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Assessment of Internal and External Antenna Configurations of Radio Transmitters Implanted in Smallmouth Bass

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Abstract.—Researchers conducting fish telemetry studies using the intraperitoneal surgical implantation of radio transmitters with whip antennas can configure the antenna to exit the body cavity through a small puncture wound (external) or leave the antenna coiled within the body cavity (internal). We conducted a behavioral field study to examine movement patterns of smallmouth bass *Micropterus dolomieu* carrying radio tags with internal or external antenna configurations. Fish movements, number of days tracked, and number of detected signals did not differ between internal or external treatment groups. To complement the field study, we conducted a laboratory investigation to examine possible effects that these treatments (antenna type) may have on the swimming performance of smallmouth bass by comparing critical swimming speeds. Swimming performance was not significantly altered by the surgical procedures related to transmitter and antenna placement. Our results also suggest no significant differences in swimming performance or movement rates of fish related to antenna configuration. However, transmitter signals were attenuated with the internal antenna configuration. As such, decisions regarding which antenna configuration to use should be based on fish morphology, study objectives, and site-specific environmental conditions.

An assumption in all telemetry studies is that the method of transmitter attachment does not alter the physical condition or behavior of the organism being monitored. Numerous studies have examined the effects of different transmitter attachment procedures (e.g., intraperitoneal, external, gastric, or oviduct), although none have examined the influence of internal versus external antennas. Radio transmitters typically include either a loop antenna (Tranquilli et al. 1981), which is completely implanted in the body cavity, or more commonly, a whip antenna that can either be coiled and left within the body (Einhouse 1981) or allowed to exit the body cavity through a small puncture (Ross and Kleiner 1982; Jepsen and Aarestrup 1999; Cooke et al. 2000).

Antenna configuration may be determined by morphological and behavioral characteristics of the fish, expected habitat use, and study objectives. External antennas may abrade the fish or tangle and become fouled with debris. Internal antennas result in additional foreign material (i.e., antenna wire) within the peritoneal cavity that could cause visceral damage. Moreover, radio signals may be attenuated by the body wall of large fish, and antenna coiling may negatively affect signal propagation (Winter 1996). However, external whip antennas exiting from an abdominal puncture can create a permanent venue for potential infection, so some jurisdictions have restricted use of external antennas. The effects of transmitter implantation are well documented among salmonids (e.g., Peake et al. 1997b; Adams et al. 1998a, 1998b) but less so for warmwater fish (see Knights and Lasee 1996) despite the increased potential for infection and fungal lesions associated with warm water temperatures (Wolke 1975).

The purpose of this study was to examine in smallmouth bass *Micropterus dolomieu* the potential effects of intraperitoneally implanted transmitters, especially the differences related to internal versus external antennas. Whip antennas were either coiled and left in the body cavity or threaded through the body cavity via a small puncture. A behavioral field study examining movements and activity, a physiological laboratory assessment of swimming performance, and a signal detection test were conducted.

Methods

Behavioral field study.—A mark–recapture study initiated in May 1998 indicated that smallmouth bass, though highly mobile, were confined

