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Section of Fisheries
# INVESTIGATIONAL REPORT

# No. 522
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July 2005

Minnesota
DEPARTMENT OF NATURAL RESOURCES

Division of Fish and Wildlife

*Minnesota Department of Natural Resources*
*Investigational Report 522, July 2005*

# EXPULSION OF MINIATURE RADIO TRANSMITTERS ALONG WITH EGGS OF NORTHERN PIKE AND MUSKELLUNGE – A NEW METHOD FOR LOCATING CRITICAL SPAWNING HABITAT[1]

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*Abstract.*–Natural shorelines and their associated watersheds are under increasing pressure from human development that has caused degradation of fish habitat. Identification and protection of critical spawning habitat for northern pike *Esox lucius* and muskellunge *Esox masquinongy* is important for preserving the reproductive potential of both species. In this study, we implanted miniature radio transmitters through the oviduct into the egg masses of female northern pike and muskellunge just prior to spawning. This non-surgical procedure is a novel approach for identifying spawning sites if transmitters are expelled with the eggs during egg deposition. Spawning sites can then be located by finding the shed transmitters.

Preliminary studies in three lakes showed that northern pike and muskellunge deposited transmitters in likely spawning habitat. A relatively high proportion (70%) of large northern pike expelled transmitters in a previously known spawning area in Willow Lake, Minnesota. Shoreline vegetation in that area consists primarily of sedges *Carex* spp., and the adjacent water is shallow with substrate consisting of large mats of water bulrush *Scirpus subterminalis*. A lower proportion (50%) of muskellunge expelled transmitters in Elk Lake, Minnesota. The 15-25-day period between implanting and transmitter deposition in Elk Lake may be due to prolonged fractional spawning by muskellunge. Vegetation in likely spawning sites was variable, but *Chara* spp. was common to most sites. In Moose Lake, Minnesota, 90% of northern pike and 60% of muskellunge expelled transmitters. Both species deposited transmitters on deepwater bars in addition to near-shore habitat, and *Chara* beds were an important substrate where transmitters were expelled in Moose Lake. Size of the transmitters in relation to fish size was an important factor influencing expulsion of transmitters.

[1] This project was funded in part by the Federal Aid in Sport Fish Restoration (Dingell-Johnson) Program. Completion Report, Study 639B, D-J Project F-26-R Minnesota.

## Introduction

Natural shorelines and their associated watersheds are under increasing pressure from human development, and development has caused degradation of fish habitat (Burns 1991; Cross and McInerny 1995; Engel and Pederson 1998; Radomski and Goeman 2001) that has included eutrophication and changes in aquatic vegetative cover. Populations of northern pike *Esox lucius* and muskellunge *Esox masquinongy* are sensitive to shoreline and related land development that removes vegetation, reduces water quality, and adds biological oxygen demand to sediments (Brynildson 1958; Dombeck et al. 1984). Northern pike are closely associated with wetlands and aquatic vegetation, especially for spawning (Becker 1983; Bry 1996). Muskellunge eggs and larvae are intolerant of low dissolved oxygen concentrations in a microzone along the bottom where they are dispersed (Dombeck et al. 1984). Northern pike can exhibit natal-site fidelity, and both species exhibit spawning-site fidelity (Crossman 1990; Miller et al. 2001), which suggests that protection and management of traditional spawning sites is warranted. Identification of these critical habitats is an important step toward protecting the reproductive potential of both species.

Three approaches have been used to identify esocid spawning habitat: (1) direct observation of fish during spawning (Franklin and Smith 1963), (2) extensive sampling for eggs (McCarraher and Thomas 1972), and (3) radio- or ultrasonic tracking of fish during spawning movements (Strand 1986; Younk et al. 1996). All three can be costly and time-consuming, especially with busy spring work schedules. Radio-tracking or ultrasonic telemetry has often involved surgical, gastric, or external attachment of transmitters, which can cause behavioral changes or physiological stress for fish (Winter 1983; Mellas and Haynes 1985).

Advances in miniaturization have led to transmitters that are small enough to fit up through the oviducts of northern pike and muskellunge. For this study, we implanted miniature radio transmitters through the oviduct into the egg mass of mature northern pike and muskellunge females. This non-surgical procedure is a novel approach that offers potential for identifying egg deposition sites if transmitters are expelled with eggs during spawning. Spawning sites can then be located by finding the shed transmitters. Results of initial implants in 10 northern pike from Willow Lake, Minnesota, during spring 2002 were reported in Pierce (2004). Only four of the fish expelled transmitters, with expulsion influenced by the size of the fish. Small fish (<650 mm total length (TL)) were unable to expel the transmitters. We continued our evaluation of the potential of this method for identifying spawning habitat in 2003-2004. Three additional trials with miniature radio transmitters were designed to (1) test the effectiveness of an alternate transmitter shape for different sizes of northern pike, (2) compare three sizes of transmitters for use in muskellunge, and (3) apply the technique in a lake where northern pike and muskellunge coexist, but where spawning sites had not previously been identified. In this report, we further describe our unique experiments in having radio transmitters expelled with eggs.

## Methods

*Effects of Fish Size and Alternate Transmitter Shape*

During spring 2003, we tested the usefulness of altering transmitter shape by reforming the potting resin to obtain a more tapered or torpedo-shaped posterior (antenna) end. The tapered end was intended to allow fish to more readily expel transmitters compared with standard transmitters having a flat posterior surface. Radio transmitters were inserted in 20 northern pike during 19-21 April while they were ripe and staging for spawning in Willow Lake. Willow Lake is a 96-ha lake located on the border of Itasca and Cass counties. The lake has a maximum depth of 14 m and moderate alkalinity (103 mg $CaCO_3$/l total alkalinity). A shallow bay in the southwest end of the lake provides the principal known spawning area for northern pike.

