Ecology of Freshwater Fish 2004: 13: 312–316
Printed in Denmark · All rights reserved

ECOLOGY OF
FRESHWATER FISH

Short communication

Effects of radio-transmitter antenna length on swimming performance of juvenile rainbow trout

Murchie KJ, Cooke SJ, Schreer JF. Effects of radio-transmitter antenna length on swimming performance of juvenile rainbow trout.
Ecology of Freshwater Fish 2004: 13: 312–316. © Blackwell Munksgaard, 2004

Abstract – Technological advances have lead to the production of micro radio-transmitters capable of being implanted in fish as small as *c.* 5 g. Although the actual tags are small, transmitters are equipped with long antennas that can increase drag and tangle in debris. We examined the effects of radio-transmitter antenna length on the swimming performance of juvenile rainbow trout, *Oncorhynchus mykiss*, ($N = 156$, mean mass = 34 g, mean fork length = 148 mm). Although we tested a variety of different antenna lengths up to a maximum of 300 mm, only the longest antenna significantly impaired swimming performance relative to control fish ($P < 0.001$). There was no difference in swimming performance between the sham (surgery, but no transmitter) and the control fish (handled, but no surgery), suggesting that the surgical procedure itself did not negatively affect the fish. Regression analysis, however, indicated that there was a significant decrease in swimming performance associated with increased antenna length ($R^2 = 0.11$, $P < 0.001$). In addition, when held in laboratory tanks, fish with the three longest antennas (150, 225 and 300 mm) frequently became entangled with the standpipe. We suggest that researchers, under the guidance of the tag manufacturer, trim antennas to the shortest possible length required to detect fish in their specific study area. Antenna length is clearly an important issue for small fish, especially for species that inhabit complex habitats where antennas may become entangled, and where fish must attain speeds near limits of their swimming capacity.

K. J. Murchie[1], S. J. Cooke[2], J. F. Schreer[3]

[1]Department of Biology, University of Waterloo, Waterloo, Ont., Canada, [2]Centre for Applied Conservation Research, University of British Columbia, Vancouver, BC, Canada, [3]Department of Biology, State University of New York at Potsdam, Potsdam, NY, USA

Key words: antenna; telemetry; swimming performance; salmonids; methods; radio-tagging

Corresponding author: Karen Murchie, Golder Associates Ltd., 4910-50th Avenue, Unit 200, Yellowknife, NWT, Canada X1A 2P1;
e-mail: Karen_Murchie@golder.com

Accepted for publication May 10, 2004

Un resumen en español se incluye detrás del texto principal de este artículo.

Introduction

Radio-telemetry has become a widely used tool for examining the ecology and behaviour of free-swimming freshwater fish. Increased interest in using this technology for studying small fish species, or early life stages has lead to the development of smaller, longer lasting radio-transmitters that are now capable of being implanted in fish as small as 5 g (e.g., Beaumont et al. 1996; Brown et al. 1999). Although the overall size of the transmitter package has decreased, the length of the antenna attached to the tag has not. When tagging small fish, antennas are often two to three times the body length (e.g., Adams et al. 1998a; Cooke & Bunt 2001). With increased studies focused on using radio-telemetry for small fish (e.g., Bunt et al. 1999; Scruton et al. 2002), there has been concern that the antennas may become entangled in debris or rocks (Cooke & Bunt 2001), become fouled from buildup of algae or other organisms (Thorstad et al. 2001), or just simply increase drag (Mellas & Haynes 1985). Collectively, these effects could lead to injury or death of the fish, disruption of normal behaviour, increased energy expenditure, and/or damage to the transmitter itself. Because of the mounting evidence that long transmitter antennas may impair the performance of the fish, some researchers have trimmed the antennas for both field (e.g., Cooke 2003) and laboratory (Brown et al. 1999) studies. Although many incidental reports of problems with transmitter antennas have been made (e.g., tangling around standpipes (Adams et al. 1998a,b), increased attacks on fish from conspecifics (Connors et al. 2002)), no study has directly manipulated antenna lengths to attempt to quantify changes in fish performance.