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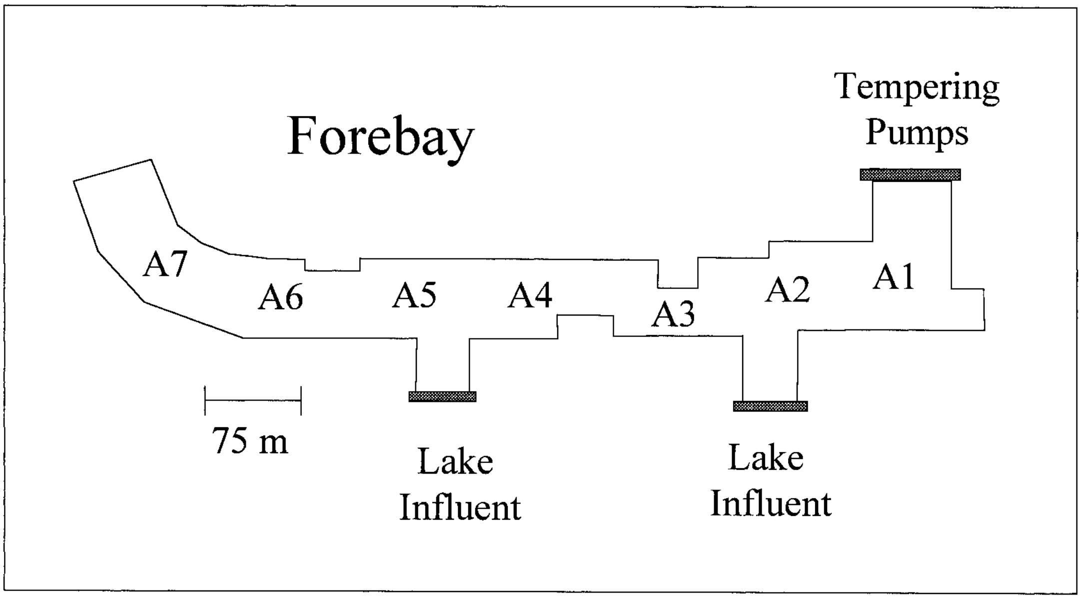

FIGURE 1.—Intake forebay of the Nanticoke Thermal Generating Station on the north shore of Lake Erie showing positions of the seven antennas and movement checkpoints (A1–A7).

to the intake forebay of the Nanticoke Thermal Generating Station on the north shore of Lake Erie (S. J. Cooke, unpublished data; Figure 1). Fish attempting to leave the forebay were impinged and perished on traveling screens or became entrained in a tempering pump. The tempering pump area was monitored to ensure that no fish could escape without being detected. Public access to the study site was prohibited, permitting the installation of a permanent monitoring system. The forebay was blasted out of bedrock and contained many rock fissures and much broken rock debris.

An array of seven antennas continuously monitored movements of fish in the study area. Antennas were evenly spaced 75 m apart within the intake forebay (Figure 1). The most distally placed antennas were aerial. Antenna 1 was an H-antenna and antenna 7 was a four-element yagi. These aerial antennas and the associated increase in reception were required to compensate for signal attenuation in long lengths of coaxial cable. The remainder of the antennas (2–6) were anchored at 4-m depths and were composed of coaxial cable with 6 cm of the shielding removed. All cables (RG58c/u) ran to a central antenna switching box (ASP_8, Lotek Engineering, Inc.). An SRX_400 receiver (Lotek Engineering, Inc.) with W-17 software continuously scanned all seven antennas for transmitters sequentially for 3 s on each antenna. To minimize scan time, we used coded radio transmitters that operated on one of four frequencies and that broadcast 1 of 16 codes. Transmitters emitted a pulse every 2.5 s. Each antenna reception zone was scanned every 84 s (3 s × 7 antennas × 4 channels). Data from the receiver were downloaded to a computer weekly.

Sixteen smallmouth bass (means ± SE: total length [TL] = 318 ± 5.0 mm, and weight = 747 ± 38.0 g) were captured by angling with small jigs on 15 June 1998. Each fish was landed quickly (<20 s) and held in a cooler. Fish were anesthetized using a 60-mg/L induction bath of clove oil and ethanol (Peake 1998). After equilibrium was lost, fish were measured and weighed before being placed ventral side up in foam padding on a surgical table. A maintenance dose (30 mg/L) of anesthetic in oxygenated water continuously irrigated the gills.

A 15-mm incision was made slightly lateral to the ventral midline, just posterior to the pelvic girdle. For each treatment, the transmitter (Lotek MCFT-3HM, 10.6-mm × 28.0-mm transmitter package, 2.0 g in air, 1.5 g in water, 1.0-mm × 300-mm Teflon-coated antenna, 40-d expected battery life) was inserted into the peritoneal cavity. For external antenna configurations ($N = 8$), the antenna wire was passed through a 16.5-guage hypodermic needle and inserted through the body cavity wall while a metal shield protected the viscera. Internal antenna placement ($N = 8$) was similar, except that the antenna was gently fed into the body cavity, and allowed to unfurl to a resting position inside the coelom. The incision was closed with two independent sutures of 3/0 nonabsorbable braided silk (Ethicon, Inc.) and then secured with Vetbond (3M, Inc.). Fish were allowed to recover in lake water for approximately 5 min before release. All fish were released at the capture location near antenna 6. During the summer of 1999, we angled extensively in the forebay to attempt recapture of previously tagged individuals.

