

Assessing the effects of passive integrated transponders (PIT tags) on the survival of Po brook lamprey (*Lampetra zanandreai*) ammocoetes

Original

Assessing the effects of passive integrated transponders (PIT tags) on the survival of Po brook lamprey (*Lampetra zanandreai*) ammocoetes / Abbà, M.; Nyqvist, D.; Candiotto, A.; Ruffino, C.; Merlin, A.; Comoglio, C.; Fenoglio, S.; Schiavon, A.. - In: THE EUROPEAN ZOOLOGICAL JOURNAL. - ISSN 2475-0263. - ELETTRONICO. - 92:1(2025), pp. 963-970. [10.1080/24750263.2025.2542469]

Availability:

This version is available at: 11583/3008951 since: 2026-03-19T16:53:27Z

Publisher:

Taylor and Francis

Published

DOI:10.1080/24750263.2025.2542469

Terms of use:

This article is made available under terms and conditions as specified in the corresponding bibliographic description in the repository

Publisher copyright

(Article begins on next page)

Assessing the effects of passive integrated transponders (PIT tags) on the survival of Po brook lamprey (*Lampetra zanandreae*) ammocoetes

M. Abbà, D. Nyqvist, A. Candiotto, C. Ruffino, A. Merlin, C. Comoglio, S. Fenoglio & A. Schiavon

To cite this article: M. Abbà, D. Nyqvist, A. Candiotto, C. Ruffino, A. Merlin, C. Comoglio, S. Fenoglio & A. Schiavon (2025) Assessing the effects of passive integrated transponders (PIT tags) on the survival of Po brook lamprey (*Lampetra zanandreae*) ammocoetes, The European Zoological Journal, 92:1, 963-970, DOI: [10.1080/24750263.2025.2542469](https://doi.org/10.1080/24750263.2025.2542469)

To link to this article: <https://doi.org/10.1080/24750263.2025.2542469>



© 2025 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group.



Published online: 22 Aug 2025.



Submit your article to this journal [↗](#)



Article views: 359



View related articles [↗](#)



View Crossmark data [↗](#)



Citing articles: 1 View citing articles [↗](#)

Assessing the effects of passive integrated transponders (PIT tags) on the survival of Po brook lamprey (*Lampetra zanandreae*) ammocoetes

M. Abbà ^{a,b}, D. Nyqvist ^c, A. Candiotto^d, C. Ruffino ^{a,b}, A. Merlin^a, C. Comoglio ^e, S. Fenoglio ^{a,b} and A. Schiavon ^e

^aDepartment of Life Sciences and Systems Biology (DBIOS), University of Turin, Torino, Italy; ^bALPSTREAM – Alpine Stream Research Center, Parco del Monviso, Ostana, Italy; ^cDepartment of Aquatic Resources, Institute of Freshwater Research, Swedish University of Agricultural Sciences, Uppsala, Sweden; ^dIndividual firm Alessandro Candiotto, Predosa, Italy; ^eDepartment of Environment, Land and Infrastructure Engineering, Politecnico di Torino, Corso, Italy

ABSTRACT

Small-sized freshwater species with little or no direct economic value, such as many endemics, are poorly known in terms of habitat requirements, foraging strategies, distribution and movement behaviour. Passive Integrated Transponder (PIT) telemetry has proven useful for studying the ecology of small-sized species in confined environments. To use this technology in the wild, it is necessary to verify that PIT tags do not affect the survival and natural performance of tagged individuals. Such studies have been carried out on some small fish, usually showing low mortality and no effect on behaviour, but few have been carried out on lampreys. We investigated the effects of PIT-tagging on ammocoetes of *Lampetra zanandreae*, a freshwater lamprey endemic to northern Italy for which very little ecological knowledge is available. In a 2-week experiment, the tagged lampreys showed a high mortality rate (74%), while untagged controls showed no mortality. This result demonstrates that PIT-tagging is not a safe technology for ammocoetes of this species, at least not with the standard 12 mm tags.

ARTICLE HISTORY

Received 3 April 2025
Accepted 28 July 2025

KEYWORDS



Telemetry; PIT tags; endemic species; freshwater; lamprey

Introduction

Freshwater habitats support a large proportion of biodiversity (Dudgeon et al. 2006; Tedesco et al. 2017). In Europe, the Mediterranean region is recognised as a biodiversity hotspot for freshwater organisms, hosting a large number of endemics (Reyjol et al. 2007; Freyhof & Brooks 2011; Tierno de Figueroa et al. 2013). These include lampreys (Cyclostomata: Petromyzontiformes: Petromyzontidae), a group of archaic vertebrates for which Europe is a centre of diversity and evolution (Freyhof & Brooks 2011).

The Po brook lamprey (*Lampetra zanandreae* Vladykov, 1955) is a non-parasitic lamprey that lives its entire life cycle in freshwater (Kottelat & Freyhof 2007; Fortini 2016). It is endemic to the Padano-Veneto district (northern Italy) and has populations in central Italy, Switzerland and Slovenia (Bianco 1992; Fortini 2016). This species has a larval phase of 4–5 years, after which it undergoes metamorphosis and becomes sexually mature. The larvae (ammocoetes) are blind and live in lowland reaches with moderate currents, sunken in soft (sandy or silty) substrates (Negro et al. 2023), where they feed by filtration. After metamorphosis, which occurs in autumn or winter, the adults are believed to make a short upstream migration where they spawn on gravelly bottoms and then die (Kottelat & Freyhof 2007; Fortini 2016). Apart from this general information, very little is known about the ecology of this species (Zerunian 2004).