In this study we examined the effects of various antenna lengths on the swimming performance of juvenile rainbow trout, *Oncorhynchus mykiss* (Walbaum). Swimming performance was chosen as it has frequently been used as a surrogate for gauging the effects of transmitter implantation on overall fish health (e.g., Mellas & Haynes 1985; Adams et al. 1998b; Brown et al. 1999; Cooke & Bunt 2001). Antenna lengths used in this study were chosen specifically to cover a range of lengths up to a maximum of 300 mm, an antenna length commonly provided on commercial radio-transmitters (e.g., Bunt et al. 1999; Cooke & Bunt 2001).

Materials and methods

Experimental fish and handling procedures

Juvenile rainbow trout (fork length = 148.3 ± 9.5 mm, mass = 34.0 ± 6 g) (mean ± SE) were purchased from Rainbow Springs Trout Farm (Thamesford, Ont.) and were transported to the University of Waterloo wet laboratory. Fish were held in a single indoor tank (350 l) under a natural photoperiod and supplied with flow-through aerated well water between 10.5 and 12 °C. Fish were fed three-point sinking pellets daily for at least 2 weeks prior to experimentation. Food was withheld for 24 h prior to surgical implantation and experimentation (Beamish 1978). Experimental fish were randomly selected and subjected to one of the eight treatment groups; control (handled but not tagged), sham (surgery but no tag), tag with no antenna, and tags with 30, 75, 150, 225 and 300 mm long antennas. Dummy radio-transmitters were constructed from rounded Teflon cylinders (12 mm long, 7 mm diameter) coated in a Prosthetic Silicone Elastomer (A-103; Lotek Engineering, Newmarket, ON, Canada), with a flexible Mini-fish wire antenna (32 AWG Sava wire; Lotek Engineering) made of Teflon-coated stainless steel. The wire material used in our study was similar to that used by commercial radio-tag manufacturers. Dummy tags weighed 0.75 g in air, representing approximately 2.2% of the body weight of the test fish. Similar functional micro radio-transmitters of this size are widely available from commercial producers and have been used in a number of published studies (e.g., Bunt et al. 1999).

Surgical implantation

Individual fish were anaesthetised in a 20 l bath containing 60 ppm clove oil (9:1 ethanol:clove oil), and were kept in the bath until they lost equilibrium and showed reduced opercular movement (Keene et al. 1998). Surgery took place in a shallow basin containing 4 l of water, with a 20 ppm maintenance dose of clove oil. Fish were stabilised with a piece of wet foam within the surgery basin. An 8 mm incision was made slightly to one side of the ventral midline, posterior to the pelvic girdle. An 18G $1\frac{1}{2}$ inch needle was used to provide an exit for the antenna 2 cm to the right of the posterior end of the incision. The incision was closed with two independent 3/0 braided silk sutures (Ethicon Inc.; Somerville, NJ, USA). These surgical procedures are generally consistent with standard techniques used for freshwater fishes in various jurisdictions (Jepsen et al. 2002). All surgeries were performed by the same researcher who had been thoroughly trained in fish surgery (including hands-on practice) to control for the effect of surgeon (Cooke et al. 2003). Immediately after treatment, fish were placed in a freshwater recovery bucket (20 l). As soon as the first four treated fish regained equilibrium, they were transferred into one of the holding tanks (70 l laundry tubs supplied with the same aerated well water as the original tank). Only four fish were kept in each laundry tub to avoid antenna entanglement, which was observed in preliminary experiments when all eight treated fish were held in one tank.