Behavioral data treatment and analysis.—All fish were released on 15 June 1998 and tracked for up to 46 d. To examine potential differences in behavior arising from the two treatments, several measures of behavior and activity were compared. We were able to infer movement by using the antenna array as a series of checkpoints (Bunt et al. 1999). A movement was defined as a signal shift from one antenna to another. Next, we compared the total number of fixes recorded at each antenna among fish in each treatment. This differs from movements because fish sometimes remained stationary within an antenna reception cell for extended periods, while numerous signals were logged. To provide a daily movement rate, we also corrected for differences in the duration that fish were tracked by dividing the total number of movements by the number of days tracked.

Data were assessed for normality using a Lilliefors test (SYSTAT 1992) and were tested for homogeneity of variance using an *F*-test. If the data were normal and the variances were homogeneous, data were analyzed using a *t*-test; otherwise, data were analyzed using a Mann–Whitney *U*-test. For nonsignificant results, power ($1 - \beta$, or the probability of rejecting a correct null hypothesis) was calculated using the UnifyPow macro in SAS (SAS Institute 1985).

Laboratory performance challenge.—Fish obtained from the field study site were transported in aerated holding tanks to facilities at the University of Waterloo during July 1998. Fish were held at 17°C ± 1°C in an 800-L tank before surgery. Surgical procedures for laboratory swimming performance trials were identical to field procedures and used the same transmitter designs. Sham controls were also carried out for each treatment. This involved the complete surgical procedure and transmitter insertion, followed by the immediate and careful removal of the transmitter. A control group was also used that did not undergo anesthesia or surgery. Following surgery, fish were placed in a tank (1.5 m × 1.5 m) with water temperature at 17°C ± 1°C and held for 48 h before performance challenge tests.

Performance challenges were conducted in a 70-L modified Blazka-type swim chamber (Smith and Newcomb 1970). The swim chamber was supplied with aerated well water at 17°C ± 1°C with an external pump. Individual fish were placed into the chamber and acclimated at a speed of approximately 0.5 body lengths/s for 10 min (Peake et al. 1997a). Fish were then exposed to incrementally increasing (by approximately 15 cm/s) 5-min velocity challenges until they were fatigued. Fatigue was noted as the second time a fish was pinned against the blocking screen (Beamish 1978). The first time a fish was pinned, it was stimulated by a sharp fluctuation in velocity followed by an immediate return to test velocity (Peake et al. 1997b). The cross-sectional area of the fish did not exceed 10% of the swimming portion of the chamber, so no correction was necessary for the blocking effect (Smit et al. 1971). Critical swimming speed was calculated using the formula of Beamish (1978) and denoted as U-crit$_5$ to reflect the reduced time interval.

Performance challenge analysis.—To determine if critical swimming speeds, lengths, or weights differed among groups, data were compared with a one-way analysis of variance (ANOVA). Normality was confirmed with a Lilliefors test (SYSTAT 1992), and homogeneity of variance was examined using Levene's test on the absolute values of the residuals. Power was calculated for nonsignificant results as noted above.

