Fisheries Research 145 (2013) 37–42

Contents lists available at SciVerse ScienceDirect

Fisheries Research

journal homepage: www.elsevier.com/locate/fishres

Effects of passive integrated transponder tagging methods on survival, tag retention and growth of age-0 brown trout

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ARTICLE INFO

Article history:
Received 21 November 2012
Received in revised form 26 February 2013
Accepted 3 March 2013

Keywords:
PIT tag implantation
Survival
Growth
Retention rate
Tagger effect

ABSTRACT

We evaluated the effect of 12-mm passive integrated transponder (PIT) tag implantation on age-0 brown trout *Salmo trutta*. The effects of implantation method (i.e. surgical incision or injection) and individual tagger on survival, tag retention and growth were assessed during a 60-day hatchery experiment. Two size classes of fish (total length) were considered: small (50–55 mm) and large (56–63 mm). For fish ≤ 55 mm, survival rate at 60 days was lower for tagged than for control fish (80.7 *vs* 91.2%, respectively), varied between taggers, but was not affected by the implantation method. For this size class injection resulted in a higher retention rate than surgical implantation (89.4 *vs* 69.4%, respectively); tag retention also varied among the individual taggers. The growth in length and weight of fish from this class was significantly impaired by tagging at 30 and 60 days (e.g. mean ± SD length at 60 days = 76.5 ± 8.4 mm for tagged fish *vs* 81.2 ± 7.9 mm for control), and individual specific growth rates (SGR) of tagged fish differed between taggers. In contrast, for larger fish (>55 mm), neither implantation method nor tagger affected survival (mean = 93.2%), tag retention (mean = 86.6%), and growth rate (mean ± SD specific growth rate = 1.07 ± 0.48% during the first 30 days). A slight slowdown in growth (length) appeared within 30 days post-tagging but was compensated at 60 days. Results suggest that implanting 12-mm PIT tags in salmonids smaller than 55 mm (TL), by different taggers and using either surgery or injection, may have significant effects on survival, tag retention, and growth.

1. Introduction

Understanding the underlying regulating processes during early life stages is critical for sound ecological knowledge of population dynamics and for management purposes. However, few tagging techniques are currently available to investigate the behavior of young-of-the-year fish (Skalski et al., 2009). Passive integrated transponder (PIT) tags are commonly used to assess individual survival, migration and growth. For more than a decade, 12-mm tags have been tested on various salmonid species such as steelhead *Oncorhynchus mykiss* (Prentice et al., 1990a; Meyer et al., 2011), Chinook salmon *Oncorhynchus tshawytscha* (Prentice et al., 1990a; Knudsen et al., 2009), Atlantic salmon *Salmo salar* (Gries and Letcher, 2002), brook trout *Salvelinus fontinalis* (Dieterman and Hoxmeier, 2009) or brown trout *Salmo trutta* (Ombredane et al., 1998; Cucherousset et al., 2006; Acolas et al., 2007; Teixeira and Cortes, 2007). Though 9-mm tags are available, their limited detection range (i.e. 10–14 cm for underwater antennas) restricts their use to studies in shallow streams (Dixon and Mesa, 2011) and recapture experiments. The recent development of the half-duplex (HDX) technology enables 12-mm tags to be detected up to 60 cm (Texas Instrument, datasheet TRPGR30TGC), increasing their potential for studying fish behavior at early life stage *in natura* (e.g. Cucherousset et al., 2006; Teixeira and Cortes, 2007) with the use of fixed and/or mobile antennas.

The effects of PIT tagging have been well documented on salmonids larger than 55 mm (Prentice et al., 1990a; Ombredane et al., 1998; Dare, 2003; Cucherousset et al., 2005; Dieterman and Hoxmeier, 2009), but few studies focused on smaller fish. In a laboratory experiment on juvenile brown trout ranging between 41 and 70 mm fork length (FL), Acolas et al. (2007) showed a survival rate of 95%, a retention rate of 70%, and no growth alteration for fish larger than 52 mm FL. While tag injection has been favored in most studies on age-0 salmonids (Prentice et al., 1990a; Ombredane et al., 1998; Acolas et al., 2007; Brakensiek and Hankin, 2007; Acolas et al., 2011) surgical implantation was only reported on fish larger than 60 mm (Gries and Letcher, 2002; Sigourney et al., 2005). However, the potential effects of both implantation methods on survival and

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http://dx.doi.org/10.1016/j.fishres.2013.03.001

growth are not well known. For instance, surgical implantation was shown to induce lower mortality than injection on silvery minnow *Hybognathus amarus* (Archdeacon et al., 2009) ranging between 45 and 90 mm standard length.

