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NOTES

Effects of Implanted Transmitter Size and Surgery on Survival, Growth, and Wound Healing of Bluegill

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Abstract.—Surgically implanted transmitters generally should be less than 2% of body weight. However, laterally compressed fish such as bluegill *Lepomis macrochirus* may be more affected by transmitter size because of their small body cavity. Previous research on the effects of transmitters on laterally compressed centrarchids has given little attention to transmitter size or shape. We evaluated the effects of two transmitter sizes (approximately 1% and 2% of fish body weight) on survival, tag loss, growth, and healing of bluegill over a 10-week period. Both transmitters were similar in width and height but differed in length. Ten fish each were implanted with one of the two transmitter sizes, 11 fish were subjected to surgery only, and 10 fish were used as controls. No fish died immediately as a result of the surgery. However, two fish implanted with a large transmitter expelled their transmitters between weeks six and eight, including one fish that subsequently died in week seven. At 2 weeks after surgery, fish with either size of transmitter were smaller than control and surgery-only fish but rebounded to growth increments similar to those of the control and surgery-only fish in subsequent weeks. The condition of transmitter-implanted fish was reduced 2 weeks after surgery, with the large-transmitter fish having the greater decrease in condition. Wound healing decreased with time and was similar across treatments. These results suggest that transmitters up to 2% of body weight may be used in laterally compressed fish such as bluegill, but smaller transmitters (i.e., 1% of body weight) should be used when possible.Transmitter shape (e.g., slender compared to cylindrical) also needs to be considered for laterally compressed fishes.

Internal transmitters are used to study many aspects of fish ecology, including fish movement, habitat use, and physiological responses. However, use of telemetry transmitters often requires invasive surgery that can alter fish behavior or performance (Mellas and Haynes 1985). Although more than 40 fish species have been studied by biotelemetry, few controlled studies have been reported on the effects of transmitters on growth, behavior, and physiology of fish (Stasko and Pincock 1977). Internal transmitter weight generally should not exceed 2% of the fish body weight (Winter 1996). Recently, the 2% rule was challenged as Brown et al. (1999) determined that swimming performance of rainbow trout *Oncorhynchus mykiss* was not affected by transmitters that ranged from 6% to 12% of body weight. In addition, they recommended that further research be conducted to provide a more scientific basis for determining the appropriate size of implanted internal transmitters.

Laterally compressed fish such as bluegill *Lepomis macrochirus* and crappie *Pomoxis* spp. may be more affected by size or shape of the transmitter than by its weight because of their relatively small coelom size. Biotelemetry studies of laterally compressed fishes often fail to address the size and shape characteristics of the transmitter. Cylindrical internal transmitters often have been used in laterally compressed fishes (bluegills: Prince and Maughan 1978; crappies: Guy et al. 1992, 1994; Pope and Willis 1997) without evaluation of transmitters shape or size. In fact, Guy et al. (1994) used two different transmitter sizes but did not evaluate differences between the two tag sizes. Studies that have used more-compressed tags (i.e., transmitter height is smaller than width) used only one transmitter size (Markham et al. 1991; Knights and Lasse 1996). Knights and Lasse (1996), evaluating the effects of transmitters on growth, tag loss, and mortality on bluegill, addressed only one transmitter size (about 2% of body weight) and focused instead on the effects of water temperature.

The objectives of this study were to evaluate survival, growth, and tag loss of bluegills tagged with two sizes of dummy radio transmitters over a 10-week period. We hypothesized that larger transmitters would reduce growth, condition, and

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wound healing more than would the smaller transmitters. In addition, we expected the control (i.e., nonmanipulated) group to have better growth and condition than those receiving any of the other treatments (i.e., surgery-only, small transmitter, large transmitter).

Methods

Fish collection.—Bluegills were collected by electrofishing in September 1999 from Hayes Lake, Stanley County, South Dakota, and transported to South Dakota State University. In the laboratory, fish were graded so that all fish used in the study were between 180 and 200 mm total length (TL), and individually tagged (Tag FD-94; Floy Tag, Inc., Seattle, Washington). Bluegills were acclimated to 21°C (mean = 21.6°C, SE = 0.20) for 1 month before transmitter implantation. Bluegills were initially fed a daily ration of fathead minnows *Pimephales promelas* at rate of 3% of body weight per day. However, the ration was increased to 4% after 1 month (just before transmitter implantation) as bluegill acclimated to tank conditions and the feeding rates increased.