Detection ranges.—We conducted reception range tests to determine if antenna configuration affected signal detectability. Signal strengths from internal versus external antenna configurations were collected from a dead smallmouth bass (374 mm TL, 675 g) that was oriented perpendicular to a linear antenna transect, at a depth of 1 m. A single transmitter (same model as used in the field study) was first implanted with the antenna exiting the body cavity. After data were collected, we retrieved the fish, threaded the antenna into the fish until it was contained within the body cavity, and conducted the next test. Signal strengths were recorded with an SRX_400 receiver (gain = 35) with both underwater and aerial antennas. Signal strengths, expressed in terms of relative dimensionless units, ranged from 0 to 235. The highest possible signal (235) is equivalent to 40 decibels of dynamic range (L. Egan, Lotek Engineering, personal communication). Ten signal strength val-

TABLE 1.—Mean (±SE) total length, weight, and 5-min critical swimming speed (U-crit$_5$) for the transmitter treatment, sham control, and control groups in swimming performance challenges. For all groups, $N = 10$.

Treatment	Total length (mm)	Weight (g)	U-crit$_5$ (cm/s)
Control	310.0 ± 8.3	397.3 ± 37.2	111.3 ± 6.1
Internal	313.7 ± 5.8	399.6 ± 20.3	95.4 ± 9.5
Internal sham	307.0 ± 3.7	373.0 ± 16.5	95.7 ± 6.5
External	315.6 ± 4.0	412.0 ± 20.1	95.0 ± 4.8
External sham	308.9 ± 7.9	384.3 ± 40.2	100.0 ± 9.7

ues were obtained at 3, 6, 9, and 12 m from the implanted fish. Significant differences in signal strength between antenna configurations at each location were assessed using Mann–Whitney *U*-tests.

Results

Results are expressed here as means ± standard errors. Statistical significance for all tests was set at $\alpha = 0.05$.

Behavioral Assessment

Total lengths and weights of fish were consistent for internal antenna (323 ± 7.4 mm; 771 ± 53.2 g) and external antenna (314 ± 6.7 mm; 723 ± 56.4 g) treatments ($P_{\text{length}} = 0.40$, $P_{\text{weight}} = 0.54$). The mean number of detected movements did not differ between internal (36.1 ± 8.9) or external (44.4 ± 8.4) treatments ($P = 0.42$, $1 - \beta = 0.10$). The number of days that fish were tracked before signals were lost did not differ between internal (37.4 ± 4.7) and external (36.1 ± 4.7) treatments ($P = 0.85$, $1—\beta = 0.10$). The corrected daily movement rates did not differ significantly between internal (0.86 ± 0.18) and external (1.20 ± 0.21) treatments ($P = 0.24$, $1—\beta = 0.09$). In addition, differences were not significant between the number of signals logged per fish for internal (173.8 ± 64.2) and external (313.5 ± 136.1) treatments ($P = 0.462$, $1—\beta = 0.19$).

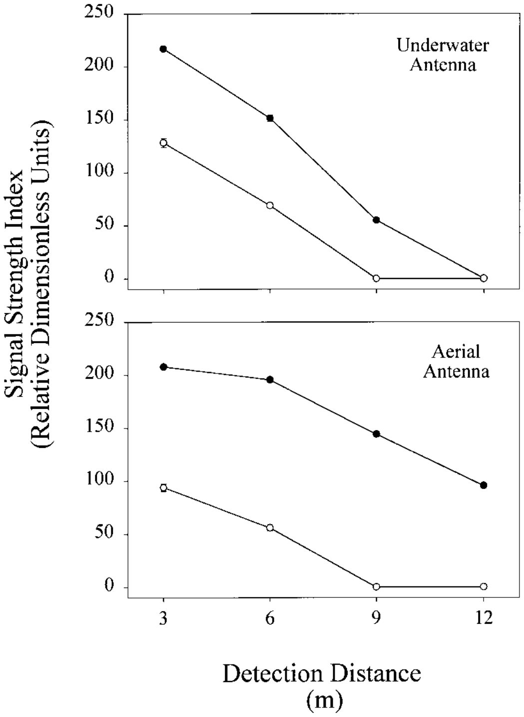

FIGURE 2.—Comparisons of signal strength for internal (empty circles) and external (filled circles) antenna configurations related to distance between the transmitter and an underwater (upper panel) or aerial (lower panel) receiver antenna.

