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Retention and effects of miniature transmitters in juvenile American eels

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A R T I C L E I N F O

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A B S T R A C T

The purpose of this study was to assess the effects of an acoustic micro transmitter (tag) on survival and swimming ability of juvenile American eels (*Anguilla rostrata*). The transmitter was designed for implantation through a $<$ 3 mm opening into the body cavity of anguilliform fishes without the need for sutures. Potential transmitter effects on swimming performance were examined by comparing critical swimming speeds (U_{crit}, an index of prolonged swimming performance) for six size groups (n = 120, 113–175 mm) of tagged and non-tagged eels. There was no significant difference in U_{crits} between tagged and non-tagged eels. Median U_{crits} for tagged eels ranged from 50.2 cm/s for the smallest group tested (113–119 mm) to 63.9 cm/s for eels 141–150 mm in length. Non-tagged group median U_{crits} ranged from 47.2 cm/s for the smallest group to 66.9 cm/s for the 141–150 mm group. An additional 26 eels (115–208 mm) were tagged and held for 38 days (without undergoing swimming performance tests) to assess survival and tag loss. No mortality occurred during the holding period and a tag loss of 3.8% (n = 1) was observed within the first 20 days post-tagging, which is the current projected battery life of the tag at a 5 s ping rate interval. Tag loss increased to 50% overall (n = 13) for eels held up to 38 days. Our results indicate that micro acoustic tags can be successfully implanted in juvenile American eels with no apparent effects on swimming ability or survival, and would be a viable option for examining eel movement patterns in river systems and near hydroelectric facilities.

1. Introduction

American eels (*Anguilla rostrata*) were once abundant throughout all tributaries of rivers flowing into the Atlantic Ocean and upstream through the St. Lawrence River to Lake Ontario. In recent decades American eels have experienced dramatic declines in stock abundance ranging from 50% in Chesapeake Bay to as much as 97% in Lake Ontario (Dixon, 2003; MacGregor et al., 2013; ASMFC, 2006; DFO, 2014). American eels are listed as Endangered under the Ontario (Canada) Endangered Species Act. This population decline has been attributed to several factors, including the construction of hydroelectric dams, fragmentation and loss of habitat, and commercial harvesting (MacGregor et al., 2013). The development of hydropower on the East Coast of the United States has had major adverse effects on eel populations because the species is catadromous and dams impede the riverine migrations of both juvenile and adult eels. Additionally, hydroelectric turbines may contribute to higher injury and mortality rates of juvenile eels (i.e., during the elver or yellow-phase) as they migrate upstream and then fall back (Normandeau, 2006). The ability to implant acoustic transmitters and track the movement of juvenile eels would help researchers better understand migration routes and survival rates to make better informed management decisions regarding new and existing hydroelectric facilities.

Previous tagging studies of American eels have focused primarily on the use of passive integrated transponder (PIT) tags to detect adults at hydro facilities during downstream migrations. The tags in these studies were implanted by both incision (Boubee and Williams, 2006) and injection (McGrath et al., 2003; Verdon et al., 2003) in eels ranging from approximately 200–1200 mm in length; however, differences in the tag retention rates using these techniques are unknown. By contrast Normandeau (2006) implanted PIT tags in 291 American eel elvers (mean ± SD of 156.5 ± 26.1 mm) and reported a tag retention rate of 99% for fish held up to 4 days. Radio tags have also been used to assess downstream movements of silver eels on the Connecticut River (Haro et al., 2000) and acoustic tags have recently been used to assess downstream movements of silver-phase longfin eels (*Anguilla dieffenbachia*) in New Zealand (Jellyman and Unwin, 2017). To our knowledge, controlled laboratory studies to assess potential transmitter

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effects on anguilliform behavior and transmitter retention prior to use of the transmitter in field studies have not been conducted, and such studies are particularly important with the development of new transmitters.