Each fish was implanted with an Advanced Telemetry Systems (ATS) model F1410 miniature radio transmitter[2]. Each transmitter was 6 mm in diameter and 18 mm long, weighed 1.0 g, and had a thin 25-cm long dipole antenna. The tapered portion extended 3-4 mm beyond the end of the transmitter. Transmitters were inserted approximately 3.5 cm up the oviduct and into the egg mass with the antenna trailing out through the oviduct (Figure 1). Transmitted frequencies were between 48.470 and 48.971 mHz with at least 10 kHz difference between frequencies.

We attempted to locate fish at least once per day with a receiver and hand-held loop antenna. At close range, a short (15 cm) whip antenna or underwater antenna (construction described in detail by Kenow et al. 1992) was used to more accurately locate transmitters. Each fish was tracked for up to 19 days or until the transmitter was expelled. UTM coordinates for daily transmitter locations were recorded using a GPS receiver, and if a transmitter became stationary for several days, we assumed it was expelled. Daily locations for individual transmitters were transferred to a Landview (Minnesota Department of Natural Resources geographic information system) map of Willow Lake. The effect of transmitter shape on expulsion by small northern pike was tested by tagging 10 small females (501-639 mm TL; Table 1), and comparing their transmitter expulsion rates with rates from spring 2002 (data from Pierce 2004; Table 1). The effect of fish size on expulsion was tested by comparing expulsion rates for 10 large fish (691-831 mm TL; Table 1) with rates of the smaller fish and with rates from 2002 (data also from Pierce 2004).

*Comparison of Transmitter Sizes for Muskellunge*

We compared expulsion rates for three sizes of radio transmitters inserted through oviducts of adult female muskellunge. A total of 15 female muskellunge were trapped and implanted with radio transmitters while they were staging for spawning during 26 April - 2 May 2003. Gonad maturation stage for the fish ranged from green to ripe. Fish were 1,048-1,211 mm TL when captured and released in Elk Lake (Table 2). Elk Lake is a 110-ha lake with a maximum depth of 28 m and total alkalinity of 155 mg/l $CaCO_3$ located within Itasca State Park (Clearwater County). This population has been managed for broodstock for the statewide muskellunge stocking program.

Transmitter size was randomly assigned, with five fish implanted with each transmitter size (Table 2). The smallest transmitter was ATS model F1410. Intermediate in size was ATS model F1420, which weighed 1.5 g and was 7.6 mm in diameter. Largest was ATS model F1630 weighing 2.5 g and having a diameter of 9 mm. Transmitter frequencies were 48.014-48.407 mHz with a minimum of 10 kHz between frequencies. Transmitter locations were monitored from 28 April through 4 June 2003. Other procedures were similar to those used for northern pike.

*Location of Northern Pike and Muskellunge Spawning Habitat in Moose Lake*

Use of radio transmitters was extended to the practical application of locating esocid spawning habitat in a lake where northern pike and muskellunge coexist. Ten female northern pike and 10 female muskellunge were trapped and implanted with transmitters in spring 2004. Fish were captured and released in Moose Lake, Itasca County, a 512-ha lake with a maximum depth of 19 m and total alkalinity of 129 mg/l $CaCO_3$. Northern pike were implanted with transmitter model F1410 and muskellunge with model F1420, and all transmitters had a tapered posterior end. Northern pike were trapped and transmitters inserted during 24-26 April in fish ranging in size from 675 to 879 mm TL (Table 3). Muskellunge were implanted during 25-30 April and were 835-1160 mm TL (Table 3). Northern pike transmitters operated at frequencies of 48.010-48.191 mHz and muskellunge transmitters operated at 48.794-48.970 mHz, allowing at least 10 kHz between frequencies. Transmitter locations were monitored almost daily (27/33 days) from 26 April through 28 May 2004. UTM coordinates, as well as depth and substrate type, were recorded for transmitter deposition sites. UTM coordinates were transferred to a Landview map of Moose Lake. Substrates and aquatic vegetation at deposition sites were described from samples

[2] Use of trade names does not imply endorsement of product.

