective factor associated with human hearing. Noncoded transmitters broadcast a single pulse at a discrete frequency. These systems do not require pulse-code discrimination but instead rely on the operator's ear or on a signal strength indicator to identify valid pulses. Noncoded transmitters are much easier to detect and yield good data when the strength of the received signal is very low. Received signal strength may be low when the lateral distance between transmitter and antenna is excessive, when the vertical distance between the transmitter and antenna is increased (i.e., the transmitter is in deep water), and when transmitter signals are obscured or attenuated by thick cover, high noise levels, or high conductivity. Therefore, our measurements of detection range with the aerial and submersible antenna are extremely conservative and would be

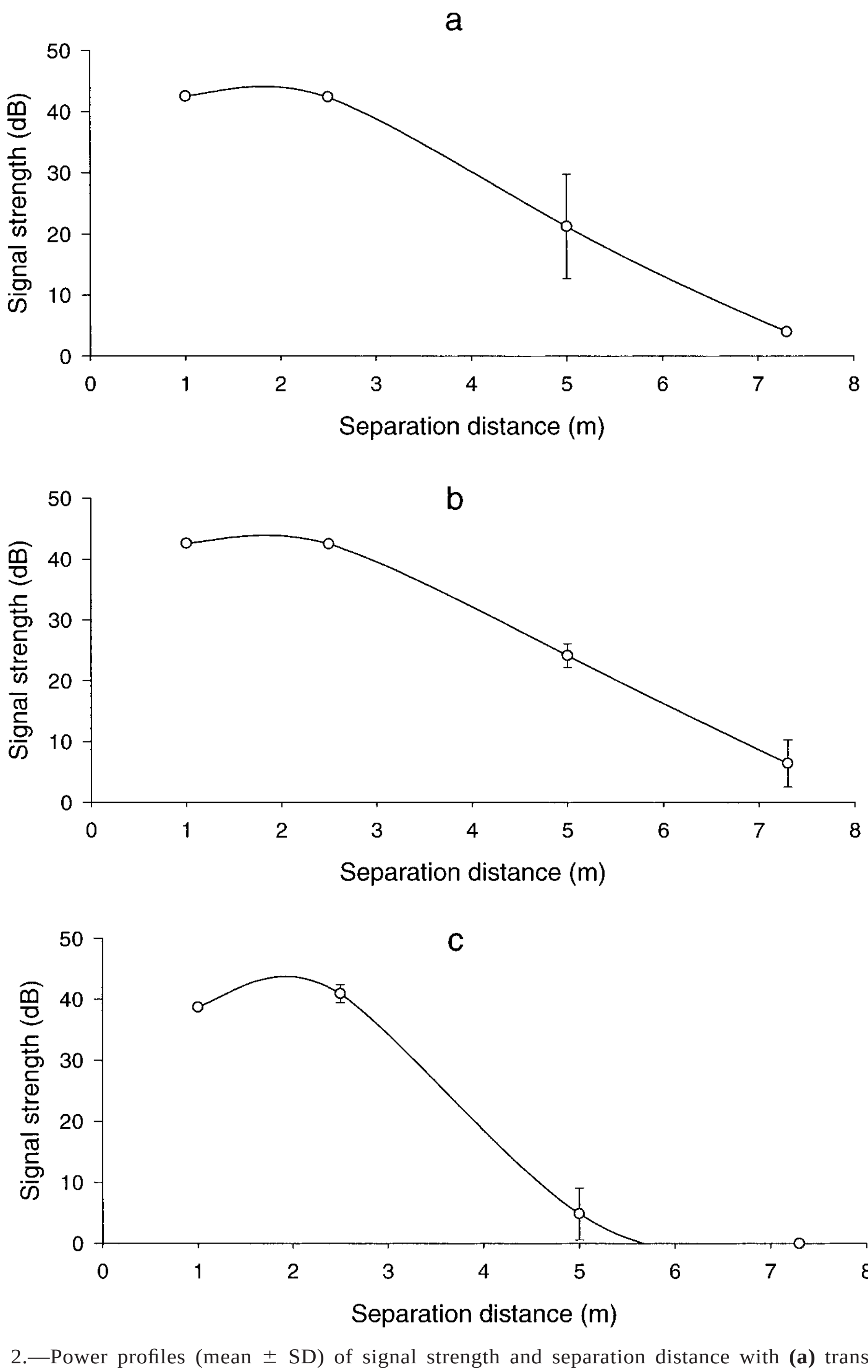

FIGURE 2.—Power profiles (mean ± SD) of signal strength and separation distance with **(a)** transmitter and antenna both at a depth of 6 m, **(b)** transmitter and antenna both at a depth of 2 m, and **(c)** transmitter at a depth of 6 m and antenna at a depth of 2 m; dB = decibels.

considerably greater if a noncoded telemetry system were used for these tests.

