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Long-term effects of passive integrated transponder tagging (PIT tags) on the growth of the yellow European eel (*Anguilla anguilla* (Linnaeus, 1758))

By V. Mazel[1], F. Charrier[1], A. Legault[1] and P. Laffaille[2]

[1]*Fish Pass, Laillé, France;* [2]*Université de Toulouse, CNRS; INP, UPS; EcoLab (Laboratoire Ecologie Fonctionnelle et Environnement); ENSAT, Avenue de l'Agrobiopole, 31326 Castanet, Tolosan, France*

Summary

Passive Integrated Transponder tags (PIT tags) are recommended as the most suitable method for tagging fish on the basis of their high retention and fish survival rates. The objective of this study was to determine the long-term effects (between 1 and 11 years) of the PIT tag on the growth of the yellow European eel (*Anguilla anguilla*). A difference of more than 50% was observed in the growth of marked and unmarked yellow eels. If this is a general long-term effect in all eels, it would seriously restrict the use of PIT tags for studying the dynamics of European eel populations, and so for their management.

Introduction

Stock levels of the European eel, *Anguilla anguilla* (Linnaeus, 1758), remain outside the safe biological limits, with recruitment having declined to <5% of that in the early 1980s (ICES, 2008). There is therefore an urgent need to take action to stop or at least slow the decline of this species, not only because of the loss of this resource would have a considerable socioeconomic impact on European fishing communities, but also because of its ecological and heritage implications (Baisez and Laffaille, 2005). As a consequence, the European Commission developed the 'Eel Recovery Plan' (EC Regulation 1100/2007). Before eel management programmes intended to restore eel stocks can be implemented, the population dynamics need to be understood. Marking of animals for their possible identification, either individually or as part of a group, is of fundamental importance in investigating population dynamics. It is essential that the marking techniques should not affect the growth, survival, behaviour or probability-of-capture of marked individuals. Passive Integrated Transponder tags (PIT tags) are recommended as the most suitable method for tagging fish on the basis of high tag retention and fish survival rates (Bolland et al., 2009; Hirt-Chabbert and Young, 2012). PIT tags are biocompatible, sealed, electronic modules that emit a unique identification number in response to stimulation from an external antenna. They have been shown to be useful for monitoring individual eel movements, migrations and habitat use (e.g. Riley et al., 2011; Charrier et al., 2012). However, all fish marking methods can potentially influence fish growth (Lucas and Baras, 2000), and it cannot be assumed that PIT tagging is suitable for all fish species and in all situations. The effects of PIT tagging on mortality and growth rate of the fish, as well as tag retention, remain highly variable. The effects depend on the species, on how and where the tags are inserted, and on the life stage and environmental circumstances (Dieterman and Hoxmeier, 2009; Cooke et al., 2011). The objective of this study was to determine the long-term effects of the PIT tag on the growth of the yellow European eel.

Materials and methods

The Frémur is a small river in northern Brittany (France). Its catchment covers about 60 km^2 comprising 17.5 km² for the main stream and 45 km² for tributaries. Eel samples were collected by electrofishing each September from 1996 to 2010 using an EFKO apparatus (EFKO Elektrofischfanggeräte GmbH, Germany) operating at 100–500 V and 0.8–10 A. All captured eel were measured to the nearest 1 mm (total length), and weighed to the nearest 1 g. Because the growth rate depends on the eel stage (Rigaud et al., 2008), only captured eels in the yellow stage were used. The yellow eel stage was identified using the method of Acou et al. (2005).

A total of 7815 eels (ranging in size from 55 to 850 mm) were collected by electrofishing in waterways within the catchment area. Individual eel lengths (total length in mm) were then used to construct length–frequency histograms using class-intervals of 10, 15 and 20 mm, with the 10-mm class giving the best polynomial decompositions (Mazel et al., 2012). Polynomial decompositions of these series of length–frequencies were adjusted using Bhattacharya's (1967) method, which fits normal distributions to each modal-class of the length–frequency histograms. The mean size for each age group, and consequently the mean growth, were then determined using the FISAT II software (Gayanilo and Pauly, 1997).

A subsample of 1183 eels (ranging in size from 69–783 mm) was sacrificed, and their sagittal otoliths extracted to obtain an estimate of their ages and consequently their mean annual growth. One sagittal otolith from each fish was embedded in methacrylate resin. This was then ground and polished until the nucleus was exposed. The exposed surface was next etched with 5% EDTA (Laffaille et al., 2006) and each otolith examined under a scanning electron microscope (JSM-6301F, JEOL, Tokyo, Japan). Two readers interpreted the resulting images, both readers analysing the same 300 otoliths to provide a consistency control.