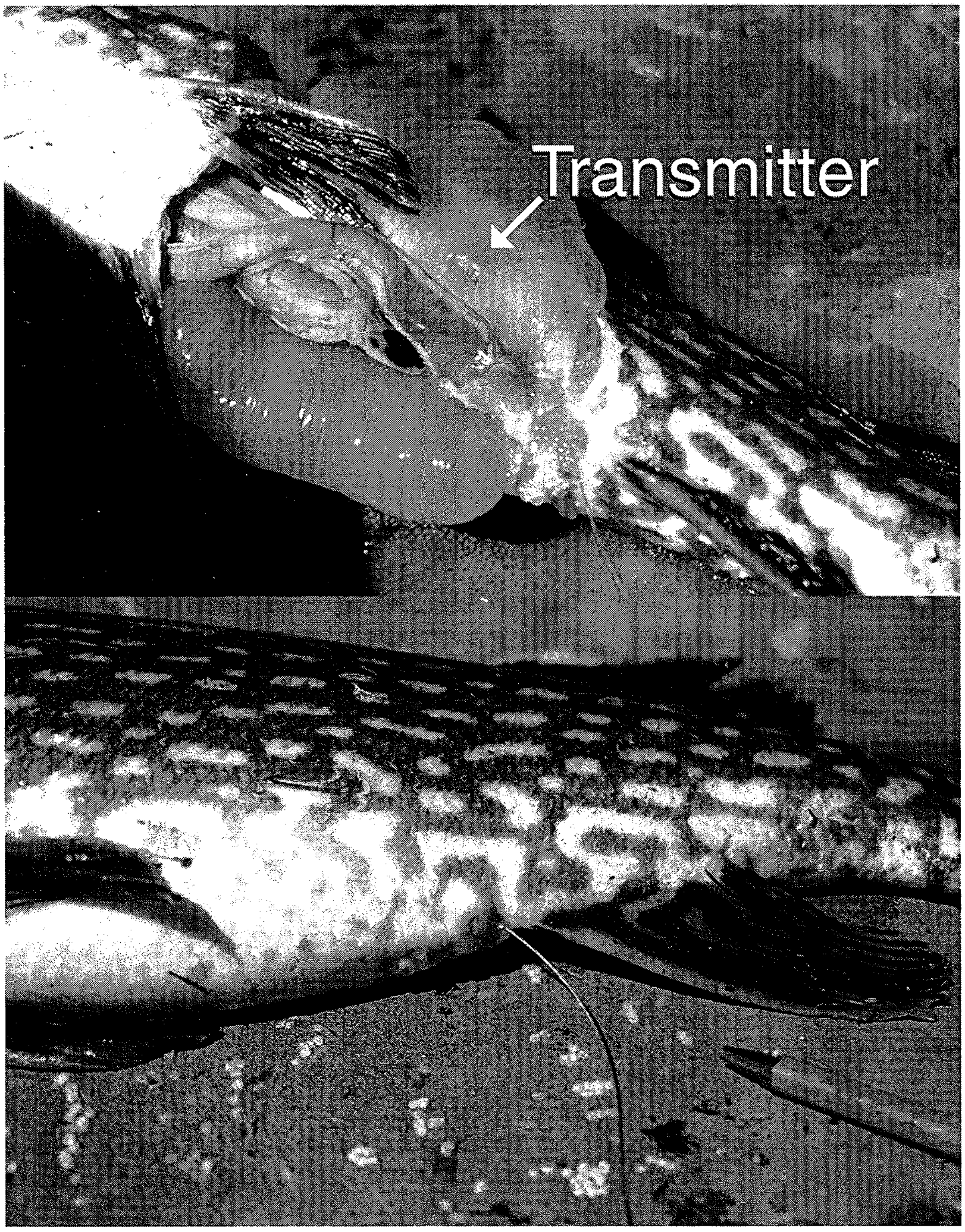


Figure 1. Photographs illustrating the location of a transmitter within an ovary, and the antenna trailing out from the oviduct of a female northern pike.

Table 1. Fish lengths and radio frequencies for implanted northern pike, along with the fate of the transmitters and dates they were deposited in Willow Lake, 2002-2003.

| Total length (mm) | Frequency (mHz) | Deposition location or fate of transmitter | Date deposited |
|---|---|---|---|
| *2002 Data from Pierce (2004); used standard (flat-shape) transmitters* | | | |
| 567 | 48.461 | Still at large | - |
| 577 | 48.491 | Still at large | - |
| 602 | 48.511 | Recaptured with gill net | - |
| 652 | 48.551 | Recaptured with gill net | - |
| 658 | 48.541 | Located in spawning area | 23 April |
| 687 | 48.481 | Recaptured with gill net | - |
| 732 | 48.571 | Still at large | - |
| 734 | 48.591 | Located in southwest end of lake | 2 April |
| 752 | 48.530 | Located in spawning area | 4 May |
| 812 | 48.561 | Located in spawning area | 2 May |
| *2003 Small northern pike; used tapered transmitters* | | | |
| 501 | 48.751 | Located in northeast end of lake | 4 May |
| 541 | 48.891 | Located in spawning area | 26 April |
| 580 | 48.931 | Located in southwest end of lake | 1 May |
| 598 | 48.951 | Located in spawning area | 2 May |
| 601 | 48.561 | Still at large | - |
| 622 | 48.731 | Located in middle of south bay | 3 May |
| 625 | 48.771 | Still at large | - |
| 630 | 48.611 | Located in spawning area | 29 April |
| 633 | 48.671 | Located in middle of south bay | 1 May |
| 639 | 48.911 | Still at large | - |
| *2003 Large northern pike; used tapered transmitters* | | | |
| 692 | 48.711 | Still at large | - |
| 692 | 48.831 | Located at north end of lake | 2 May |
| 700 | 48.791 | Located in spawning area | 2 May |
| 700 | 48.851 | Still at large | - |
| 702 | 48.501 | Located in spawning area | 26 April |
| 750 | 48.691 | Located in spawning area | 26 April |
| 782 | 48.811 | Located in spawning area | 26 April |
| 798 | 48.971 | Located in spawning area | 26 April |
| 822 | 48.871 | Located in spawning area | 26 April |
| 831 | 48.470 | Located in spawning area | 30 April |

Table 2. Lengths and radio frequencies for three sizes of transmitters implanted in muskellunge, along with the fate of the transmitters and dates they were deposited in Elk Lake, 2003.

| Total length (mm) | Frequency (mHz) | Deposition location or fate of transmitter | Date implanted | Date deposited |
|---|---|---|---|---|
| *Small transmitters* | | | | |
| 1,165 | 48.014 | Located in southwest bay | 27 April | 16 May |
| 1,112 | 48.034 | Still at large | 27 April | - |
| 1,163 | 48.055 | Expelled during recapture[1] | 2 May | - |
| 1,048 | 48.075 | Still at large | 28 April | - |
| 1,081 | 48.095 | Still at large | 29 April | - |
| *Intermediate transmitters* | | | | |
| 1,052 | 48.114 | Still at large | 2 May | - |
| 1,211 | 48.134 | Located at northwest shore | 27 April | 19 May |
| 1,059 | 48.154 | Located in southwest bay | 28 April | 19 May |
| 1,173 | 48.174 | Located at northwest shore | 30 April | 16 May |
| 1,105 | 48.194 | Still at large | 1 May | - |
| *Large transmitters* | | | | |
| 1,170 | 48.337 | Located at west shore | 29 April | 19 May |
| 1,174 | 48.358 | Found dead[1] | 1 May | - |
| 1,194 | 48.371 | Still at large | 30 April | - |
| 1,181 | 48.397 | Found dead[1] | 26 April | - |
| 1,206 | 48.407 | Located in mouth of creek | 28 April | 14 May |

[1]Excluded from analysis

Table 3. Fish lengths and radio frequencies for implanted northern pike and muskellunge, along with the transmitter deposition location and depth, and dates they were deposited in Moose Lake, 2004.