Transmitter implantation.—After acclimation, 41 fish were subjected to one of four treatments: (1) large transmitter implantation, (2) small transmitter implantation, (3) surgery with no transmitter implantation, and (4) control (no surgery, but handled). To reduce the possibility of differences in mean initial length, we attempted to have about five randomly selected fish per cm-group in each treatment. All treatments included 10 fish except the surgery only group, which included 11 fish. Fish receiving large transmitters were implanted with 3.2-g dummy radio transmitters (Holohil, Ontario, Canada), 21 × 12 × 6 mm (model PD-2), whereas the small- transmitter-implanted fish received 1.5-g transmitters, 16 × 10 × 6 mm (model BD-2G). All transmitters were inserted with the narrow axis positioned dorsal-laterally. The third treatment consisted of surgery similar to the transmitter implantation procedures, except that no transmitter was implanted. The control group (i.e., unmanipulated) received no surgery or transmitter but were handled similarly to the fish in the other treatments. All fish were held together in a 1,017-L aerated rectangular tank with a constant flow of 1.6 L/min and a 12-h dark:12-h light photoperiod.

Surgery procedures.—Before surgery, all instruments and transmitters were sterilized with ethyl alcohol. Bluegills were anaesthetized with a 100-mg/L solution of MS-222 until they showed signs of equilibrium loss. Bluegills then were implanted with transmitters by placing the fish ventral side up in a v-shaped trough contained within a tank filled with water deep enough to submerge the gills of the fish. Transmitters were inserted through a lateral 15-mm-long incision located 5 mm above the ventral surface, just anterior to the pelvic fin (Prince and Maughan 1978). The whip antennae exited the fish from a separate opening prepared by using the shielded needle technique (Ross and Kleiner 1982), which minimizes bluegill mortality (Brent Knights, U.S. Geological Survey, personal communication). The transmitter insertion wound was sutured with two or three interrupted nonabsorbable sutures (size 4–0; Ethicon Inc., Cornelia, Georgia). After surgery, the fish were placed into a holding tank and monitored until equilibrium was established. We recorded total surgery time, time to regain equilibrium, and time under anesthesia for each fish.

Monitoring procedures.—After surgery, bluegills were monitored every 8 h for the first 48 h and daily thereafter for 10 weeks to quantify mortality. Every 2 weeks, all bluegills were anesthetized with MS-222, weighed (±0.1 g), measured (mm), inspected for tag loss, and assigned a severity index value (Adams et al. 1993) for maximum wound gape (no gape: 0; gape < 1.0 mm: 10; gape ≥ 1.0 mm: 20), wound redness (none: 0; only near incision and sutures: 10; expanded beyond sutures: 20; entire area around incision: 30). For consistency in indexing, the same person assigned these values throughout the entire experiment.

Data analysis.—Survival and tag loss were estimated for the entire experiment for each treatment.

Relative length increment for each time interval (e.g., week 2 to week 4, and so forth) was assessed for individual fish by means of the equation

$$G_i = [(L_{ik} - L_{ij}] \times 100,$$

where G_i is the length increment (mm) of fish i, L_{ik} is the length of fish i at time k, and L_{ij} is the length of fish i at time j.

The change in condition for each time interval was assessed for each individual in terms of relative weight (W_r; Anderson and Neumann 1996):

$$C_i = [(W_{rik} - W_{rij})/ W_{rij}) \times 100$$

where C_i is the percent change in W_r of fish i, W_{rik} is the relative weight for fish i at time k, and W_{rij} is the relative weight for fish i at time j. The weight of the transmitter was subtracted from the calculations before this analysis.

At the end of the experiment, all fish were euthanatized with an overdose of MS-222 and autopsied. For each fish, gonadosomatic (GSI), hepatosomatic (liver; HSI), and viscerosomatic (VSI) indices were calculated (Strange 1996). These somatic indices were analyzed separately by sex because of potential sex-related physiological differences.