For increasingly common large-scale studies, the required tagging effort can be very high and cannot be performed by a unique tagger. In a tagging project on 145,000 juvenile spring Chinook salmon, Dare (2003) related the higher tag loss rate at the start of the tagging process (1.15% after 48 h *vs* 0.06% in subsequent marking) with the initial lack of experience of the personnel. Meyer et al. (2011) showed that rainbow trout longer than 100 mm marked by experienced taggers had significantly higher retention rates than those marked by inexperienced ones, even if the retention rates remained high in both cases (98% and 95% respectively).

In this study, we simultaneously tested the effects of tag implantation method and tagger on survival, retention rate and growth rate of age-0 brown trout. Our results aimed at providing guidelines for an acceptable tagging protocol for small trout, which is a prerequisite to carry out large-scale tagging campaigns in the field.

2. Material and Methods

2.1. Experimental design

The experiment took place at the French hatchery of Rives (Thonon-les-Bains, France). Tagging started on 27 July 2011 on first hatched fry (17 February 2011, median hatching date). The minimum size for the experiment was 50 mm total length (TL), as preliminary trials highlighted the difficulty to implant 12-mm tags in smaller trout. A batch of 360 fingerlings was used, with TL ranging between 50 and 63 mm (mean ± SD = 55.6 ± 2.6 mm). Fish were sorted according to their size into two length classes (180 fish per class): 50–55 mm (mean ± SD = 53.6 ± 1.4 mm) and 56–63 mm (mean ± SD = 57.6 ± 1.8 mm). Mean weights were 1.57 g (range = 1.2–2.0, SD = 0.16) and 1.99 g (range = 1.6–2.9, SD = 0.25) for the small and large fish group respectively, and significantly differed ($t = 19.16$, $p < 0.001$). In each size class, one-third of the fish (i.e. $n = 60$ fish) was not tagged (control), one-third was tagged by surgical implantation ($n = 60$), and one-third was tagged by injection ($n = 60$). Two taggers (tagger1 and tagger2), having both tagged 200–300 fish in preliminary tests using both methods, each marked 30 fish per tagging procedure. In each length class, individuals were randomly assigned to one treatment, thereafter defined as a tagger × an implantation method (4 treatments). After tagging, fish were dispatched in four rectangular tanks (2.4 m × 0.55 m, Vol. = 0.2 m^3), with two tanks per length class, each one containing a mix of the different treatments (90 fish per tank, i.e. 15 fish per treatment, except 30 for the control).

2.2. Tagging method and rearing

All 360 fish were first anesthetized using a 10% clove oil stock solution (Keene et al., 1998), dissolved in water at a final eugenol concentration of 30–35 ppm. A maximum of five fish were bathed simultaneously for about 3 min, to prevent overexposure. Each one was measured (±1 mm) and weighed (±0.1 g). A total of 240 fish were implanted with half duplex PIT tags (Texas Instrument; model TRPGR30TGC; 134.6 kHz; 12 mm × 2.15 mm, 0.1 g in air), while the 120 remaining fish were kept for control. Direct injection (Prentice et al., 1990b) was done with a lock needle equipped with a plunger and mounted on a plastic injector. Surgical implantation (Baras et al., 1999) consisted of a preliminary short incision (2 mm max) with a scalpel, before introducing the tag with the lock needle. In this case, the needle was only used as a guide to ensure sterile conditions. Injection and incision were both done just posterior to the insertion of the pectoral fin, close to the mid-ventral line (Prentice et al., 1990b). All needles and tags were disinfected in a 70% ethanol solution for at least 10 min before operation and throughout the tagging (Wagner et al., 2011), therefore 10 different needles were used. The scalpel was also plunged in ethanol between two markings. Handling time varied according to fish size and tagger, but ranged between 30 and 60 s. After implantation, the wound was not sutured, and fish were immediately released in their final tank for recovery. At the start of the experiment, tag to body weight ratio in air ranged between 5.0 and 7.7% (mean ± SD = 6.5 ± 0.6%) for small fish, and between 3.4 and 6.3% (mean ± SD = 5.1 ± 0.6%) for large ones.