Swimming performance

Swimming performance was evaluated using a Blazka type swim chamber (see Smith & Newcomb 1970), 24–28 h postsurgery. The swim chamber (100 cm long and 25 cm inside diameter) was longitudinally divided into four compartments thus allowing four fish to be tested simultaneously (e.g., Adams et al. 1998b). Fish were randomly allocated to one of the four compartments. Black plastic was draped over the front 50 cm of the tube to provide cover, encourage the fish to swim, and ensure the fish were not disturbed by general laboratory activity (Adams et al. 1998b). Fish were acclimated to the chamber by swimming them at 0.045 m s^{-1} for 10 min (Beamish 1978). An electrified screen at the back of the swimming chamber was attached to a 12 V battery outside the swim tube and was controlled by the experimenter. The mild electrical stimulus provided further encouragement for the fish to swim (Beamish 1978). Beginning at 0.26 m s^{-1}, fish were made to swim for 5 min. After the 5-min interval, the speed was increased 0.17 m s^{-1} every 5 min until each test fish became fatigued. Fatigue was determined when the fish became impinged on and would not leave the electrified screen at the back of the tube, despite 2–1 s shocks in a 10-s period. Time spent at each interval was noted for each fish. Trials lasted as long as it took for the last fish to become fatigued. Once the last fish was fatigued, the swimming chamber's velocity was reduced to 0 m s^{-1} and the fish were removed from each compartment, and their treatment, weight and fork length were recorded. The fish were then killed to remove transmitters. Following the trial, critical swimming speed (U_{crit}) was determined using the formula provided by Beamish (1978).

Analysis

A total of 18 trials were conducted. Homogeneity of variance and normality assumptions for U_{crit}, weight and fork length data were confirmed with Levene's tests and normality plots. To determine if critical swimming speeds, fork lengths or weights differed among groups, data were compared using a one-way ANOVA. Dunnett's test was used to compare individual treatments to control fish (Day & Quinn 1989). We also conducted a power analysis on the critical swimming speed data (Guenther 1964). Least squares linear regression was used to examine the relationship between antenna length and swimming speed, while the control and sham treatments were excluded. Statistical significance of all tests was determined with $\alpha = 0.05$. All statistical analyses were computed using JMPIN (SAS Inc., Cary, NC, USA).

Results

Summary statistics for all of the fish used in the swimming performance trials are given in Table 1. There was no significant difference in the mass (ANOVA, $F = 0.067$, $P = 0.999$) or fork lengths (ANOVA, $F = 0.408$, $P = 0.896$) among the treatment groups (Table 1). There was a significant difference in swimming performance among the treatment groups (ANOVA, $F = 2.304$, $P = 0.029$; Fig. 1). The 300 mm group was the only treatment that had significantly poorer swimming performance than the control group (Dunnett's test, $P < 0.001$). The surgical procedure did not impair swimming performance as there was no significant difference between the control and the sham treatment (Dunnett's test, $P = 0.995$). A conservative calculation of at least 80–85% power of detecting a maximum difference between two mean values was computed for the swimming performance data. Despite the fact that only the mean critical swimming speed for longest antenna length treatment (300 mm) was significantly different from controls, there was a negative relationship between critical swimming speed and antenna length. Regression analysis indicated that a significant proportion of the variation in U_{crit} could be explained by antenna length [$U_{crit} = 0.735 - 5 \times 10^{-4} \times$ antenna length (mm); $R^2 = 0.11$, $F = 12.216$, $P < 0.001$].

Table 1. Summary characteristics of fish exposed to critical swimming speed tests.