| Total length (mm) | Frequency (mHz) | Deposition location or fate of transmitter | Date deposited |
|---|---|---|---|
| *Northern pike* | | | |
| 675 | 48.071 | Deepwater bar, 5.8 m | 7 May |
| 682 | 48.010 | Deepwater bar, 5.5 m | 10 May |
| 682 | 48.151 | Lost signal | - |
| 711 | 48.131 | Deepwater bar, 5.2 m | 5 May |
| 715 | 48.051 | Moose Creek | 27 April |
| 730 | 48.111 | Near south shore, 1.8 m | 9 May |
| 752 | 48.191 | Deepwater bar, 5.2 m | 5 May |
| 810 | 48.091 | Deepwater bar, 4.9 m | 27 April |
| 821 | 48.031 | Moose Creek | 27 April |
| 879 | 48.171 | Expulsion due to handling? | 27 April |
| *Muskellunge* | | | |
| 835 | 48.911 | Northeast shore, 0.6 m | 9 May |
| 900 | 48.870 | Still at large | - |
| 1,000 | 48.930 | Northeast shore, 1.5 m | 10 May |
| 1,000 | 48.951 | Still at large | - |
| 1,020 | 48.814 | Deepwater bar, 3.7 m | 7 May |
| 1,030 | 48.970 | Deepwater bar, 3.7 m | 20 May |
| 1,075 | 48.834 | South shore, 2.1 m | 27 May |
| 1,090 | 48.794 | Still at large | - |
| 1,125 | 48.891 | Northeast shore, 1.8 m | 11 May |
| 1,160 | 48.854 | Caught by angler | - |

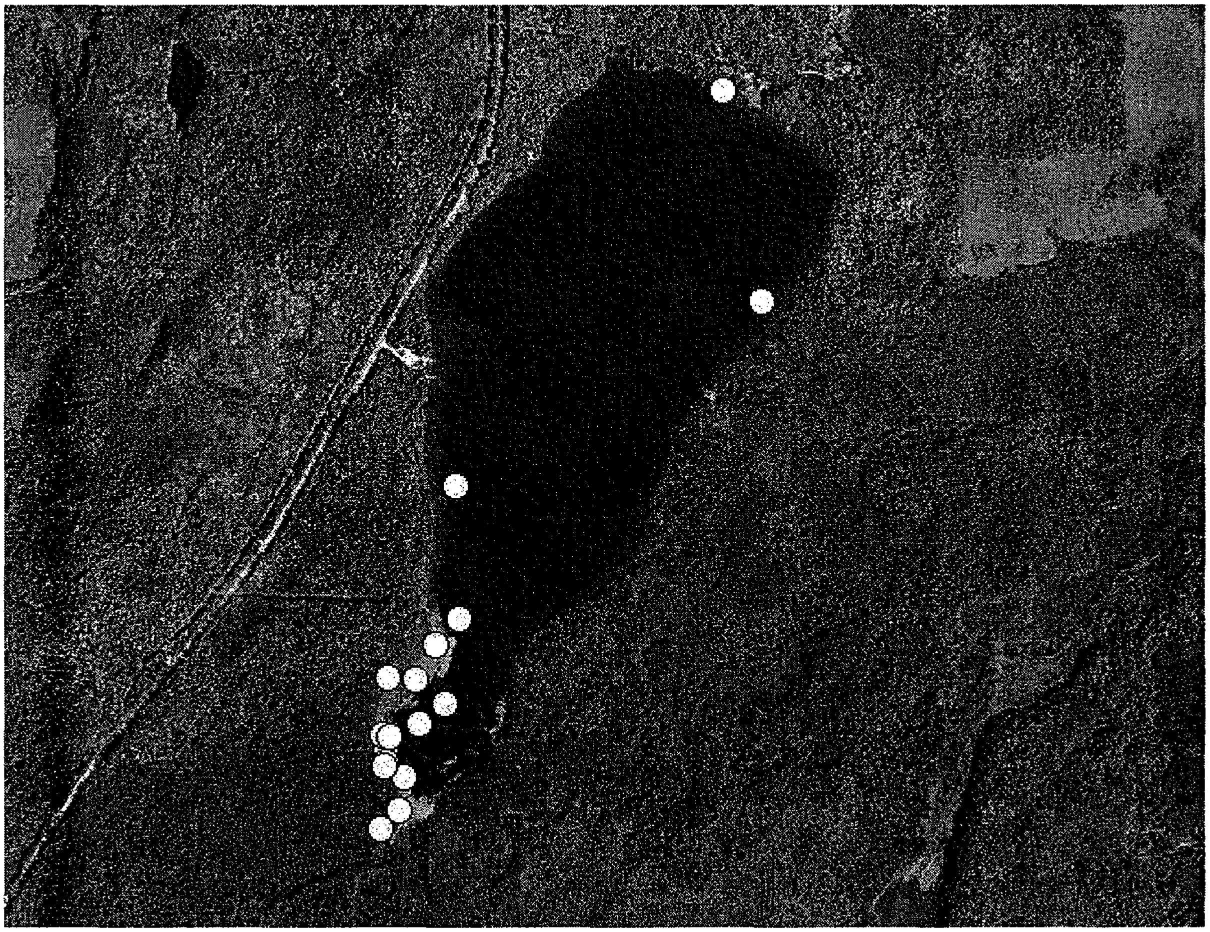

Figure 2. Locations of transmitter deposition sites for northern pike in Willow Lake, 2002-2003.

taken with an Ekman dredge. Scap nets and visual observations with an underwater viewing scope were used to try to find eggs in areas where transmitters were shed.

## Results

*Effects of Northern Pike Size and Transmitter Shape*

A relatively high proportion of large northern pike expelled their transmitters in the previously known spawning area in Willow Lake during spring 2003. Mean TL of the large northern pike was 747 mm (SE=18 mm; Table 1). Eight out of 10 large fish expelled transmitters, and 7 of them were shed in the known spawning area at the west side of the south bay of Willow Lake (Figure 2). Shoreline vegetation along that portion of the lake consists primarily of sedges *Carex* spp., and the adjacent water is shallow and has large mats of water bulrush *Scirpus subterminalis* (where all seven transmitters were located). One transmitter was deposited in an unlikely spawning location, over sand substrate in water less than 1 m deep at the north end of the lake. Two transmitters were retained by large fish. Large northern pike expelled transmitters during the one-week period between 26 April and 2 May 2003, although most of the spawning appeared to occur on 26 April, a warm, sunny spring day. Five transmitters were shed in the spawning area on 26 April, one on 30 April, and one on 2 May. We were unable to recover any of the transmitters.