One technology that has proven effective in increasing knowledge of animal ecology, particularly movement, migration and habitat use, is telemetry (Cooke et al. 2013; Thorstad et al. 2013). Passive integrated transponder (PIT) tags are small (typically 7–32 mm) and have therefore proven useful for studying small-sized fish (Cooke et al. 2013; Thorstad et al. 2013; Musselman et al. 2017). PIT tags are glass-encapsulated microchips, each with a unique identification code (Musselman et al. 2017). The tags are activated by the electromagnetic field of a reader antenna, and the lack of an internal battery has allowed a significant reduction in size while ensuring long-term viability (Cooke et al. 2013; Thorstad et al. 2013; Musselman et al.

CONTACT Margherita Abbà  margherita.abb@unito.it  Department of Life Sciences and Systems Biology (DBIOS), University of Turin, Via Accademia Albertina, 13, 10123, Torino, Italy

© 2025 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group.

This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. The terms on which this article has been published allow the posting of the Accepted Manuscript in a repository by the author(s) or with their consent.

2017). Tagged individuals can be detected by antennas installed at strategic locations or by portable antennas (Thorstad et al. 2013). PIT tags can be used to estimate population size, growth, survival, movement, habitat use, predation, behaviour, and sampling efficiency (Musselman et al. 2017; Schiavon et al. 2024), as well as to evaluate and refine conservation measures (Castro-Santos et al. 1996; Watz et al. 2019) and to map the spread of invasive species (Thorlacius et al. 2015).

A fundamental assumption for the use of this technology is that the performance of tagged animals does not deviate significantly from their natural performance (Brown et al. 2011; Crossin et al. 2017). To test this assumption, studies focusing on the effect of PIT tags on mortality, tag retention and growth, as well as behaviour of species, are needed. Such studies have been carried out on a variety of freshwater fish, usually demonstrating the suitability of PIT tags for the species studied with no or small effects on survival or behaviour (e.g. Ficke et al. 2012; Nyqvist et al. 2023), given that the tag is not too large compared to the tagged fish (e.g. 16% length ratio in salmonids; Vollset et al. 2020). For small-sized fish, PIT tags have been found to be suitable for example for Cypriniformes (Schiavon et al. 2023; Nyqvist et al. 2024), loaches (Nyqvist et al. 2023), salmonids (Newby et al. 2007; Vollset et al. 2020), bullheads (Knaepkens et al. 2007), and gobids (Nyqvist et al. 2024).

Some studies are also available for lampreys, in particular ammocoetes or juveniles of Pacific lamprey (*Entosphenus tridentatus* Gairdner in Richardson, 1836) and sea lamprey (*Petromyzon marinus* Linnaeus, 1758), two anadromous, semelparous and parasitic species. Some of these studies found no effect of PIT tags on mortality and reported good tag retention for both species (Quintella et al. 2005; Mueller et al. 2006; Mesa et al. 2012; Moser et al. 2017; Simard et al. 2017), while Dawson et al. (2015) reported high mortality rates for sea lamprey larvae and Hanson and Barron (2017) for Pacific lamprey larvae. In terms of behavioural effects, some parameters indicative of swimming performance were found to not differ between tagged and untagged lampreys (Mueller et al. 2006; Moser et al. 2017), while others, including substrate burrowing speed, were lower in tagged lampreys than in controls (Dawson et al. 2015; Mueller et al. 2006). To our knowledge, no studies on the effects of PIT-tagging, or PIT telemetry studies for that matter, on Po brook lamprey ammocoetes has been published.

While the effects of PIT-tagging have been studied in sea and Pacific lampreys, and PIT telemetry has been successfully used to study sea and river lampreys (Pereira et al. 2017; Tummers et al. 2018; Moser et al. 2019), its application on other species is still an open question. In this study, we evaluated the effects of PIT-tagging on *Lampetra zanandreae* ammocoetes, in terms of survival, to assess the feasibility of using telemetry to improve our understanding of this particular endemic.

Materials and methods

On 27 September 2024, 40 lampreys (ammocoetes) were caught by electrofishing (direct current; ELT60IIGI, Scubla, Italy) in the Roggia Marina, a semi-natural, spring-fed stream located in Vercelli Province, Italy (UTM 433891E, 5006821N, zone 32T). The lampreys were transferred to the Alessandria Province Fish Hatchery (Predosa, Italy) and placed in a 150 x 44 x 20 cm spring-fed tank with a constant water exchange and equipped with shelters (tiles and perforated bricks), where they were left to acclimatise. After 3 days, the lampreys were anaesthetised with clove oil (Aromalabs, France; approximately 0.2 mL clove oil/L water), and their length and weight were measured. Thirty lampreys were tagged with 12 mm (12 mm x 2.1 mm; 0.10 g) passive integrated transponders (PIT tags; HDX, 134.2 kHz, ISO 11,784/11785; Oregon RFID, USA).