		Fork length (mm)		Mass (g)	
Treatment	*N*	Mean	SE	Mean	SE
Control	32	148.6	1.9	33.9	1.2
Sham	18	149.9	2.5	34.5	1.5
0.0 mm antenna	17	149.0	2.6	34.2	1.8
30 mm antenna	18	146.5	1.9	34.2	1.4
75 mm antenna	18	150.3	1.7	33.8	1.2
150 mm antenna	18	146.9	1.9	33.6	1.5
225 mm antenna	18	147.3	2.3	34.5	1.6
300 mm antenna	17	147.3	2.4	33.4	1.7

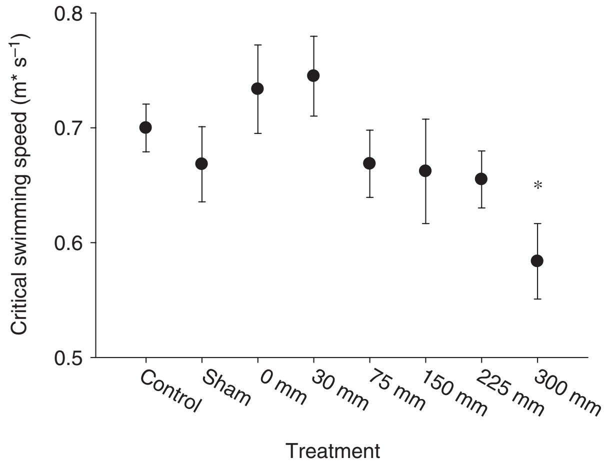

Fig. 1. Critical swimming speed of juvenile rainbow trout exposed to different treatments. The control and sham fish did not carry transmitters, while the other values in millimetre represent the length of the trailing radio-transmitter antenna. Values plotted are mean ± SE and sample sizes are provided in Table 1. Asterisk indicates values that are significantly different (Dunnett's test, $P < 0.05$) from control values.

Discussion

In this study, swimming performance of juvenile rainbow trout was not significantly altered by the intraperitoneal surgical implantation technique, or the presence of the transmitter alone. This finding supports the use of surgical implantation techniques as a method of tagging juvenile rainbow trout between 120 and 170 mm in fork length. However, we determined that radio-transmitters with long antennas

(300 mm) negatively affect the swimming performance of small salmonids, and that a significant, negative relationship exists between swimming performance and radio-transmitter antenna length. Indeed, suspicions by Brown et al. (1999), that antenna lengths may affect swimming performance have been confirmed. This supports the evidence that the 2% rule for biotelemetry studies of small fish should be replaced by guidelines that not only consider tag weight to body weight ratio when determining the right tag for the study fish, but also antenna length.

Not only did increased antenna lengths impair swimming performance of juvenile rainbow trout, but observations of fish with antennas >150 mm entangled around the standpipe of holding tanks were made when fish were held for assessment of tag retention and wound healing (personal observation). Adams et al. (1998b) noticed the same problem when three of their surgery fish tangled their antennas around the tank's standpipe and pulled the transmitter out through the opening of the antenna exit wound. This would obviously be highly detrimental to fish in the wild. The likelihood of such tangling or snagging events would increase in the wild, as fish would have to contend with complex cover and substrates. Further to the possible injury or death caused by entanglement or snagging of antennas is the possibility of increased predation and altered fish behaviour.

It has been suggested that trailing antennas may attract predators because of increased conspicuousness (Mesa et al. 1994) or reduce performance such that transmitter carrying fish can be captured more easily (Adams et al. 1998b). Connors et al. (2002) found that antennas trailing from Atlantic salmon smolts, *Salmo salar* (Linnaeus) (37–54 g, 165–185 mm), implanted with radio-transmitters elicited aggressive attacks from conspecifics. In one instance, an implanted smolt was dragged a short distance by an untagged smolt. The authors concluded that the presence of the antenna might have been responsible for the frequent depression of social rank by tagged individuals. Connors et al. (2002) also reported that the presence of the antenna has also drawn attention from implanted fish itself, providing additional opportunity for altered behaviour.