Statistical analyses.—Analysis of variance (ANOVA) was used (after testing for homogeneity of variances; Zar 1996) to test for differences in mean total length, W_r, surgery time, the time fish were under anesthesia, and the time fish needed to regain equilibrium at the beginning of the experiment. Because measurements were taken on the same fish over a 10-week period, we used a repeated-measures ANOVA to test for differences in length increments and W_r changes. Because variances for wound gape and wound redness could not be stabilized, we rank-transformed the data before analysis and used a repeated-measures ANOVA on the ranked data (Zar 1996). ANOVA was used to test for differences in the somatic indices among treatments by sex. Linear orthogonal contrasts were used to identify differences when the ANOVA tests were significant ($P \leq 0.05$). All statistical analysis were performed in Statistical Analysis Systems (SAS) (SAS Institute 1987).

Results

Neither bluegill initial length nor initial W_r differed among treatments (length range, 189.7–190.1 mm, $P = 0.999$; W_r range, 98–103, $P = 0.60$). In addition, surgery time, which ranged from 3 to 8 min, did not differ among treatments ($P = 0.09$). Also not differing among treatments were the amount of time fish were under anesthesia ($P = 0.27$) and the time they needed to regain equilibrium ($P = 0.66$). Transmitters in the large transmitter treatment group averaged 2.19% (range, 1.77–2.58%) of fish weight, whereas those in the small transmitter treatment group averaged 1.01% (range, 0.82–1.14%) of fish weight. No acute (i.e., within 48 h) mortality occurred as a direct result of the surgery. All fish were distributed throughout the tank and no dominance hierarchy was apparent throughout the 10-week study.

One bluegill in the large transmitter treatment group expelled its transmitter through the incision during week six, and another expelled its transmitter through the incision between weeks six and eight. The fish that expelled its transmitter during week six subsequently died during week seven. Thus the large transmitter group had 80% tag retention and 90% survival over the 10-week study. Tag retention and survival for all other treatments were both 100%.

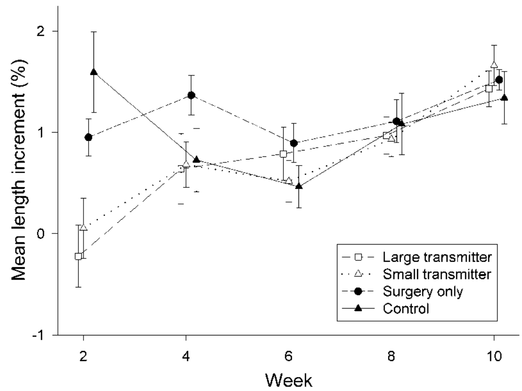

FIGURE 1.—Mean (±1 SE) length increment (%) for bluegills implanted with large or small transmitters or subjected to surgery only and that of unmanipulated control fish over a 10-week period.

Growth

Length increments differed over time during the 10-week study ($P < 0.001$) and differed among treatments during week 2 ($P = 0.001$; Figure 1). Although there were no differences in length increments between the small and large transmitter treatments in week 2 ($P = 0.69$), length increments in the non-transmitter-implanted fish (i.e., both control and surgery-only) exceeded those in the transmitter-implanted fish ($P < 0.001$). In subsequent weeks, length increments did not differ among treatment groups (all contrasts $P > 0.07$). Consequently, mean length at week 10 for both transmitter-implanted groups (large transmitter: 198 mm, SE = 2; small transmitter: 197 mm, SE = 2) were smaller than non-transmitter-implanted groups (surgery only: 201 mm, SE = 2; unmanipulated control: 201 mm, SE = 2).

The mean percent change in W_r significantly differed over time ($P < 0.001$; Figure 2). Mean relative weight increments were lowest in week 2 (all treatments reduced their condition during this period) but gradually increased until week 8, where W_r stabilized. For weeks 4–10, mean W_r increment did not differ among treatments ($P \geq 0.44$). However, linear orthogonal contrasts revealed that mean W_r for the large transmitter group decreased more than for the small transmitter group 2 weeks after surgery ($P = 0.05$; Figure 2).