Tagging was performed by making a 2–3 mm latero-ventral incision with a scalpel, approximately 12 mm posterior to the gill openings, and pushing the tag in and forward in the abdominal cavity to align with the lamprey's body, following the procedure described by Mesa et al. (2012) and Moser et al. (2017). Lampreys were tagged by three different operators (10 each), all with experience in fish tagging. Two lampreys died during tagging and were not included in the subsequent stages of the study. After tagging and before transfer to the experimental tanks, the lampreys were placed in tanks with clean spring water and an oxygenator to recover from anaesthesia.

Two 52 x 35 x 18 cm holding tanks were set up within a larger 150 x 44 x 20 cm spring-fed tank with constant water exchange (Figure 1). The tanks were perforated on the bottom and all four sides with a series of 8 mm holes to promote oxygenation of the substrate and lined internally with non-woven fabric to prevent escape of substrate and lampreys. One tank was filled with the original substrate (SUB) and the other

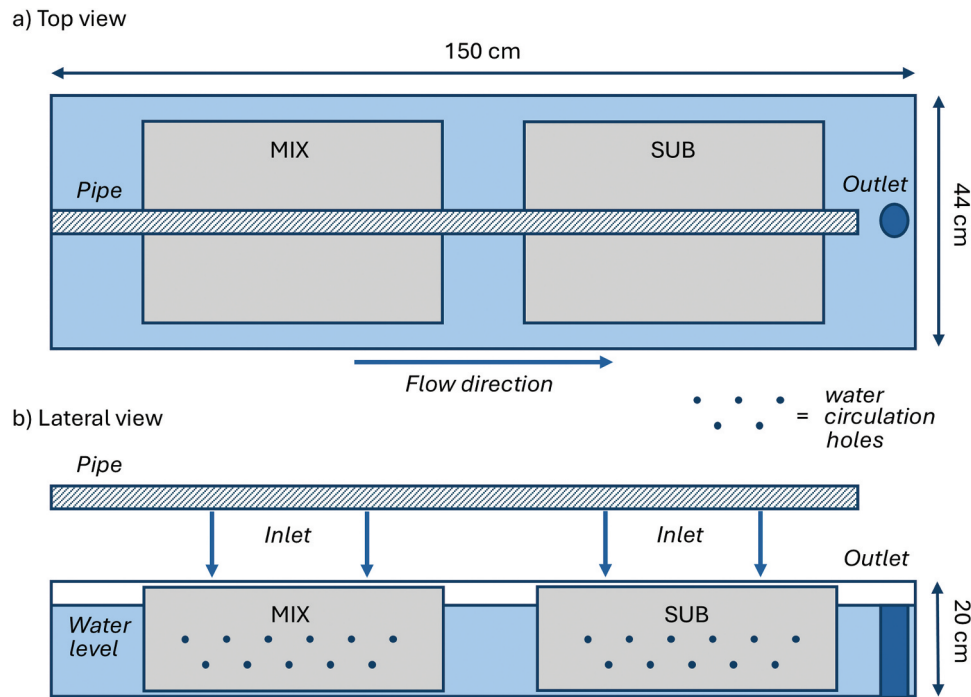


Figure 1. Experimental set-up. The set-up consisted of two 52 x 35 x 18 cm perforated and internally lined non-woven tanks, one filled with the original substrate (SUB) and the other with a 50:50 mixture of substrate and sand (MIX). These were placed in a 150 x 44 x 20 cm spring-fed tank with two water jets directed into each of the two smaller tanks. Panel (a) shows a top view of the set-up and panel (b) a lateral view.

with a mixture of the original substrate and aquarium sand with a grain size of 2–3 mm in a 50:50 ratio (MIX). Both were filled with a 14 cm layer of substrate. The substrate of the capture site consists of very fine sediment (silt) and Fine Particulate Organic Matter (FPOM) and is likely to provide a suitable environment for the lampreys, including food. We tested the original substrate mixed with sand to make it more permeable and facilitate oxygen exchange, which was identified as a potential issue in the hatchery environment. The bottoms of the smaller tanks were slightly raised to allow some water exchange also from below. A rigid pipe with four holes also supplied water directly into the two holding tanks. The water level was set at 16 cm, and the temperature was monitored using a data logger (MX2202, HOBO, USA) installed in the larger tank.

Fourteen tagged lampreys and five untagged lampreys (controls) were placed in each of the two tanks. After 2 weeks, the experiment was ended and the tanks checked for alive and dead lampreys. A handheld reader (TracKing-1 Portable Reader, Datamars, USA) was used to read the PIT tags and identify the tagged lampreys individually. One tagged lamprey was missing from the SUB tank (likely an escape) and was therefore not included in subsequent analyses. Surviving lampreys were released at the capture site.

Parametric tests (Student's test, Welch's test and analysis of variance (ANOVA)) were used to test for differences in length between lampreys tagged by different operators, between lampreys in the two tanks, between tagged lampreys and controls, and between surviving tagged lampreys and dead tagged lampreys. Shapiro's test and Levene's test were used to test the normality and homogeneity of variance of the lamprey length data. Fisher's exact tests were used to assess whether mortality differed between tagged lampreys and controls, among lampreys tagged by the three operators, and between lampreys in the two tanks. Data management, plotting and statistical tests were performed in R (R Core Team 2023; Posit Team 2024) using the packages *car* (Fox & Weisberg 2019), *dplyr* (Wickham et al. 2023), *ggplot2* (Wickham 2016), and *ggfortify* (Horikoshi & Tang 2016; Tang et al. 2016).