Fewer small northern pike shed transmitters in likely spawning habitat in Willow Lake. Mean total length of the small fish implanted with transmitters during spring 2003 was 597 mm (SE=14 mm; Table 1). Although 7 out of 10 fish expelled transmitters, only 3 were shed in the previously known spawning area. The three transmitters were shed on 26 April, 29 April, and 2 May. Three other transmitters were expelled in deeper (1.5-1.8 m) water near the previously known spawning area over sediments consisting of *Chara* spp. or muck with various plant fragments. A final transmitter was shed in a different bay at the northeast end of the lake over a bottom consisting of *Potamageton* spp., *Chara,* and silt. None of the transmitters were recovered. In spite of low sample sizes, the proportion of large fish depositing transmitters in known spawning grounds in 2003 seemed to be greater than for small fish (Chi-square=3.20; *df*=1; *P*=0.07). The most consistent deposition of transmitters at the known spawning area was for northern pike >700 mm TL (Table 1).

Altering the shape of the transmitters for spring 2003 appeared to make it easier for small northern pike to expel transmitters. Females expelled transmitters (regardless of location) at a greater rate in 2003 than in 2002 (Table 1; Chi-square=3.52; *df*=1; *P*=0.06). Although some selection for fish size was imposed in 2003, there was no significant difference in the average length of fish implanted between the two years (*t*=0.16; *df*=28; *P*=0.88). The difference in expulsion rates between the two years was primarily due to small fish because there was no apparent difference in expulsion rate for large (>691 mm TL) fish between the two years (Chi-square=0.04; *df*=1; *P*=0.84). A difference in expulsion rates was evident for small fish (<650 mm) between 2002 and 2003 (Chi-square=4.55; *df*=1; *P*=0.03).

*Effects of Transmitter Size for Muskellunge*

Three muskellunge were excluded from analyses in Elk Lake because of stress due to multiple recaptures and handling during sampling in spring 2003. The muskellunge with transmitter 48.055 expelled her transmitter in a holding tank when recaptured during an electrofishing population estimate. Two muskellunge implanted with large transmitters (48.358 and 48.397) died before depositing their tags. Multiple captures and handling (2-4 times) during the sampling period coupled with spawning stress were the probable causes of their deaths. Visual contact with muskellunge 48.358 occurred two times prior to finding her dead. She was observed along the south shore spawning on 14 May and again on 16 May resting in an adjacent bay. Muskellunge 48.358 was found dead on 19 May. Muskellunge 48.397, identified as a green female, was captured and implanted on 26 April. Sixteen days later, following three additional net recaptures and five tracking locations, fish 48.397 was found dead. A necropsy performed on both fish showed no obvious evidence of death due to the transmitter implants. Ovaries from both fish appeared healthy, but there was a difference in the quantity of eggs remaining in the ovaries. Muskellunge 48.358 was approximately 70-75% spent. Ovaries from muskellunge 48.397 were full, but in contrast to when she was tagged, the eggs were ripe and free flowing.

As a result of the three fish excluded from analyses and low sample sizes, no effect of transmitter size on expulsion rate was detected. Transmitter expulsion rates were 1/4 for small transmitters, 3/5 for intermediate-size transmitters, and 2/3 for large transmitters (Table 2). Significant differences in expulsion rates were not apparent for the different sized transmitters (Chi-square=1.53; *df*=2; *P*=0.46). Combining all fish yielded a ratio of 6/12 transmitters expelled, or an equal probability (*P*=0.50; 95% C. I.=22.3-77.7%) of individuals depositing or retaining transmitters.

For muskellunge included in our analyses, expulsion rate seemed primarily related to fish size and the state of gonad maturation when the implants were made. Although sample sizes were small, muskellunge that expelled transmitters appeared to be larger

($n$=6; mean length=1164 mm; SE=22 mm) than fish that retained transmitters ($n$=6; mean length=1099 mm; SE=22) ($t$=2.08; $df$=10; $P$=0.06). Females that were ripe and running eggs when implanted had a better chance of expelling radio transmitters. A significant difference was found in expulsion rates of fish that were green versus fish that were ripe when implanted (Chi-square=4.00; $df$=1; $P$=0.05). All fish (3/3) implanted when gonad maturation stage was ripe expelled their transmitters. For fish implanted when gonad maturation stage was green, only 3/9 transmitters were expelled.

Elk Lake muskellunge spawning areas were not well defined prior to the current study. Pre-spawning study fish were extremely active, circling the lake numerous times with brief stops at the various bulrush beds and bays that are characteristic of Elk Lake. The period between implanting and transmitter deposition ranged from 15 to 25 days (mean=18 days; SE=1.6), providing evidence of prolonged and possibly fractional spawning. Based on transmitter deposition, likely spawning habitat appeared to be concentrated along the western and southern shores of Elk Lake (Figure 3). Water depth at transmitter deposition sites averaged 1.1 m (SE=0.2), and forms of aquatic vegetation varied among the sites, although *Chara* spp. was common to most of the sites. Other forms of vegetation represented included *Elodea canadensis*, *Ceratophyllum demersum*, *Potamogeton natans*, *P. zosteriformis*, *P. foliosus*, *P. natans*, *Scirpus validus*, *Stuckenia pectinata*, *Typha angustifolia*, and *Zizania aquatica*.

*Location of Northern Pike and Muskellunge Spawning Habitat in Moose Lake*

An unusually long cold period with windy, cloudy, and rainy weather kept spring 2004 water temperatures 10°C or colder through 15 May, and probably delayed and protracted spawning in Moose Lake. Ice was moving off the lake on 23 April and was gone after 24 April. Nine of the 10 northern pike transmitters were deposited between 27 April and 10 May (Table 3). The tenth northern pike presumably migrated out into the Deer River as we were unable to locate it after 1 May. Four northern pike expelled tags on 27 April, two on 5 May, and the others between 7 and 10 May.