Fish were fed every 2 days with pellets (Inicio plus 801, 1.5 mm, BioMar, contents = 54% protein, 18% lipids, 11% N-free extract) slowly distributed by automatic feeders. Food ration was approximately 3.0% of total body weight during the first month (small ration so as to prevent disease proliferation), then *ad libitum* until the end of the experiment. Fish feeding was not interrupted before tagging to mimic eating habits of wild fish. Water was supplied from a natural spring, and did not re-circulate (flow = 1.1 m^3/h). Temperature was recorded every day and ranged between 13 °C and 14 °C over the period (mean = 13.35 °C). Oxygen concentration was regularly checked, and remained in the range of tolerance for brown trout (>8 mg/L). Tanks were cleaned every day, dead fish removed, measured and weighed, and assigned to their treatment. Furthermore, the bottom of each tank was screened for any lost tags. After 30 and 60 days, all fish were anesthetized, measured, weighed and scanned with a handheld tag detector. The presence of a scar was noted, allowing the distinction between control and fish that lost their tag.

2.3. Data analysis

Tag retention was calculated as the percentage of fish that retained their tag, relative to the number of live fish tagged. Survival was the percentage of live fish relative to the number of fish initially tagged. Because we mixed different treatments in each tank, we could not assign to their initial treatment fish that died but that had previously shed their tag. We chose not to account for those fish in survival calculation, as their low number only marginally affected the survival estimates (6 fish died over 35 fish that lost their tag). For tagged fish, specific growth rate (SGR) was individually computed over two periods (SGR1 from 0 to 30 days and SGR2 from 30 to 60 days post-tagging) using the following formula (Busacker et al., 1990): $\mathrm{SGR}\,(\%) = \log_e (W_{t2}/W_{t1})/(t2 - t1) \times 100$, with W_{t1} and W_{t2} the weights (g) of a fish at time $t1$ and $t2$. PIT tag weight (0.1 g) was removed from all fish weights at recapture.

As control fish were not individually identifiable, survival and growth of tagged fish were first compared with untagged fish. Survival was analyzed using 2 × 2 contingency tables and Barnard's unconditional tests with Wald (W) statistics (Barnard, 1945; "Barnard" R package), which are more powerful than Fisher's exact tests for two binomial proportions (Mehta and Senchaudhuri, 2003). Log-transformed TL and weights were considered as proxies for growth to compare tagged to control fish. For this purpose, we used analyses of variance (ANOVA), with tagging and tank as fixed effects at 0, 30 and 60 days after tagging.

Generalized linear mixed models (GLMM) on a binomial probability distribution (logit model) were implemented to analyze survival and tag retention. SGR was analyzed using linear mixed models (LMM) on repeated measures (0–30 days, and 30–60 days post-tagging). For both GLMM and LMM, tagger and implantation method (and time in LMM) were treated as fixed effects. Tank was considered as a random effect. The significance of the variables was tested using likelihood ratio tests, compared to a χ^2 distribution (LR tests, Pinheiro and Bates, 2000). Residuals for linear mixed