Results

In total, 38 lampreys were included in the experiment, 28 tagged and 10 controls, equally divided between the SUB and MIX tanks. The controls (10.2 ± 0.8 cm) were significantly smaller than the tagged lampreys (12.7

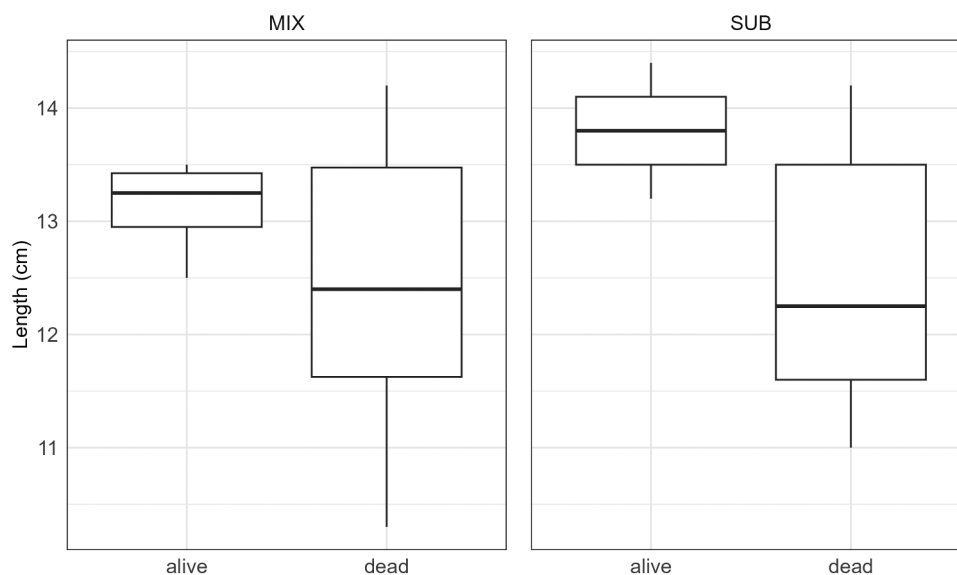


Figure 2. Box plot of lengths (cm) of alive ($n = 7$) and dead ($n = 20$) tagged lampreys in MIX and SUB tanks.

± 1.2 cm; t test: $t = -7.14$; $df = 22.68$; $p = 3.1e^{-07}$). No significant differences in size were found among lampreys tagged by the three operators (ANOVA: $F = 2.78$; $df = 2$; $p = 0.08$) or between lampreys placed in the two tanks (t test: $t = 0.21$; $df = 35.21$; $p = 0.83$).

At the end of the experiment, 20 tagged lampreys had died (10 in each tank), 7 survived (4 in the MIX tank and 3 in the SUB tank), and one was missing. All controls survived ($n = 10$). Mortality was significantly higher among the tagged lampreys than in controls (Fisher test: $p = 5.58e^{-05}$; test performed on a 2×2 contingency table). No difference in mortality was found among lampreys tagged by different operators (Fisher test: $p = 1$; test performed on a 3×2 contingency table) or between lampreys in the tanks with different substrates (Fisher test: $p = 1$; test performed on a 2×2 contingency table), suggesting that these two variables (operator and type of substrate) had no effect on mortality. Among the tagged lampreys, those that did not survive were significantly smaller than those that survived (alive: 13.4 ± 0.59 cm, dead: 12.5 ± 1.21 cm; Welch test: $t = 2.70$; $df = 21.71$; $p = 0.01$), suggesting an effect of size on mortality as a result of the tagging procedure (Figure 2).

After tagging, during recovery from anaesthesia, 15 tagged lampreys showed a change in colouration behind the tag location, a symptom which indicates that the tag was blocking blood flow through the dorsal aorta. Of the 15 lampreys that showed symptoms of blood flow obstruction, 12 did not survive, two survived and one was missing. By the end of the 2-week experiment, the surviving lampreys had incisions that were still open, partially closed or closed but not fully healed, but no wound infections were observed (Figure 3).

The mean water temperature was $14.3 \pm 0.6^\circ\text{C}$ during the experiment.

Discussion

This study assessed, for the first time, the effects of PIT tagging on the ammocoetes of the Po brook lamprey, endemic to the Padano-Veneto district. Most of the tagged lampreys (74%) did not survive the experiment, while all untagged control lampreys survived the experimental period. No effect of tagger or substrate type (MIX and SUB) on lamprey mortality was detected.