A total of 1342 eels, all >200-mm, was captured by electrofishing and marked using a biocompatible ISO 24631 12-mm Trovan PIT tag, 2-mm in diameter (EID Aalten BV, The Netherlands). Winter (1996) recommended that the weight of the tag (0.1 g) should not exceed 2% of the fish bodyweight (in air), because of the adjustment capacity of the swimbladder in teleost fish. Small eel <200 mm were not usually PIT tagged because of their high rates of induced mortality and PIT tag rejection (authors' observations). The PIT tags were inserted using a trocar into the visceral cavity of the eels after anaesthetizing them with Eugenol. Before inserting each tag, and to prevent disease transmission between individuals, the equipment was first disinfected with iodine. Once the eels had been marked and measured, they were released back into the river.

Twenty-one marked eels (332–592 mm, and 1.5–7.5 years old post-tagging) were sacrificed and their sagittal otoliths extracted to obtain age estimates and consequently their mean annual growth.

We used a Trovan apparatus (LID500 Portable reader) to identify the marked eels. A total of 207 yellow eels (202 mm –604 mm; average size length ±SD: 315.7 ± 80.9 mm) were captured, tagged and recaptured. An Anova with a Tukey post-hoc test was used to compare the mean growth of these recaptured eels according to the their size and depending on the time between the tagging procedure and the recapture.

Drawbacks of the tag-marking method are the possibilities of tag loss and potential fish mortality. Consequently, mortality was induced and the PIT tag rejection tested by holding 56 yellow eels (size range 247–732 mm) in a storage hamper lowered into the natural habitat (the Frémur River) for 28 days.

Results

Of the 56 tagged eels tested, only one fatality was observed (eel size: 276 mm), and no tags were lost during the 28-day test. Visual inspection of each eel showed that the incision site on 54 of the 56 eels had already healed by the end of the test, confirming that no tag would be lost thereafter.

The average annual growth observed for marked yellow eels recaptured 1–11 years after marking was 24.1 mm year^{-1} (SD: 11.4 mm) (Fig. 1). This growth was less than half that obtained by length–frequency analyses (61.5 ± 23.3 mm year^{-1}) and by otolith readings (61.7 ± 15.1 mm year^{-1}). There was no significant difference in annual growth found for the time between marking and recapture (ANOVA, $F = 1.265$, $P = 0.262$; Fig. 1). Similarly, there was no significant difference in the annual growth rate depending on the size of the marked and recaptured eels (ANOVA, $F = 0.699$, $P = 0.553$; Fig. 2).

The average annual growth observed for the 21 yellow eels marked, recaptured and sacrificed was 25.6 mm year^{-1} (SD: 7.1 mm). This result was significantly lower (Wilcoxon matched pairs test, $W = -231$, $P < 0.0001$) than the growth obtained by otolith readings (77.1 ± 16.5 mm year^{-1}).

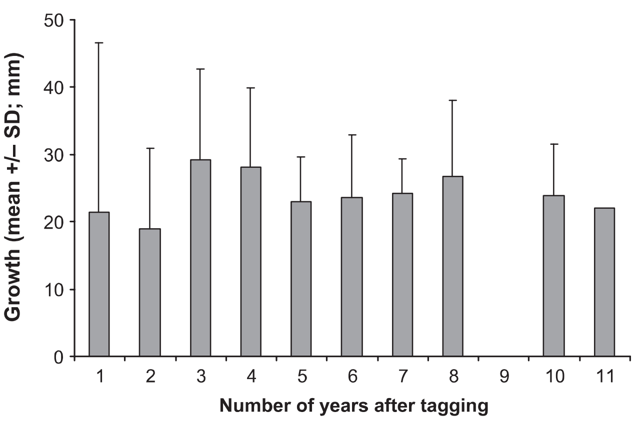

Fig. 1. Mean growth of yellow European eel (*Anguilla anguilla*) according to time (in years) after PIT-tag marking