Conclusions from this study and observations made by other researchers clearly illustrate that transmitter antenna length must be considered an important variable when undertaking a radio-telemetry study. We suggest that researchers, under the guidance of the tag manufacturer, consider trimming antenna lengths, when reductions in the transmission range are acceptable (i.e., a closed system, multiple antenna arrays, etc.). Consultation of the tag manufacturer is paramount as some tags will become water permeable when antennas are trimmed. Dependent on water conductivity and temperature, slightly shorter antennas (e.g., 240 mm long) may work as well, or better, than typical factory determined antenna lengths of 300 mm (Mike VanDen Tillaart, personal communication).

Although it is possible to coil whip antennas into the body cavity of fish, negative aspects of such configurations have been outlined by Cooke & Bunt (2001). While internal coiling of the antenna is an option, most telemetry studies with internally implanted transmitters continue to opt for externally trailing antennas. As such, we also suggest that researchers explore the utility of cryptic antenna colours (Connors et al. 2002). We also encourage researchers to discuss antenna characteristics with the commercial producer during the tendering stage. The producer should be able to provide a selection of antenna lengths, colours and gauges that will allow the user to customize the transmitters for their specific application. In some cases, the loss of signal propagation may be compensated through increases in transmitter power output.

Further investigation into the influence of tag antenna length as a cofactor with the size and mass of the transmitter package is required. Few published studies report the antenna length, gauge, colour, coating, or flexibility. This information is required to detect possible patterns or begin to develop generalities regarding choice of antenna characteristics, and will further strengthen future applications of radio-telemetry.

Resumen

1. Los avances tecnológicos han llevado a producir micro radio-trasmisores capaces de ser implantados en peces de muy pequeño tamaño (≈5 g). Aunque las marcas actuales son pequeñas, los trasmisores están equipados con antenas largas que pueden llegar a enredarse en los restos de vegetación. Examinamos los efectos de la longitud de la antena sobre la rutina natatoria de juveniles de *Oncorhynchus mykiss* ($n = 156$, peso medio = 34 g, longitud furcal media = 148 mm).
2. Aunque analizamos varias longitudes de antena, hasta 300 mm, solamente las de mayor longitud alteraron la rutina natatoria en relación a los peces control ($P < 0.001$). No hubo diferencia en la rutina natatoria entre individuos bajo cirugía pero sin trasmisores respecto de los individuos control (manipulados pero sin cirugía) lo que sugiere que los procedimientos de cirugía no afectaron negativamente a los peces. Sin embargo, análisis de regresión indicaron un declive significativo en la rutina natatoria asociado a la longitud de la antena ($R^2 = 0.11$, $P < 0.001$). Además, al ser mantenidos en tanques, los individuos con las tres antenas mas largas (150, 225, y 300 mm) frecuentemente se enredaron con las tuberías.
3. Sugerimos a los investigadores que, bajo la dirección de los productores de marcas y antenas, consideren el uso de las antenas más pequeñas que permitan detectar a los peces en sus respectivas áreas de estudio. La longitud de la antena es una cuestión importante para los pequeños peces, especialmente

para especies en hábitats complejos donde las antenas pueden llegar a enredarse y donde los peces pueden alcanzar velocidades casi al limite de su capacidad natatoria.

Acknowledgements

All experiments outlined in this paper were conducted under the guidance of the University of Waterloo Animal Care Committee. Laboratory assistance and care of the experimental fish was provided by Wendy McCaul. Jeanette O'Hara Hines provided insight on the statistical analysis of the data. Comments by Geoff Power and Rich Brown helped to improve earlier versions of this manuscript. Scott McKinley provided access to laboratory space and financial support for this study. Additional funding was provided by the Waterloo Biotelemetry Institute and the University of Waterloo.

References

Adams, N.S., Rondorf, D.W., Evans, S.E. & Kelly, J.E. 1998a. Effects of surgically and gastrically implanted radio transmitters on the growth and feeding behavior of juvenile chinook salmon. Transactions of the American Fisheries Society 127: 128–136.

Adams, N.S., Rondorf, D.W., Evans, S.E., Kelly, J.E. & Perry, R.W. 1998b. Effects of surgically and gastrically implanted radio transmitters on swimming performance and predator avoidance of juvenile chinook salmon. Canadian Journal of Fisheries and Aquatic Sciences 55: 781–787.