Among the tagged lampreys, smaller individuals seemed to fare worse than larger individuals, as the tagged lampreys that did not survive were significantly smaller than those that did. In particular, all lampreys shorter than 12.5 cm died. Several other studies have shown higher mortality of smaller compared to larger tagged lampreys of other species (Schreck et al. 1999; Mesa et al. 2012; Dawson et al. 2015; Hanson & Barron 2017; Simard et al. 2017). Different threshold lengths between 120 and 150 mm have been proposed for tagging (Schreck et al. 1999; Mueller et al. 2006; Mesa et al. 2012;

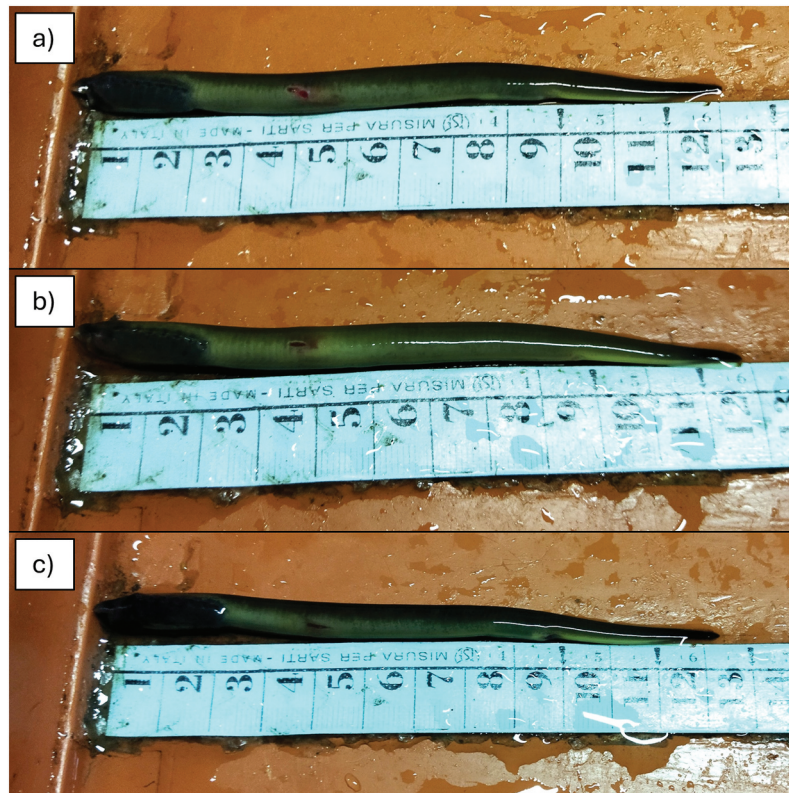


Figure 3. Different stages of healing at the end of the 2-week experiment: (a) incision still open; (b) incision partially closed; (c) incision closed but not fully healed.

Simard et al. 2017). In our study, however, even many large tagged lampreys died. Considering only lampreys larger than 12.5 cm, the mortality is still very high (53.8%), indicating that tagging resulted in high mortality of Po brook lampreys of all sizes.

The 100% survival of the control lampreys indicates that the tank conditions in the artificial environment of the experiment were adequate to maintain the lampreys, at least for the duration of the experiment (2 weeks). Although there was a large overlap in size between the tagged and control groups, the tagged lampreys were significantly longer than the controls. This is a bias likely introduced by the operators, who unintentionally selected the easiest lampreys to tag, i.e. the largest. Hanson and Barron (2017) and Mesa et al. (2012) also reported a difference in length between the PIT-tagged lampreys and the controls at the start of their experiments. Despite this bias, the fact that all of our controls survived excludes the possibility that factors other than tagging were the main cause of lamprey mortality.

After the 2-week experiment, none of the surviving lampreys had a fully healed incision. Studies of lampreys that have assessed wound healing over time have shown longer healing times, e.g. Moser et al. (2017) calculated 88 days for the complete healing of all individuals involved in their study, while after 15 days very few individuals showed signs of healing. It is therefore possible that our experiment was too short to allow the incisions to heal completely.

Our results clearly show that PIT-tagging causes high mortality in Po brook lamprey ammocoetes. Lampreys have a slim body profile and relatively small body cavity, and spatial constraints within the body cavity are likely to be a major issue in tagging mortality (Dawson et al. 2015; Hanson & Barron 2017). Indeed, 54% of tagged lampreys showed a colour change posterior to the tag within minutes of tagging, indicating that the tag had caused a disruption in blood flow through the dorsal aorta. Eighty percent of the lampreys with this symptom, which was also observed by Dawson et al. (2015), did not survive our experiment. Therefore, it appears that the tagging itself was the cause of mortality, rather than possible subsequent complications such as infection. Some studies have identified fungal infection as a cause of mortality in tagged lampreys of other species (Schreck et al. 1999; Mueller et al. 2006; Mesa et al. 2012; Simard et al. 2017), but we did not observe such issues.

Although smaller tags (down to 8 mm) than the one we used (12 mm) are available and could improve the results obtained (Cooke et al. 2013; Dawson et al. 2015), reducing the size of the tag usually also reduces the detection range (Zydlewski et al. 2006), making it more difficult to detect tagged individuals in the field. Given that *L. zanandreae* is a fossorial species, the use of smaller tags would likely prevent active tracking along watercourses with portable backpack antennas and limit the detection of the tagged lampreys only to times when they are actively moving through narrow sections equipped with stationary antennas or are recaptured during subsequent electrofishing. Nevertheless, future studies should test the use of smaller tags, which could open the door to tagging and tracking Po brook lamprey ammocoetes (Nyqvist et al. 2024). As for 12 mm tags, the high mortality of Po brook lamprey ammocoetes advises against using this method to study the movements and ecology of this species.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This study was realised within the scientific activities of the LIFE21-NAT-IT-LIFE Minnow Project: “Small fish, small streams, big challenges: conservation of endangered species in tributaries of the upper Po River” [LIFE21-NAT-IT-LIFE-Minnow /101074559].