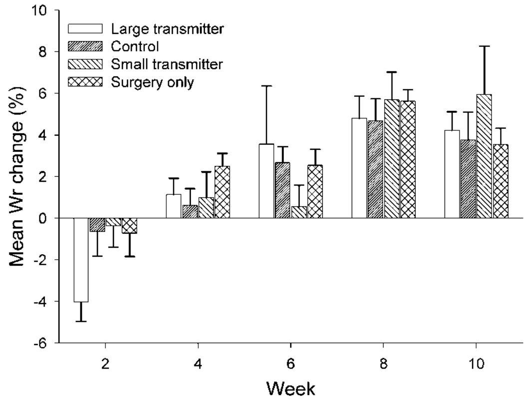

FIGURE 2.—Mean (±1 SE) relative weight (W_r) increment over the previous 2 weeks for bluegills implanted with large or small transmitters or subjected to surgery only and that of unmanipulated control fish over a 10-week period.

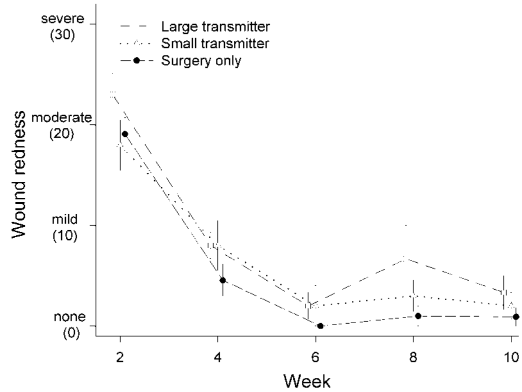

FIGURE 3.—Mean (±1 SE) measure of wound redness for bluegills implanted with large or small transmitters or subjected to surgery-only over a 10-week period.

Wound Healing

Mean wound gape did not differ greatly among weeks ($P = 0.08$) or between transmitter treatments ($P = 0.36$). Mean wound gape was less than 1.0 mm for all weeks and both transmitter treatments. The surgery-only fish never exhibited any wound gape. Mean wound redness decreased with time ($P = 0.001$; Figure 3), with no differences among treatments throughout the study ($P = 0.54$).

Somatic Indices

Because we did not sex the fish before transmitter implantation, male and female samples sizes were not equal for the different treatments. Mean GSI, HSI, and VSI for the females ($N = 3$–6, depending on treatment) did not differ among treatments ($P \geq 0.14$; $1—\beta \geq 0.07$). In males ($N = 4$–7, depending on treatment), mean HSI and VSI were lower for transmitter-implanted fish than for non-transmitter-implanted fish ($P \leq 0.009$). In both indices, the large-transmitter-treatment group tended to have the lower mean somatic indices than did the small-transmitter-treatment group (Figure 4). Male GSI indices did not differ among treatments ($P = 0.34$, $1—\beta = 0.22$).

Discussion

Biotelemetry transmitters used in fish generally should be less that 2% of the body weight of a fish in air (Winter 1996). Adverse effects on fish physiology and behavior may increase as the size or weight of the implanted transmitter increases (Marty and Summerfelt 1986). This ''2% rule'' has precluded the use of smaller fish in long-term (e.g., >3 months) biotelemetry studies. In particular, fishes such as bluegill and crappies have a laterally compressed body cavity that may prohibit implantation of larger (i.e., 2% body weight) trans-

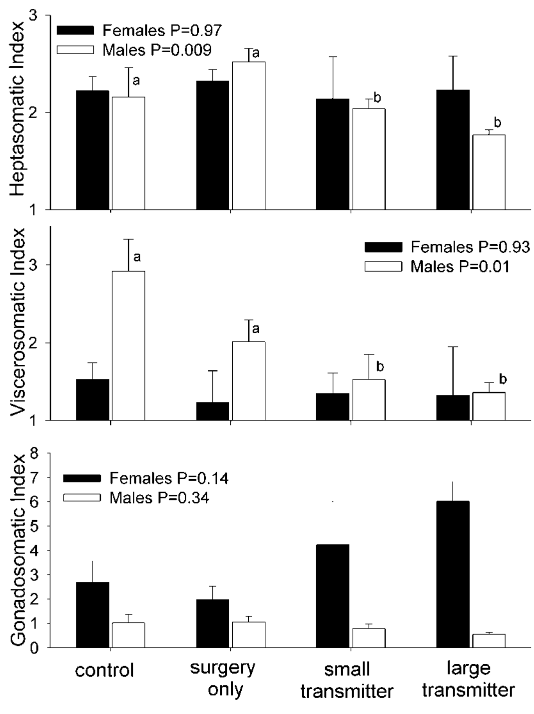

FIGURE 4.—Mean (±1 SE) hepatosomatic, viscerosomatic, and gonadosomatic indices for male and female bluegills implanted with large or small transmitters or subjected to surgery only and those of unmanipulated controls over a 10-week period. Mean values with the same letters did not differ across treatments within sexes ($P > 0.05$).