Field Comparison with Aerial Antenna

At Miller's Lake, the maximum detection range for the modified downrigger was 10 m. The maximum range with an aerial antenna was approximately 150 m, but this decreased to 0 m when transmitters were approximately 15 m deep.

Depth Determination

When the test transmitter was set at a depth of 10 m, the depth estimated using the modified downrigger with an antenna gain of 85 was 11.8 m. With the same high antenna gain, the transmitter was set at a depth of 3 m and the predicted depth was 9.8 m; reducing the antenna gain to 50 led to a predicted transmitter depth of 3.8 m, whereas the actual depth of the transmitter was 2 m. Reducing the gain to 10 resulted in no difference in estimated depth versus actual depth of the test transmitter. This illustrates the inverse relationship between receiver gain and the ability to accurately predict the locations of transmitters.

When radio-tagged fish occupy depths greater than 15 m, detecting signals from them may be difficult or impossible using aerial antennas (Winter 1996). Systematic scanning along transects spaced less than 10 m apart would be necessary to detect coded transmitters when using the modified downrigger. This limits use of the downrigger to small, confined bodies of water or to discrete patches of habitat in larger bodies of water that may conceal tagged fish, such as a deep hole in a lake. Tracking efficiency may be increased by restricting downrigger scanning to suspected critical habitat based on previous locations of fish or bathymetric mapping. When radio-tagged fish are located, swimming (or suspended) depth may be estimated by carefully lowering the cannonball receiving element near the fish and maximizing signal reception while minimizing antenna gain.

Valid signals (i.e., successfully decoded transmissions) were detected from radio-tagged free-swimming smallmouth bass in the winter aggregation in Miller's Lake by using the modified downrigger. Fish positions were resolved within 10 m of the boat location, and by using an antenna gain of 50, we determined that the smallmouth bass were suspended at a depth of approximately 7 m in 10 m of water. Signals were reduced and decoding of transmitters was unsuccessful when the antenna was lowered to the lake bottom. We did not have the opportunity to test the device in water deeper than 15 m; however, the reception zone (a presumably spherical volume in open water with no signal bounce, reflection, or absorption; Winter 1996) should remain unchanged to a depth of 33 m (i.e., the entire length of the cable). Using cable with the least possible loss will maximize the zone of detection, which should increase scanning efficiency when fish locations are unknown or when water conductivity is high. Further experimentation is necessary to determine the effect of the cannonball and the orientation of the receiving antenna on the shape and size of the reception zone.

By providing information on the swimming depth of free-swimming fish, the modified downrigger can eliminate expenses associated with specialized transmitters that use pressure transducers to accurately measure swimming depth (e.g., Bégout Anras et al. 1999; Gowans et al. 1999). The downrigger can be used to monitor benthic species, to determine swimming or suspended depth, to track seasonal movements of fish into deep water in lakes and rivers, to identify locations of lost or expelled transmitters (Marty and Summerfelt 1986; Baras and Westerloppe 1999), and to locate "missing" fish that have moved into discrete patches of deep water, while retaining the aforementioned advantages associated with the use of radio transmitters. The device can also be used to locate low-power microtransmitters in small, confined systems or radio transmitters with trimmed antennas (Brown et al. 1999) in shallow to moderately deep water. This receiving system should not be the exclusive method used to track free-swimming fish; however, it can usefully augment radiotelemetry data, particularly in cases where transmitters may have "disappeared" as a result of movement of fishes beyond the detection range of aerial antennas. In experiments where fish are expected to occupy depths greater than approximately 15 m, ultrasonic telemetry is most appropriate; however, fish movements into deep water may not be anticipated during the a priori design phase of telemetry experiments. In such cases, the modified downrigger described in this paper will allow researchers to make additional observations of free-swimming radio-tagged fish.

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