In the summer of 1999 we recaptured three fish with external antennas. One antenna had been sheared off 8 cm from the transmitter package without pulling the transmitter out of the body cavity, and the other two antennas were kinked. Exit sites of these antennas were somewhat inflamed. No fish with internally coiled antennas were known to have been recaptured.

Performance Challenge

We failed to reject the null hypothesis of no difference in swimming performance among control fish, treatment fish, and sham controls. Swimming performance was not altered by either of the transmitter implantation methods nor by the effects of the surgical procedures ($F = 0.87$, $P = 0.49$, $1—\beta = 0.13$). No significant differences were observed among treatments in smallmouth bass total length ($F = 0.32$, $P = 0.87$) or weight ($F = 0.28$, $P = 0.89$; Table 1).

Signal Attenuation

Antenna configuration significantly altered signal strength (Figure 2). The signal strength of the internal antenna was consistently lower than that of the external antenna for all distances ($P < 0.001$) and for both aerial and underwater antennas, except for the furthest distance from the underwater antenna (12 m), where signals from both internal and external antennas were undetectable.

Discussion

The results of our field behavioral assessment suggest that smallmouth bass with external or internal antennas had similar movement rates. Other examples of behavioral field comparisons are limited, but Martinelli et al. (1998) used a similar approach to contrast the effects of surgically and gastrically implanted tags on downstream movement of chinook salmon *Oncorhynchus tshawytscha*. However, sample sizes in their field tests, like ours, tended to be low and led to low test power.

A disadvantage of using external antenna configurations is that foreign material can adhere to or trap the antenna wire, as we observed. Similarly, Adams et al. (1998a, 1998b) noted that implanted chinook salmon tangled their external antennas around the center standpipe of a holding tank, and pulled the transmitters out through the antenna opening. To avoid these problems, some researchers have trimmed antennas to shorter lengths for specific applications (Brown et al. 1999). No tangling was observed during the holding portion of our study, but we used transmitters with thicker, more rigid antennas. We also detected inflammation of the antenna exit site in fish recovered in 1999, which was consistent with the observations of other studies (Knights and Lasee 1996; Adams et al. 1998a). However, the effects of such inflammation on fish behavior have not been studied.

Internal antennas should avoid the difficulties associated with external antennas. However, we hypothesize that internal antennas may tangle with viscera or transmitters could be expelled more easily through the incision if healing was incomplete. Marty and Summerfelt (1986) showed that a fibrous capsule develops around implanted transmitters in channel catfish *Ictalurus punctatus* to isolate the implant, stabilize the transmitter in the body cavity, or to facilitate expulsion. This capsule may exert pressure on the body wall. The additional material of the internal antenna increases the volume to be encapsulated. We observed signal attenuation in radio transmitters with internal antennas, which reduces signal strength and detection range. An internal antenna makes a radio-tagged fish more difficult for the public to detect, which may or may not be desirable depending upon study objectives. These pros and cons should be considered when the advantages and disadvantages of different antenna configurations are evaluated.

Our laboratory study indicated that after a recovery of 48 h, swimming performance of smallmouth bass was not significantly impaired by the surgery, including anesthesia, or by transmitter implantation. Because swimming involves the integrated effects of numerous physiological processes, measures of swimming ability can provide a sensitive index to general health and stress in fish (Schreck 1990). The anesthetic clove oil has been used on several species, including smallmouth bass (Peake 1998; Bunt 1999; Cooke et al. 2000), but its utility is still poorly documented. Similar to our results, Anderson et al. (1997) reported that the swimming performance of rainbow trout *Oncorhynchus mykiss* after recovering from anesthetization with clove oil did not differ from that of control fish.

Because of the generally low power of our tests, we believe that additional research is required on the effects of transmitter antenna configurations on the behavior and physiology of fish. Longer-term studies in which fish can be retrieved for histological examination of appropriate tissues and to assess fish condition would be relevant. Based on our findings, we suggest that researchers consider the specific environmental conditions (i.e., water temperature, expected habitat use, and tangling or fouling potential), fish morphology, and the study objectives (desired detection range) when determining which antenna configuration is most appropriate.

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