mitters. In addition, transmitter shape may be more important that transmitter weight. Both transmitters we used were compressed (i.e., 6 mm thick), but were of different widths (10 and 12 mm) and lengths (16 and 21 mm). Other studies have used cylindrical transmitters (Guy et al. 1992, 1994; Pope and Willis 1997), but the effects of size were not evaluated. Knights and Lasse (1996) evaluated the effects of compressed tags on bluegill growth, tag loss, and mortality, but at two temperatures (6°C and 20°C). In our study, we found that larger tags (both by weight and dimension) had greater mortality (20%) and tag loss at a water temperature of 21°C than did smaller tags (no mortality).

In our experiment, bluegills implanted with transmitters showed less growth than the other groups 2 weeks after implantation. In particular, the large transmitter treatment showed a greater decrease in condition (i.e., weight loss) than did the small transmitter group. After 4 weeks, however, growth generally remained constant in all treatments. This is similar to another bluegill study, in which dummy radio transmitters caused weight loss up to 4 weeks after implantation (Knights and Lasse 1996). However, the increased weight loss for tagged fish occurred at warmer temperatures, suggesting water temperature may have had an effect (Knights and Lasse 1996). Other studies have suggested that growth was not reduced in tagged fish (Tyus 1988; Lucas 1989; Martin et al. 1995; Walsh et al. 2000). However, these studies evaluated only one transmitter size, and our study suggests that a larger transmitter (i.e., 2% of body weight) may have a more pronounced short-term impact on bluegill (e.g., greater reduction in condition after 2 weeks) than do smaller transmitters. However, within 4 weeks, growth increments of transmitter-implanted fish rebounded to amounts similar to that of control fish.

Bluegills showed strong evidence of continued healing, regardless of treatment. Wound redness decreased as the study progressed, suggesting that the stress associated with surgical implantation of transmitters was decreasing. Other fish species show this same trend (black crappies: Petering and Johnson 1991; chinook salmon *O. tshawytscha*: Adams et al. 1998; channel catfish *Ictalurus punctatus*: Marty and Summerfelt 1990; hybrid striped bass: *Morone saxatilis* × *M. chrysops*: Walsh et al. 2000). Water temperature, which was not examined in this study, also may affect growth and healing of transmitter-tagged fish (Anderson and Roberts 1975; Knights and Lasse 1996; Walsh et al. 2000).

Transmitter-implanted male bluegill had significantly lower mean LSI and VSI indices than non-transmitter-implanted fish. However, females did not show this trend. Lower visceral fat and liver weight suggest greater stress in transmitter-tagged males (Goede and Barton 1990) than in females. GSI values showed no differences among treatments for males or females. In fact, females implanted with the large transmitters had the highest mean GSI values. We did not expect to see this gonadal response because the study was conducted over winter (October to December) and not during the spawning period. However, the power and sample sizes for these tests were low. Further research needs to be done to determine the effects of transmitters on gonadal development.

These results suggest that surgically implanted radio transmitters may adversely affect laterally compressed fish, such as bluegills. However, bluegills apparently recover from the transmitter implants after about 4 weeks. In addition, transmitters up to 2% of fish body weight may be necessary for long-term (e.g., >4 weeks) studies in laterally compressed fish. However, we recommend that, if feasible, transmitters should be ≤ 1% of body weight to reduce tag loss, mortality, and stress (i.e., short-term weight loss) in compressed fishes. Knights and Lasse (1996) found tag loss and mortality of transmitter-tagged bluegills were greater in 20°C than in 6°C surroundings. Their results, along with our evaluation of transmitter size, suggest that smaller tags (i.e., 1% of body weight) implanted in cooler water temperatures may reduce tag loss, mortality, and short-term (<4 week) stress on bluegills. To enhance the utility of biotelemetry, further study on the effects that tag shape of surgically implanted transmitters may have on behavior of fishes is needed.

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