Northern pike deposited transmitters along an outlet stream or in deeper water within the lake basin. Two transmitters were expelled along Moose Creek, a narrow channel that runs out through a cattail and sedge meadow to the Deer River (Figure 4). One transmitter (48.171) may have come out when the fish was released, as the transmitter was located the next day in an unlikely spot in deep water where the fish was released. Other transmitters were deposited in the lake, usually in deeper water over bars extending out from shore, or a bar rising up from deeper water farther out in the lake (Figure 4). Water depths for 6 of the transmitters were 4.9-5.8 m, and substrates for all but one were beds of *Chara* spp. The exception was found on a bar extending south from the north shore of the lake, where the substrate at 5.2 m depth was a dense bed of *Nitella* spp. Two transmitters were deposited within about 5 m of each other at depths of 4.9-5.2 m on a bar protruding from a point of land on the south side of the lake. These two northern pike were originally trapped in different nets and deposited their transmitters in nearly the same spot on different dates. A final transmitter was shed near the south shore in 1.8-m water depth, also in a bed of *Chara* spp. None of the transmitters were recovered.

Muskellunge spawning apparently began later and lasted longer than northern pike spawning, and the muskellunge were less successful at expelling radio transmitters. The first muskellunge transmitter was not dropped until 7 May. The last expelled transmitter we were able to find was dropped 27 May. The peak of activity was likely during 7-11 May, as the other transmitters were dropped during 9, 10, 11, and 20 May (Table 3). We found no evidence that 4 of the 10 females dropped their transmitters, and in fact, transmitter 48.854 was recovered when the fish was caught by angling 24 October 2004.

Muskellunge appeared to use both near-shore and offshore habitat for spawning. Three muskellunge shed transmitters near shore along the northeast end of Moose Lake

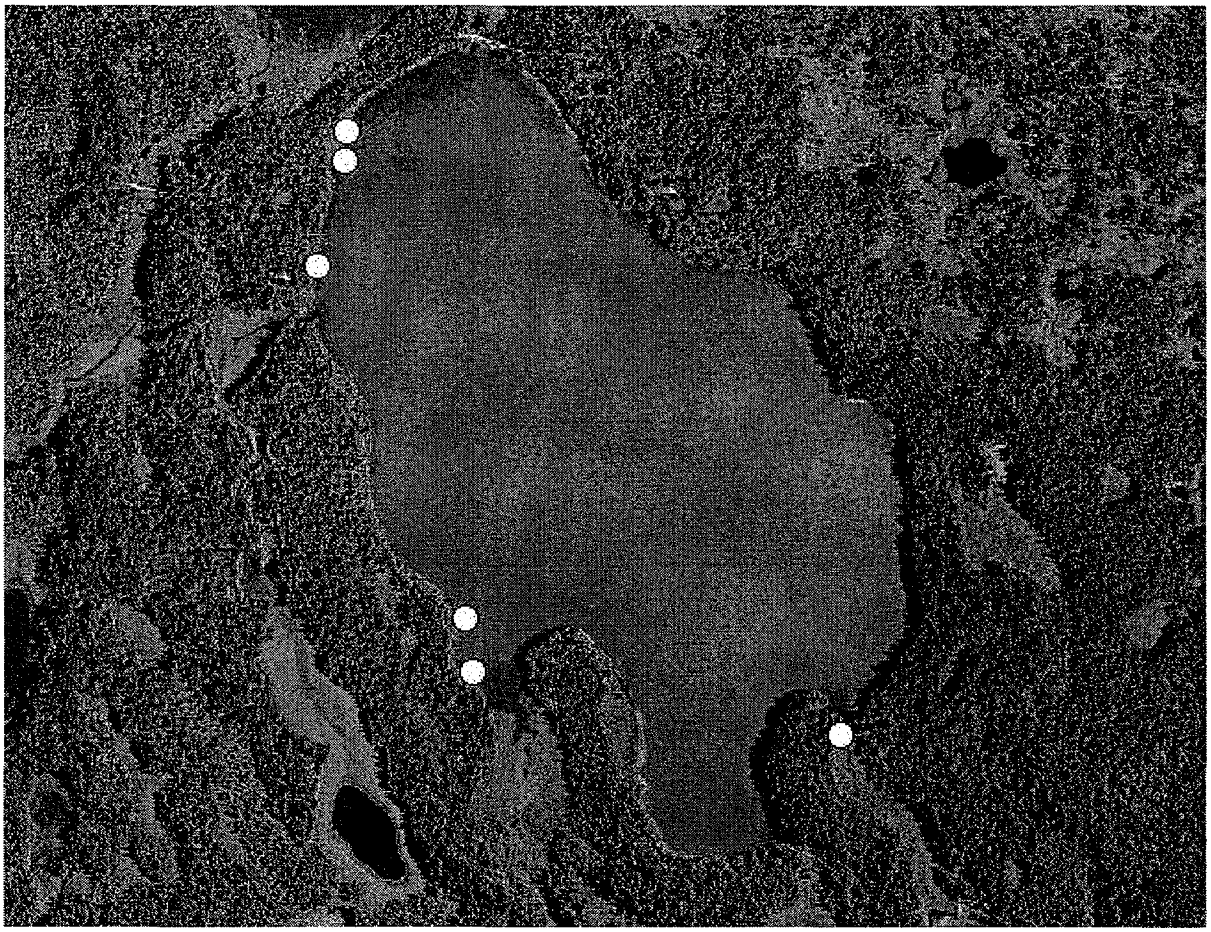

Figure 3. Locations of transmitter deposition sites for muskellunge in Elk Lake, 2003.

in proximity to two inlet streams (Figure 5). The two streams provide inflow from Fawn and Little Moose lakes during the spring. These transmitters were in 0.6-1.8-m depth where the predominant vegetation was *Chara* spp. Two more muskellunge shed transmitters in deeper water over offshore bars. Water depth where both tags were located was 3.7 m. One was in a bed of *Chara* spp. whereas vegetation on the other bar was *Elodea canadensis*. The final transmitter was shed in *Chara* spp. in 2.1-m deep water on a drop off near the south shore of Moose Lake. None of the transmitters were recovered, even though one of them was in water only 0.6 m deep in a relatively sparse *Chara* spp. bed. An intensive search was made for that transmitter, but even with use of an underwater viewing scope and underwater radio antenna, we were unable to discover the shed transmitter.