ORCID

M. Abbà  <http://orcid.org/0009-0009-3557-9271>
D. Nyqvist  <http://orcid.org/0000-0002-3098-0594>
C. Ruffino  <http://orcid.org/0009-0005-0843-4860>
C. Comoglio  <http://orcid.org/0000-0002-7962-0653>
S. Fenoglio  <http://orcid.org/0000-0001-6931-652X>
A. Schiavon  <http://orcid.org/0000-0002-4386-4912>

References

- Bianco PG. 1992. Zoogeographical implications of a first record of *Iethenteron zanandreae* on the Adriatic slope of central Italy (Cyclostomata: Petromyzontidae). *Ichthyological Exploration of Freshwaters* 3(2):183–186.
- Brown RS, Eppard MB, Murchie KJ, Nielsen JL, Cooke SJ. 2011. An introduction to the practical and ethical perspectives on the need to advance and standardize the intracoelomic surgical implantation of electronic tags in fish. *Reviews in Fish Biology and Fisheries* 21(1):1–9. DOI: [10.1007/s11160-010-9183-5](https://doi.org/10.1007/s11160-010-9183-5).
- Castro-Santos T, Haro A, Walk S. 1996. A passive integrated transponder (PIT) tag system for monitoring fishways. *Fisheries Research* 28(3):253–261. DOI: [10.1016/0165-7836\(96\)00514-0](https://doi.org/10.1016/0165-7836(96)00514-0).
- Cooke SJ, Midwood JD, Thiem JD, Klimley P, Lucas MC, Thorstad EB, Eiler J, Holbrook C, Ebner BC. 2013. Tracking animals in freshwater with electronic tags: Past, present and future. *Animal Biotelemetry* 1(1):5–19. DOI: [10.1186/2050-3385-1-5](https://doi.org/10.1186/2050-3385-1-5).
- Crossin GT, Heupel MR, Holbrook CM, Hussey NE, Lowerre-Barbieri SK, Nguyen VM, Raby GD, Cooke SJ. 2017. Acoustic telemetry and fisheries management. *Ecological Applications* 27(4):1031–1049. DOI: [10.1002/eap.1533](https://doi.org/10.1002/eap.1533).
- Dawson HA, Potts DD, Maguffee AC, O'Connor LM. 2015. Feasibility of passive integrated transponder technology to study in situ movements of larval sea lamprey. *Journal of Fish and Wildlife Management* 6(1):71–82. DOI: [10.3996/102013-JFWM-067](https://doi.org/10.3996/102013-JFWM-067).
- Dudgeon D, Arthington AH, Gessner MO, Kawabata ZI, Knowler DJ, Lévêque C, Naiman RJ, Prieur-Richard AH, Soto D, Stiassny MLJ, Sullivan CA. 2006. Freshwater biodiversity: Importance, threats, status and conservation challenges. *Biological Review* 81(2):163–182. DOI: [10.1017/S1464793105006950](https://doi.org/10.1017/S1464793105006950).
- Ficke AD, Myrick CA, Kondratieff MC. 2012. The effects of PIT tagging on the swimming performance and survival of three nonsalmonid freshwater fishes. *Ecol Eng* 48:86–91. DOI: [10.1016/j.ecoleng.2011.07.011](https://doi.org/10.1016/j.ecoleng.2011.07.011).
- Fortini N. 2016. *Nuovo atlante dei pesci delle acque interne italiane: guida completa ai pesci, ciclostomi e crostacei decapodi di acque dolci e salmastre*. Roma: Aracne. pp. 696.
- Fox J, Weisberg S. 2019. *An R Companion to applied regression*. 3rd ed. Thousand Oaks, California: Sage. <https://socialsciences.mcmaster.ca/jfox/Books/Companion/>.
- Freyhof J, Brooks E. 2011. *European red list of freshwater fishes*. Luxembourg: Publications Office of the European Union.