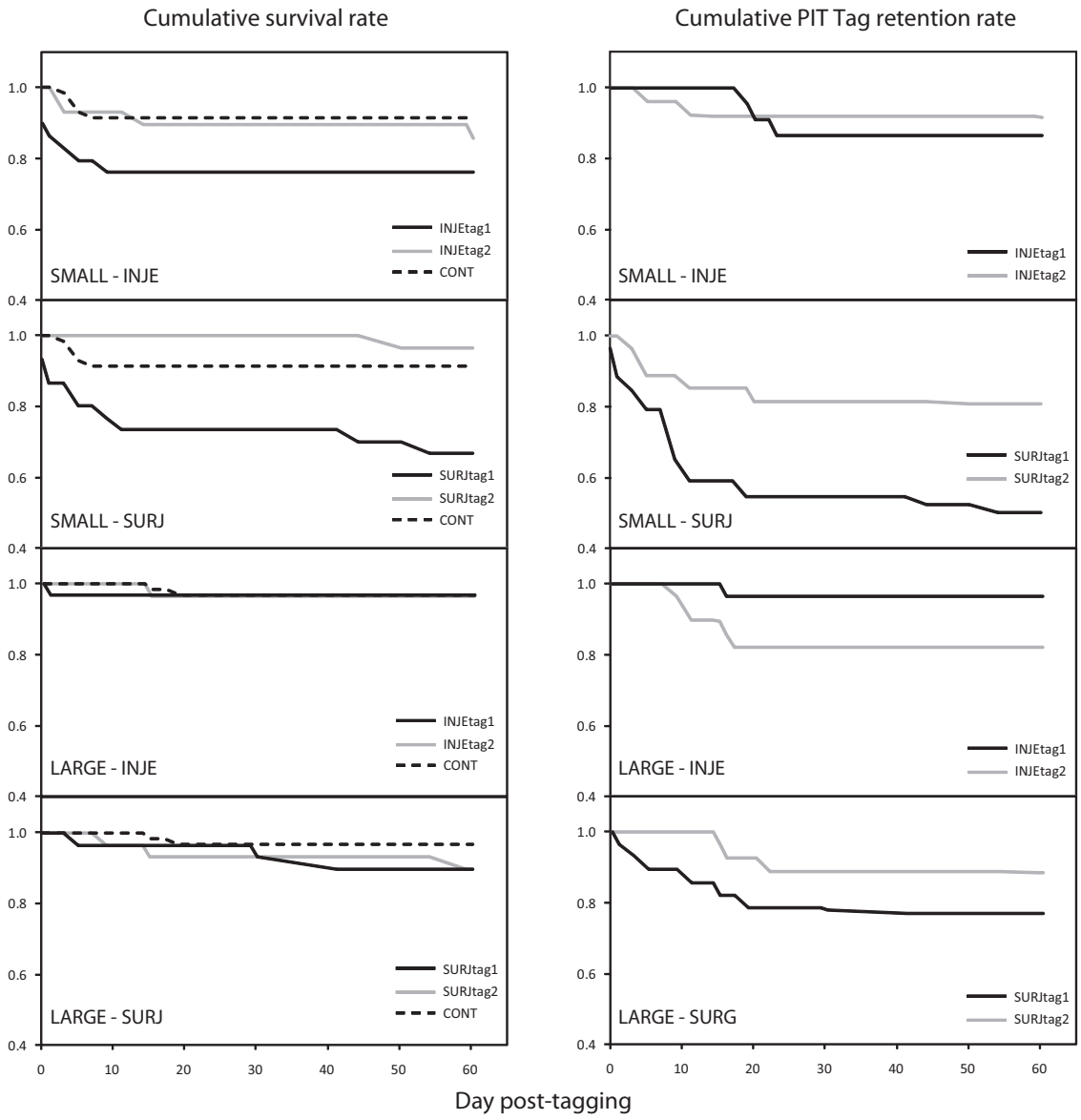

Fig. 1. Cumulative survival rate (left) and cumulative PIT tag retention rate (right), until 60 days post-tagging, for small fish and large fish. For each length class, survival and tag retention are plotted according to the method of tag implantation: injection (INJE) and surgical implantation (SURJ). Black line and gray line represent respectively taggers 1 and 2; control (CONT) is figured by a dashed line.

models and ANOVAs were checked and complied with assumptions of normality and homoscedasticity. All statistical analyses were done using Systat 12.0 or R version 2.15.0 ("lme4" package for mixed models), and α was set to 0.10.

3. Results

3.1. Survival

Six fish escaped from their tank before the end of the experiment and were removed from the analysis. Another six fish died of overexposure to anesthetics immediately after the first campaign of measurement (30 days) and were also excluded from survival calculations. A total of 37 fish died during the experiment (excluding the six fish that died after losing their tag). Higher mortalities ($n = 30$; 81.1%) occurred within 30 days of tagging (Fig. 1), with most deaths recorded within the first five days ($n = 20$; 54.1%). From day 31 to day 60 only seven fish died (18.9%).

At the end of the experiment (60 days), mean survival rate was higher for large than for small fish (93.2 and 80.7% respectively, Barnard's test, $W = -2.82$, $p = 0.006$, Table 1). Survival of tagged fish did not differ from the control at 30 days ($W = 1.27$, $p = 0.237$ for small fish; $W = 0.30$, $p = 0.797$ for large fish), but was lower than the control at 60 days for small fish ($W = 1.78$, $p = 0.078$). For small fish ($\leq$55 mm), survival significantly differed between taggers (LR test, $p = 0.006$) but was not affected by the implantation method ($p > 0.10$) and the interaction between the two parameters was not significant (Table 2). For larger fish (>55 mm), survival was neither correlated to tagger nor to implantation method. Tank effect was not significant in both models ($p > 0.10$).