The Pacific Northwest National Laboratory (PNNL) has developed a new, acoustic micro transmitter specifically for use in juvenile eels and lamprey, called the Eel/Lamprey Acoustic Tag (ELAT). The final version will have an operating frequency of 416.7 kHz. The tag can be monitored via autonomous receivers (hydrophones), at fixed structures or tracked by mobile systems. Prior studies have shown that fish outfitted with similar acoustic transmitters have been successfully tracked in the proximity to hydroelectric facilities (Skalski et al., 2014; Haro et al., 2000). The size of the prototype transmitter used in this study (11.4 mm length × 2 mm diameter, weighing 0.088 g in air, and having a specific density of 2.54 g, and a volume of 0.035 cm^3) has been designed for implantation into anguilliform fishes without the need for sutures to close the incision, in part because the incision is < 3 mm long. A small incision without sutures can shorten surgery and healing time, and minimize potential negative effects of surgical implantation on the eels (Mesa et al., 2012). Surgical implantation effects can vary in response to species, life stage, body cavity length, incision location, study duration, and environmental conditions (Brown et al., 1999; Zale et al., 2005; Panther et al., 2011; Økland and Thorstad, 2013). Tagging methods, tag loss, and healing rates have been documented on silver-phase eels in the laboratory (Baras and Jeandrain, 1998; Wargo Rub et al., 2014). Transmitter weight is also an important consideration because it provides a measure of the tag burden (i.e., the weight of the tag relative to the weight of the fish) that, when coupled with the surgical implantation process (e.g., anesthesia, handling, surgery), can affect tag retention, survival, growth, swimming performance, or the ability of fish to avoid predation (Adams et al., 1998; Jepson et al., 2008; Brown et al., 2013; Walker et al., 2016). Moreover, although implanted or externally attached transmitters have been shown to adversely affect swimming performance of Atlantic cod (*Gadus morhua*) and white sturgeon (*Acipenser transmontanus*; Counihan and Frost, 1999; Cote et al., 1999, respectively), no studies have examined the swimming performance of yellow-phase American eels implanted with small acoustic or PIT tags. Thus, the objectives of this study were to evaluate the implantation effects of an ELAT on the swimming performance, survival, and tag retention in a wide size range (113–175 mm) of yellow-phase American eels.

2. Methods

2.1. Fish acquisition

Glass stage American eels (< 30 mm) were obtained from the Delaware Valley Fish Company, South Shore Trading Co. LTD (Port Elgin, NB, Canada) in June 2014. The eels were reared indoors in 38 L aquaria at PNNL's Aquatic Research Laboratory (Richland, WA). They were fed a mixture of live artemia and Otohime commercial feed (size A through C2) during the glass and yellow life stages. At the time of testing, the eels had reached the yellow-phase (1.5 years post glass-stage) and were 113–175 mm in total length and 1.7–7.5 g in weight (Table 1). All test eels were reared in flow-through Columbia River water that was sand-filtered and passed through ultraviolet light. The water temperature followed the ambient river cycle until approximately one month prior to tagging when it was increased to 16 ± 0.5 °C (median ± SD) and then maintained throughout the study period. Dissolved oxygen was recorded via an electronic monitoring system and ranged from 88 to 101% (median ± SD of 94.4 ± 1.9%). The eels experienced a natural photoperiod provided by clerestory windows.

2.2. Surgical procedures

There were two treatment groups: eels implanted with a non-functioning ELAT (tagged group), and eels that were not tagged (control group). The non-functioning ELAT housed a full duplex PIT tag (8.5 mm length × 1.4 mm diameter, 0.033 g; Biomark HPT-8, Boise, ID) for individual eel identification. The non-functioning ELAT had the same specifications of length, diameter, and weight as the prototype functioning ELAT. Food was withheld from all eels 24 h prior to surgery. The tags were implanted by one surgeon throughout the duration of the study. Prior to surgery, the eels were anesthetized in 240 mg/L of tricaine methanesulfonate (MS-222) buffered with equal parts of sodium bicarbonate. Time to stage four sedation (Summerfelt and Smith, 1990) was ~3.5 min. Eels were tagged by placing them ventral side up on a closed-cell foam pad saturated with 150 μL/L Fish Protector® (Kordon LLC, Hayward, CA; Harnish et al., 2011). A 2–3 mm incision was made ~25 mm posterior to the base of the pectoral fin on the left lateral side (i.e., approximately 1/3 of the total length of the eel) with a sterile 3.0 mm microsurgical scalpel (15° blade; Beaver Visitec, Waltham, MA). The disinfected (submersed in 70% ethanol for 20 min, then submersed in sterilized water for 10 min) ELAT was then inserted anteriorly into the body cavity by hand (Fig. 1). The tagging procedure took < 60 s, after which eels were placed into recovery buckets with fresh aerated river water at 16 °C, then transferred to segregated holding troughs (300 L) that had the same environmental conditions as the holding tanks. Control eels did not undergo surgery or receive an

Table 1
Length, weight, and tag burden of American eels by size bin for the swimming performance trials. The mean tag burden only refers to implanted individuals from the associated size bin. The sample size (*N*) refers to the total number of individuals tagged in the associated size bin.

Size Bin	*N*	Length (mm)		Weight (g)		Tag Burden (%)	
	Tagged/ Control	Median	Range	Median	Range	Median	Range
111–120	10/10	115	113–120	2.0	1.7–2.5	4.4	3.5–5.2
121–130	10/10	127	121–130	2.8	2.1–3.6	3.1	2.8–3.8
131–140	10/10	135	131–140	3.6	2.5–4.6	2.4	2.1–3.5
141–150	10/10	145	141–150	4.1	3.0–5.9	2.3	1.5–2.9
151–160	10/10	154	148–159	4.6	3.4–5.8	1.9	1.5–2.4
161–170	10/10	165	160–175	6.3	4.4–7.5	1.3	1.1–1.8

Fig. 1. Tagging procedure before incision (a), after incision (b), and after anterior insertion of an ELAT (c). All pictures were taken of the same eel (138 mm, 4.0 g).