We continued to track muskellunge that retained transmitters, with some locations obtained through 10 June. One fish was regularly located, and even observed, in shallow water among bulrushes along the southeast bay of Moose Lake. However, three individuals were only sporadically located after mid-May, presumably because they made movements off shore into deepwater habitat that we were unable to monitor with our radio receivers.

Figure 4. Locations of transmitter deposition sites for northern pike in Moose Lake, 2004.

The smaller transmitters used for northern pike had a shorter lifespan than those used for muskellunge. On 28 May, after 35 days, one-half (5) of the northern pike transmitters were off the air. By June 4 (42 days), all northern pike transmitters were off the air. In contrast, all six muskellunge transmitters that had been dropped were still on the air. On 21 June (58 days), 2 of the 6 muskellunge transmitters were dead, and only 1 was still functioning after 68 days (1 July 2004).

## Discussion

Oviduct insertion of radio transmitters offers several advantages over other methods for locating spawning sites. Because the transmitters are implanted during the spawning run, they do not need to have a long battery life. This reduces the size of transmitter Oviduct insertion requires minimal effort for. implanting. Small transmitters slide easily up the oviduct, requiring less than a minute to actually implant the transmitter, reducing handling time and eliminating use of anesthetics. Transmitters do not need to be monitored continuously, but rather need only be located several times at the end of the spawning period to ensure that the transmitter is stationary. Thus, this method provides for a more efficient use of time in locating critical spawning habitat during spring, which is a busy time of

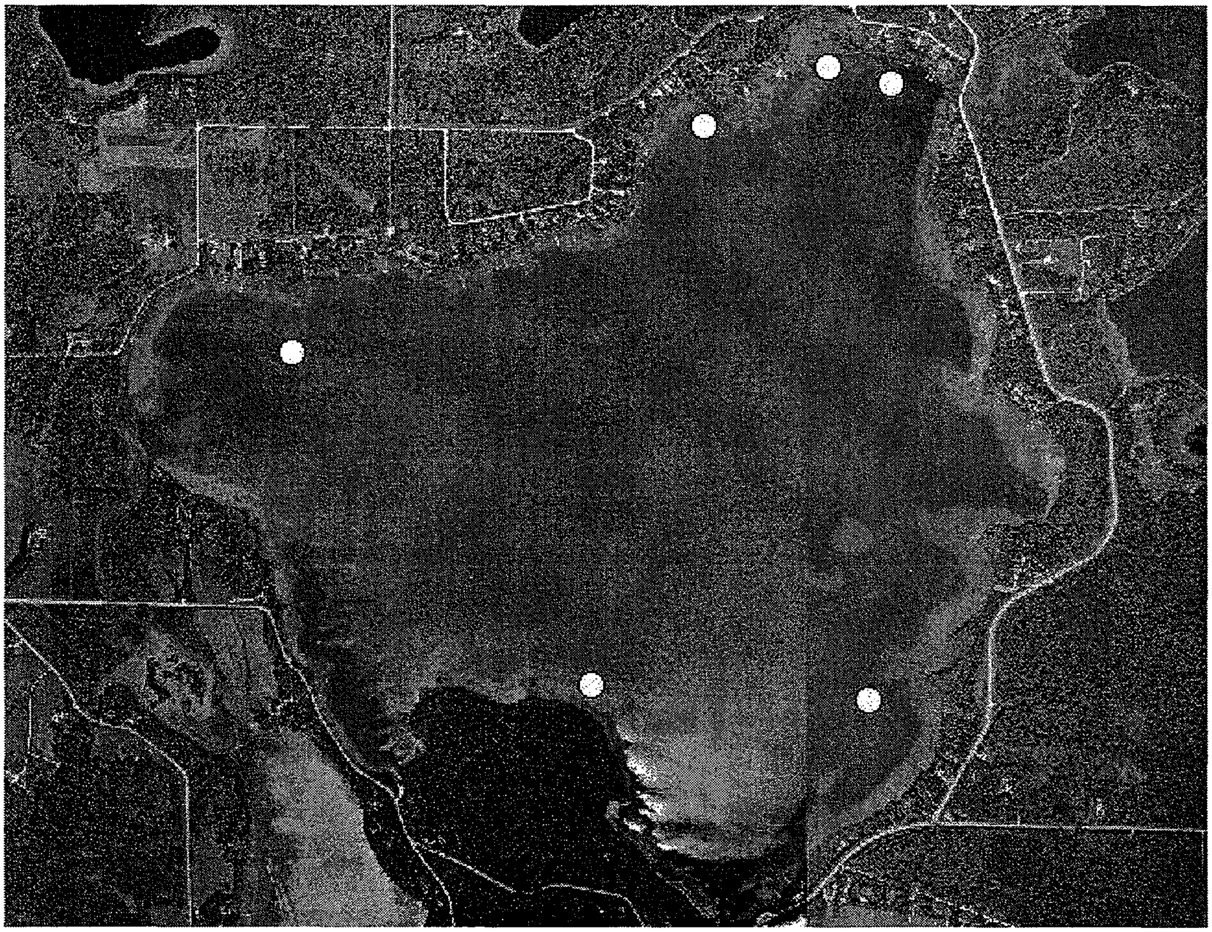

Figure 5. Locations of transmitter deposition sites for muskellunge in Moose Lake, 2004.

year for most fisheries personnel. Because implantation is non-surgical, the technique should be less intrusive. Previous research on telemetry has compared the effects of transmitter attachment methods on fish health and behavior, and shown that attachment methods can have adverse effects on some fish. For example, surgically or gastrically implanted transmitters affected swimming speeds, vulnerability to predation, and physiological measures of stress for young Chinook salmon *Oncorhynchus tshawytscha* (Adams et al. 1998; Jepsen et al. 2001). Rainbow trout *Onchorynchus mykiss* and white perch *Morone americana* with external and surgical attachments contracted serious fungal infections, and regurgitation or stomach atrophy was encountered with gastric tagging (Mellas and Haynes 1985).