- Hanson KC, Barron JM. 2017. Evaluation of the effects of marking Pacific lamprey ammocoetes with visual implant elastomer, coded wire tags, and passive integrated transponders. *Transactions of the American Fisheries Society* 146 (4):626–633. DOI: [10.1080/00028487.2017.1290681](https://doi.org/10.1080/00028487.2017.1290681).
- Horikoshi M, Tang Y. 2016. Ggfortify: Data visualization tools for statistical analysis results. R package version 0.4.16. <https://CRAN.R-project.org/package=ggfortify>.
- Knaepkens G, Maerten E, Tudorache C, De Boeck G, Eens M. 2007. Evaluation of passive integrated transponder tags for marking the bullhead (*Cottus gobio*), a small benthic freshwater fish: Effects on survival, growth and swimming capacity. *Ecology of Freshwater Fish* 16(3):404–409. DOI: [10.1111/j.1600-0633.2007.00231.x](https://doi.org/10.1111/j.1600-0633.2007.00231.x).
- Kottelat M, Freyhof J. 2007. Handbook of European freshwater fishes. Vol. 13. Cornol, Switzerland: Publications Kottelat.
- Mesa MG, Copeland ES, Christiansen HE, Gregg JL, Roon SR, Hershberger PK. 2012. Survival and growth of juvenile Pacific lampreys tagged with passive integrated transponders (PIT) in freshwater and seawater. *Transactions of the American Fisheries Society* 141(5):1260–1268. DOI: [10.1080/00028487.2012.686951](https://doi.org/10.1080/00028487.2012.686951).
- Moser ML, Corbett SC, Keefer ML, Frick KE, Lopez-Johnston S, Caudill CC. 2019. Novel fishway entrance modifications for Pacific lamprey. *Journal of Ecohydraulics* 4(1):71–84. DOI: [10.1080/24705357.2019.1604090](https://doi.org/10.1080/24705357.2019.1604090).
- Moser ML, Jackson AD, Mueller RP, Maine AN, Davisson M. 2017. Effects of passive integrated transponder (PIT) implantation on Pacific lamprey ammocoetes. *Animal Biotelemetry* 5(1):1–9. DOI: [10.1186/s40317-016-0118-3](https://doi.org/10.1186/s40317-016-0118-3).
- Mueller RP, Moursund RA, Bleich MD. 2006. Tagging juvenile Pacific lamprey with passive integrated transponders: Methodology, short-term mortality, and influence on swimming performance. *North American Journal of Fisheries Management* 26(2):361–366. DOI: [10.1577/M05-017.1](https://doi.org/10.1577/M05-017.1).
- Musselman WC, Worthington TA, Mouser J, Williams DM, Brewer SK. 2017. Passive integrated transponder tags: Review of studies on warmwater fishes with notes on additional species. *Journal of Fish and Wildlife Management* 8(2):353–364. DOI: [10.3996/122016-JFWM-091](https://doi.org/10.3996/122016-JFWM-091).
- Negro G, Marino A, Forte S, Lo Conte P, Bo T, Fenoglio S, Vezza P. 2023. Ecological notes on an endemic freshwater lamprey, *lampetra zanandrei* (Vladykov, 1955). *European Zoological Journal* 90(2):556–567. DOI: [10.1080/24750263.2023.2226680](https://doi.org/10.1080/24750263.2023.2226680).
- Newby NC, Binder TR, Stevens ED. 2007. Passive integrated transponder (PIT) tagging did not negatively affect the short-term feeding behavior or swimming performance of juvenile rainbow trout. *Transactions of the American Fisheries Society* 136(2):341–345. DOI: [10.1577/T06-110.1](https://doi.org/10.1577/T06-110.1).
- Nyqvist D, Schiavon A, Ashraf MU, Candiotta A, Palazzi A, Parolini M, Comoglio C. 2024. Survival and swimming performance of small-sized gobiidae implanted with mini passive integrated transponders (PIT-Tags). *Water* 16 (19):2745. DOI: [10.3390/w16192745](https://doi.org/10.3390/w16192745).
- Nyqvist D, Schiavon A, Candiotta A, Mozzi G, Eggers F, Comoglio C. 2023. PIT -tagging Italian spined loach (*cobitis bilineata*): Methodology, survival and behavioural effects. *Journal of Fish Biology* 102(3):575–580. DOI: [10.1111/jfb.15289](https://doi.org/10.1111/jfb.15289).
- Nyqvist D, Schiavon A, Candiotta A, Tarena F, Comoglio C. 2024. Survival and swimming performance in small-sized South European Cypriniformes tagged with passive integrated transponders. *Journal of Ecohydraulics* 9(2):248–258. DOI: [10.1080/24705357.2024.2306419](https://doi.org/10.1080/24705357.2024.2306419).
- Pereira E, Quintella BR, Mateus CS, Alexandre CM, Belo AF, Telhado A, Quadrado MF, Almeida PR. 2017. Performance of a vertical-slot fish pass for the sea lamprey *petromyzon marinus* L. and habitat recolonization. *River Research and Applications* 33(1):16–26. DOI: [10.1002/rra.3054](https://doi.org/10.1002/rra.3054).
- Posit Team. 2024. Rstudio: Integrated development environment for R. Boston, MA: Posit Software, PBC. <http://www.posit.co/>.
- Quintella BR, Andrade NO, Espanhol R, Almeida PR. 2005. The use of PIT telemetry to study movements of ammocoetes and metamorphosing sea lampreys in river beds. *Journal of Fish Biology* 66(1):97–106. DOI: [10.1111/j.0022-1112.2005.00584.x](https://doi.org/10.1111/j.0022-1112.2005.00584.x).
- R Core Team. 2023. R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing. <https://www.R-project.org/>.
- Reyjol Y, Hugueny B, Pont D, Bianco PG, Beier U, Caiola N, Casals F, Cowx I, Economou A, Ferreira T, Haidvogel G, Noble R, de Sostoa A, Vigneron T, Virbickas T. 2007. Patterns in species richness and endemism of European freshwater fish. *Global Ecology & Biogeography* 16(1):65–75. DOI: [10.1111/j.1466-8238.2006.00264.x](https://doi.org/10.1111/j.1466-8238.2006.00264.x).
- Schiavon A, Comoglio C, Candiotta A, Hölker F, Ashraf MU, Nyqvist D. 2023. Survival and swimming performance of a small-sized cypriniformes (*Telestes muticellus*) tagged with passive integrated transponders. *Journal of Limnology* 82. DOI: [10.4081/jlimnol.2023.2129](https://doi.org/10.4081/jlimnol.2023.2129).
- Schiavon A, Comoglio C, Candiotta A, Spairani M, Hölker F, Tarena F, Watz J, Nyqvist D. 2024. Navigating the drought: Upstream migration of a small-sized cypriniformes (*telestes muticellus*) in response to drying in a partially intermittent mountain stream. *Knowledge and Management of Aquatic Ecosystems* 425(425):6. DOI: [10.1051/kmae/2024003](https://doi.org/10.1051/kmae/2024003).
- Schreck CB, Fitzpatrick MS, Lerner DL. 1999. Determination of passage of juvenile lamprey: Development of a tagging protocol. Oregon State University, Oregon Cooperative Fish and Wildlife Research Unit, Corvallis, Oregon.
- Simard LG, Sotola VA, Marsden JE, Miehl S. 2017. Assessment of PIT tag retention and post-tagging survival in metamorphosing juvenile sea lamprey. *Animal Biotelemetry* 5(1):1–7. DOI: [10.1186/s40317-017-0133-z](https://doi.org/10.1186/s40317-017-0133-z).
- Tang Y, Horikoshi M, Li W. 2016. Ggfortify: Unified interface to visualize statistical results of popular R packages. *The R Journal* 8(2):474–489. DOI: [10.32614/RJ-2016-060](https://doi.org/10.32614/RJ-2016-060).