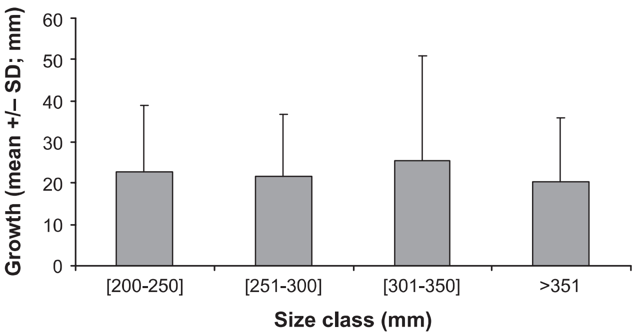

Fig. 2. Mean growth of yellow European eel (*Anguilla anguilla*) according to size class (in mm)

Discussion

The continental growth phase of the European yellow eel lasts between 3 and 15 years in most areas of Europe. Growth clearly differs in relationship to geographical location and to certain parameters of the respective water bodies (productivity, temperature, habitat quality). Growth in freshwater is virtually linear for at least 6–7 years, with an average for all areas of about 50 mm year^{-1} (see review of Rigaud et al., 2008). The origin (e.g. diversity of colonized environments, individual potential, sex) of diversity in eel growth performance is a complex and controversial topic. However, it should be noted that most of the results were obtained by otolith readings. Those values are very similar to our results obtained by length–frequency analyses and by otolith readings in the Frémur River. Baisez (2001) reported an annual growth of 80 mm in reclaimed marshes using the PIT tag marking recapture method. However, his estimates were obtained during a follow-up period of 7 months, which was much shorter than that in our study.

We observed a difference of more than 50% in the growth of marked and unmarked yellow eels. Only Berg (1986) working in Lake Constance (Italy) also reported that the use of external tags (located on the jaw) on eels could reduce growth by around 50%. This weak growth is maintained steadily over time. Indeed, eels recaptured 1–11 years after tagging display the same growth rates. This weak growth is not necessarily related to the invasive procedure of the PIT tag methodology. We also demonstrated that the size of the individual during the marking is not an aggravating factor in this phenomenon. The effects of PIT tag methodology on fish growth are controversial. Indeed, many authors have found no effect on the growth of many species (e.g. Knaepkens et al., 2007 in *Cottus gobio*, Park and Park, 2009 in *Epinephelus bruneus*). In contrast, other authors have observed a significant effect (e.g. Frost et al., 2010 in *Oncorhynchus tshawytscha*). This is the first report of the effects of PIT tagging on the growth rate of anguillids (but see Hirt-Chabbert and Young, 2012).

There was no significant difference in the annual growth rate related to the size of the marked and recaptured eels or to the time between marking and recapture. However, several different hypotheses could explain the reason/mechanism for the reduced growth of marked eels. First, we cannot rule out the possibility that the method of capture affected our observations. Indeed, the eels we used to assess growth using the PIT tags had been captured by electrofishing on at least two occasions. It is therefore possible that in the second capture we were observing the effects of the first. The eels used for otolith readings were sacrificed immediately after the first capture, which cannot therefore have had any effect on their growth. However, the effect of electrofishing on the subsequent growth of fish has never been demonstrated. Second, the low water quality of the Frémur can cause infection and indirectly lead to low growth rates. However, our results show that healing progressed smoothly in most of the eels. Finally, there could be an effect of either the marking method or the location of the PIT tag implantation. We inserted a trocar into the visceral cavity of the eels after anaesthetizing them with Eugenol. It is possible that the needle used for the injection could reach the internal organs and have an impact on growth. In fact, Zimmerman and Welsh (2008) suggested that the use of an injector needle on American eel *Anguilla rostrata* (Lesueur 1817) might increase the risk of mortality, because of the potential damage to internal organs. Scalpel incision required less handling time than injection, and the penetration depth was better controlled (Hirt-Chabbert and Young, 2012).

Briand et al. (pers. comm.), using the same marking technique, observed the same average annual growth (34 ± 20 mm year^{-1}) for 17 yellow eels marked and recaptured in the Vilaine (Brittany, France). If this long-term effect is general in all eels, it would seriously restrict the use of PIT tags for studying the dynamics of European eel populations, and so for managing them.

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Author's address: Pascal Laffaille, Université de Toulouse, CNRS, INP, UPS, EcoLab (Laboratoire Ecologie Fonctionnelle et Environnement), ENSAT, Avenue de l'Agrobiopole, F-31326 Castanet Tolosan, France. E-mail: pascal.laffaille@ensat.fr