3.2. Retention

A total of 35 fish shed their tag during the experiment (Table 1). Most rejections occurred within 20 days after tag implantation

Table 1
Survival, tag retention, mean total length, mean weight and specific growth rate (SGR) for tagged fish and control, according to size class and treatment (*INJE* for injection; *SURJ* for surgical implantation; *tag1* for tagger1; *tag2* for tagger2).

Size class	Treatment	*n*	Survival (%) day 30	Survival (%) day 60	Retention (%) day 30	Initial mean TL (mm)	Mean TL (mm) day 30	Mean TL (mm) day 60
≤55 mm	*INJEtag1*	29	75.9 (22)	75.9 (22)	86.4 (19)	53.2 ± 1.4	60.0 ± 4.0	76.2 ± 9.5
	INJEtag2	28	89.3 (25)	85.7 (24)	92.0 (23)	53.7 ± 1.3	61.9 ± 4.3	77.2 ± 9.0
	SURGtag1	30	73.3 (22)	66.7 (20)	54.5 (12)	53.6 ± 1.1	58.1 ± 3.2	69.8 ± 8.3
	SURGtag2	27	100.0 (27)	96.3 (26)	81.5 (22)	53.9 ± 1.3	61.4 ± 4.0	79.4 ± 4.7
	Total tagged	114	84.2 (96)	80.7 (92) *	79.2 (76)	53.6 ± 1.3	60.7 ± 4.1***	76.5 ± 8.4**
	Control	57	91.7 (55)	91.2 (52)	–	53.5 ± 1.6	64.9 ± 3.7	81.2 ± 7.9
>55 mm	*INJEtag1*	30	96.7 (29)	96.7 (29)	96.6 (28)	57.5 ± 1.7	63.4 ± 4.5	75.8 ± 9.2
	INJEtag2	29	96.6 (28)	96.6 (28)	82.1 (23)	58.2 ± 1.6	65.3 ± 3.0	79.0 ± 5.4
	SURGtag1	29	96.6 (28)	89.7 (26)	78.6 (22)	57.6 ± 1.5	64.0 ± 3.7	77.7 ± 6.5
	SURGtag2	29	93.1 (27)	89.7 (26)	88.9 (24)	57.4 ± 1.8	64.4 ± 3.9	79.3 ± 7.5
	Total tagged	117	95.7 (112)	93.2 (109)	86.6 (97)	57.7 ± 1.7	64.3 ± 3.9*	77.9 ± 7.4
	Control	60	96.7 (58)	96.7 (58)	–	57.6 ± 2.0	65.7 ± 4.5	78.0 ± 8.7

Size class	Treatment	Initial mean weight (g)	Mean weight (g) day 30	Mean weight (g) day 60	SGR1 (%) day 0–30	SGR2 (%) day 30–60
≤55 mm	*INJEtag1*	1.49 ± 0.13	2.29 ± 0.54	5.04 ± 1.94	1.33 ± 0.67	2.44 ± 0.89
	INJEtag2	1.56 ± 0.13	2.45 ± 0.54	5.20 ± 1.78	1.41 ± 0.76	2.27 ± 0.71
	SURGtag1	1.56 ± 0.14	2.01 ± 0.44	3.73 ± 1.48	0.80 ± 0.70	1.68 ± 0.93
	SURGtag2	1.61 ± 0.18	2.48 ± 0.41	5.45 ± 0.92	1.42 ± 0.52	2.52 ± 0.38
	Total tagged	1.55 ± 0.15*	2.35 ± 0.51***	5.03 ± 1.64*	1.30 ± 0.68	2.31 ± 0.76
	Control	1.61 ± 0.18	2.73 ± 0.62	5.86 ± 1.96	–	–
>55 mm	*INJEtag1*	1.94 ± 0.24	2.69 ± 0.62	4.83 ± 1.82	1.03 ± 0.52	1.80 ± 0.69
	INJEtag2	2.09 ± 0.29	2.94 ± 0.54	5.40 ± 1.14	1.09 ± 0.44	2.00 ± 0.30
	SURGtag1	1.98 ± 0.24	2.79 ± 0.55	5.21 ± 1.41	1.01 ± 0.51	1.95 ± 0.49
	SURGtag2	1.96 ± 0.23	2.80 ± 0.54	5.45 ± 1.57	1.14 ± 0.47	2.07 ± 0.62
	Total tagged	1.99 ± 0.25	2.80 ± 0.57	5.20 ± 1.52	1.07 ± 0.48	1.95 ± 0.56
	Control	1.99 ± 0.23	2.83 ± 0.64	5.13 ± 1.74	–	–