Although our study was the first attempt to have radio transmitters expelled with eggs, Peake et al. (1997) used oviduct insertion to tag and track adult female Atlantic salmon *Salmo salar* and rainbow trout (1.7-3.6 kg each), and found that 69% of transmitters were retained in Atlantic salmon for 60 days and 83% of transmitters were retained in rainbow trout for 45 days. Transmitters for the salmon and trout were much larger (9.9 g) than the transmitters we used, and affected egg expulsion and viability in the rainbow trout (Peake et al. 1997). Both the Peake et al. study and our work show that even if transmitters are not expelled with eggs, oviduct insertion can be a viable method of attachment for short-term biotelemetry studies. Daily monitoring of northern pike and muskellunge illustrated their early spring movements and use of habitat in all three lakes that we studied. As technological improvements lead to smaller batteries with a longer lifespan, oviduct implants may allow for even longer-term biotelemetry and the application could be extended to other species.

Locations of expelled tags in our study were considered only to be potential spawning sites because we were unable to recover transmitters or esocid eggs in the vicinity (about 3 $m^2$ area) with the strongest radio signal. This remains the most serious problem in validating transmitter locations as spawning sites. Miniature transmitters were not found in the sediments and plant debris, even with intensive effort. Northern pike eggs, which adhere to vegetation, were not found at four of the shallowest transmitter locations in Willow Lake. Muskellunge eggs were also not found at the most readily examined shallow location in Moose Lake. Most helpful would be development of an antenna that could better pinpoint shed transmitters, making it easier to sample eggs near the transmitters.

Northern pike have previously been found to spawn in deeper water in Lake Windermere, England, and in the St. Lawrence River. Pike in Windermere apparently used beds of *Elodea* spp., *Myriophyllum* spp., and *Nitella* spp. in 2.0-3.5-m water depths (Frost and Kipling 1967). Farrell et al. (1996) found northern pike eggs in water up to 2.6 m deep in Point Marguerite Marsh in the upper St. Lawrence River. *Chara* spp. was a very important substrate where both northern pike and muskellunge transmitters were found in Moose Lake. Previous studies have shown that *Chara* is used by spawning northern pike (McCarraher and Thomas 1972; Farrell et al. 1996) and muskellunge (Strand 1986; Farrell et al. 1996). *Chara* spp. was the dominant vegetation in muskellunge spawning sites that were distinctly off shore in depths of 1-2 m in Leech Lake, Minnesota (Strand 1986).

## Management Implications

Size of the transmitter in relation to fish size was important. Our most consistent success with the smallest transmitters was for northern pike >700 mm TL. A more tapered transmitter design also appeared to facilitate expulsion. Although we were unable to discriminate between expulsion rates for different size transmitters in muskellunge, large transmitters were more difficult to insert (more resistance encountered from the oviduct), so their size may have impeded expulsion through the oviduct. We had less success with muskellunge expelling their transmitters than with northern pike. Only 50% of muskellunge deposited transmitters in Elk Lake and 60% in Moose Lake. Transmitter sizes were larger for muskellunge, but maybe just as important for interpreting these results is their more extended spawning period, and their more fractional egg-laying behavior (Lebeau et al. 1986). For both esocids, transmitters seemed easiest to insert in ripe females, though ripe fish need to be handled carefully when released so that eggs and transmitters are not inadvertently extruded. In view of these experiences, we recommend (1) using the smallest available transmitter, (2) using transmitters that are tapered at the posterior end, (3) using northern pike > 700 mm TL, and (4) inserting transmitters in ripe (as opposed to green) females.

The utility of oviduct insertion of radio transmitters as a fisheries management technique was demonstrated in Moose Lake. Information from this telemetry study identified how esocids used various habitats in Moose Lake during spring spawning. Moose Lake does not have marshes with sedges and grasses that might be considered classic northern pike spawning habitat. While two northern pike dropped transmitters in the outlet channel, most of the other fish appeared to adopt a different strategy of spawning over bars with *Chara* spp. and *Nitella* spp. in deeper water. The biggest potential for overlap of northern pike and muskellunge spawning habitat in Moose Lake seemed to be at *Chara* spp. beds over offshore bars.

Identification and protection of critical fish habitat is a high priority for proactive fisheries management in Minnesota and elsewhere. In this study, we demonstrated how oviduct insertion of radio transmitters can be used to identify important habitat prior to human shoreland alteration. For example, development such as wetland destruction over a relatively small area in Willow Lake would have a very large impact on northern pike production. In Moose Lake, a combination of existing and future development along the northeast shore and near the two inlets has the potential to degrade muskellunge spawning habitat in the lake. Our telemetry work provides impetus for more careful use and monitoring of shoreland surrounding the inlets.

In summary, this report described the first attempts to use oviduct insertion of radio transmitters to find spawning grounds of fish. Our preliminary studies with northern pike and muskellunge demonstrate that they deposited transmitters in likely spawning habitat in three lakes. Small sample sizes and an inability to find eggs limited the usefulness of this work. Future efforts should couple this method with a well-designed egg collection study. Nevertheless, oviduct implantation of miniature radio transmitters was a quick and easy method of attaching radio tags to fish. This illustrates that fisheries personnel should not have to track fish throughout the spawning season to locate spawning grounds. Rather, effort can be narrowed to finding transmitters at egg deposition sites immediately after the spawning season. If these sites are deemed to be critical habitat, they can be afforded extra protection from human development.

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## Acknowledgments

We thank D. Arola, D. Dustin, B. Herwig, P. Jacobson, D. Pereira, G. Phillips, R. Thompson, and J. Tillma for help with the manuscript or fieldwork.

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Paul J. Wingate, Fish and Wildlife Research Manager

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