Beamish, F.W.H. 1978. Swimming capacity. In: Hoar, W.S. & Randall, D.J., eds. Fish physiology, Vol. 7. New York: Academic Press, pp. 101–187.

Beaumont, W.R.C., Clough, S., Ladle, M. & Welton, J.S. 1996. A method for the attachment of miniature radio tags to small fish. Fisheries Management and Ecology 3: 201–207.

Brown, R.S., Cooke, S.J., Anderson, W.G., & McKinley, R.S. 1999. Evidence to challenge the "2% rule" for biotelemetry. North American Journal of Fisheries Management 19: 867–871.

Bunt, C.M., Cooke, S.J., Katopodis, C. & McKinley, R.S. 1999. Movement and summer habitat of brown trout (*Salmo trutta*) below a pulsed-discharge hydroelectric generating station. Regulated Rivers: Research and Management 15: 395–403.

Connors, K.B., Scruton, D., Brown, J.A. & McKinley, R.S. 2002. The effects of surgically implanted dummy radio transmitters on the behaviour of wild Atlantic salmon smolts. Hydrobiologia 483: 231–237.

Cooke, S.J. 2003. Externally attached radio transmitters do not affect the parental care behaviour of rock bass. Journal of Fish Biology 62: 965–970.

Cooke, S.J. & Bunt, C.M. 2001. Assessment of internal and external antenna configurations from transmitters implanted in smallmouth bass. North American Journal of Fisheries Management 21: 236–241.

Cooke, S.J., Graeb, B.D.S., Suski, C.D. & Ostrand, K.G. 2003. Effects of suture material on incision healing, growth and survival of juvenile largemouth bass implanted with miniature radio transmitters: case study of a novice and experienced fish surgeon. Journal of Fish Biology 62: 1360–1388.

Day, R.W. & Quinn, G.P. 1989. Comparisons of treatments after an analysis of variance in ecology. Ecological Monographs 59: 433–463.

Guenther, W.C. 1964. Analysis of variance. New Jersey: Prentice Hall Inc. pp. 49.

Jepsen, N., Koed, A., Thorstad, E.B. & Baras, E. 2002. Surgical implantation of telemetry transmitters in fish: how much have we learned? Hydrobiologia 483: 239–248.

Keene, J.L., Noakes, D.L.G., Moccia, R.D. & Soto, C.G. 1998. The efficacy of clove oil as an anaesthetic for rainbow trout, *Oncorhynchus mykiss* (Walbaum). Aquaculture Research 29: 89–101.

Mellas, E.J. & Haynes, J.M. 1985. Swimming performance and behavior of rainbow trout (*Salmo gairdneri*) and white perch (*Morone americana*): effects of attaching telemetry transmitters. Canadian Journal of Fisheries and Aquatic Science 42: 488–493.

Mesa, M.G., Poe, T.P., Gadonmski, D.M. & Petersen, J.H. 1994. Are all prey created equal? A review and synthesis of differential predation on prey in substandard condition. Journal of Fish Biology 45: 81–96.

Scruton, D.A., Clarke, K.D., Ollerhead, L.M.N., Perry, D., McKinley, R.S., Alfredsen, K. & Harby, A. 2002. Use of telemetry in the development and application of biological criteria for habitat hydraulic modeling. Hydrobiologia 483: 71–82.

Smith, L.S. & Newcomb, T.W. 1970. A modified version of the Blazka respirometer and exercise chamber for large fish. Journal of the Fisheries Research Board of Canada 27: 1321–1324.

Thorstad, E.B., Økland, F. & Heggberget, T.G. 2001. Are long term negative effects from external tags underestimated? – Fouling of an externally attached telemetry transmitter. Journal of Fish Biology 59: 1092–1094.