- Tedesco PA, Paradis E, Lévêque C, Huguény B. 2017. Explaining global-scale diversification patterns in actinopterygian fishes. *J Biogeogr* 44(4):773–783. DOI: [10.1111/jbi.12905](https://doi.org/10.1111/jbi.12905).
- Thorlacius M, Hellström G, Brodin T. 2015. Behavioral dependent dispersal in the invasive round goby *Neogobius melanostomus* depends on population age. *Current Zoology* 61(3):529–542. DOI: [10.1093/czoolo/61.3.529](https://doi.org/10.1093/czoolo/61.3.529).
- Thorstad EB, Rikardsen AH, Alp A, Økland F. 2013. The use of electronic tags in fish research—an overview of fish telemetry methods. *Turkish Journal of Fisheries and Aquatic Sciences* 13(5):881–896.
- Tierno de Figueroa JM, López-Rodríguez MJ, Fenoglio S, Sánchez-Castillo P, Fochetti R. 2013. Freshwater biodiversity in the rivers of the Mediterranean Basin. *Hydrobiologia* 719(1):137–186. DOI: [10.1007/s10750-012-1281-z](https://doi.org/10.1007/s10750-012-1281-z).
- Tummers JS, Kerr JR, O'Brien P, Kemp P, Lucas MC. 2018. Enhancing the upstream passage of river lamprey at a microhydropower installation using horizontally-mounted studded tiles. *Ecol Eng* 125:87–97. DOI: [10.1016/j.ecoeng.2018.10.015](https://doi.org/10.1016/j.ecoeng.2018.10.015).
- Vollset KW, Lennox RJ, Thorstad EB, Auer S, Bär K, Larsen MH, Mahulm S, Näslund J, Stryhn H, Dohoo I. 2020. Systematic review and meta-analysis of PIT tagging effects on mortality and growth of juvenile salmonids. *Reviews in Fish Biology and Fisheries* 30(4):553–568. DOI: [10.1007/s11160-020-09611-1](https://doi.org/10.1007/s11160-020-09611-1).
- Watz J, Calles O, Carlsson N, Collin T, Huusko A, Johnsson J, Nilsson PA, Norrgård J, Nyqvist D. 2019. Wood addition in the hatchery and river environments affects post-release performance of overwintering brown trout. *Freshwater Biology* 64(1):71–80. DOI: [10.1111/fwb.13195](https://doi.org/10.1111/fwb.13195).
- Wickham H. 2016. *ggplot2: Elegant graphics for data analysis*. New York: Springer-Verlag.
- Wickham H, François R, Henry L, Müller K, Vaughan D. 2023. *dplyr: A grammar of data manipulation*. R Package Version 1.1.3. <https://CRAN.R-project.org/package=dplyr>.
- Zerunian S (2004). *Pesci delle acque interne d'Italia* (No. 20). Ministero dell'ambiente e della tutela del territorio, Direzione conservazione della natura.
- Zydlewski GB, Horton G, Dubreuil T, Letcher B, Casey S, Zydlewski J. 2006. Remote monitoring of fish in small streams: A unified approach using PIT tags. *Fisheries* 31(10):492–502. DOI: [10.1577/1548-8446\(2006\)31\[492:RMOFIS\]2.0.CO;2](https://doi.org/10.1577/1548-8446(2006)31[492:RMOFIS]2.0.CO;2).