The numbers of fish which survived or retained their tag figure in brackets. Values for mean and weight are given as mean ± SD. Statistical significances of ANOVAs (weight and TL) and Barnard's tests (survival) between total tagged fish and control are indicated ("***", "**" and "*" for $p < 0.001$, $p < 0.01$ and $p < 0.1$).

(Fig. 1): 45.7% within 10 days, 94.3% within 20 days, and the last shed tag was collected on day 23. Therefore tag retention was compared at 30 days (Table 1). Tag retention rate did not significantly differ between the two length classes (79.2% for small fish and 86.6% for large fish, Barnard's test, $W = 1.43$, $p = 0.175$). The overall mean retention rate was 82.9%. For small fish, retention differed according to the implantation method and the tagger (Table 2). Indeed, surgical implantation caused lower tag retention than injection (69.4 and 89.4% respectively, LR test, $p = 0.014$), and fish marked by tagger1 showed a lower retention than those tagged by tagger2 (LR test, $p = 0.053$). Tag retention in the large fish group was neither affected by the tagger nor the implantation method, but the interaction was significant (Table 2). However the full model (incl. interaction) was not different from the null model (LR test, $\chi^2 = 5.30$, $df = 3$, $p = 0.151$).

3.3. Growth

At the beginning of the experiment, there was no difference in TL between tagged fish and control for both size classes (Table 1) and no tank effect ($p > 0.10$). For fish ≤ 55 mm, TL of tagged fish was lower than control at 30 days ($F_{1,133} = 35.03$, $p < 0.001$) and 60 days post-tagging ($F_{1,124} = 9.33$, $p = 0.003$), with a significant tank effect at 30 days ($F_{1,133} = 8.12$, $p = 0.005$), but not at 60 days ($F_{1,124} = 0.04$, $p = 0.835$). In the larger size class, marked fish showed lower TL than control after 30 days ($F_{1,154} = 4.38$, $p = 0.038$) but not after 60 days, and the tank effect was not significant ($p > 0.10$). Unlike TL, fish weights of tagged fish were slightly lower than the control at the beginning of the experiment ($F_{1,179} = 3.57$, $p = 0.060$). All other results observed on weight were similar to TL, except at 30 days for larger fish, where weights did not differ ($F_{1,154} = 0.02$, $p = 0.880$).

Table 2
Likelihood ratio tests on generalized linear mixed models (survival at 60 days and retention at 30 days) and linear mixed models for repeated measures (SGR, defined for 0–30 days, and 30–60 days). For SGR, only significant interactions are reported. Significant *p*-values are in bold. A random tank effect was included but was not significant in either model ($p > 0.10$).

Model	Parameter	*df*	Small (≤55 mm)		Large (>55 mm)	
			χ^2	*p*	χ^2	*p*
Survival	Tagger	1	7.47	**0.006**	0.00	0.980
	Implantation method	1	0.00	0.999	2.31	0.128
	Tagger × implantation method	1	2.60	0.107	0.00	0.983
Retention	Tagger	1	3.75	**0.053**	0.12	0.725
	Implantation method	1	6.03	**0.014**	0.83	0.363
	Tagger × implantation method	1	0.36	0.550	4.35	**0.037**
SGR	Time	1	90.94	**<0.001**	126.93	**<0.001**
	Tagger	1	3.69	**0.055**	1.71	0.192
	Implantation method	1	0.48	0.507	0.97	0.325
	Tagger × implantation method	1	3.44	**0.063**	0.03	0.871
	Tagger × implantation method × time	1	4.84	**0.028**	0.59	0.444

For both size classes, SGR increased during the second period of the experiment (Table 1), thus time was highly significant in GLMM analyses (Table 2). For small fish, SGR was dependent on tagger (LR test, $p = 0.055$) and two interactions were also significant (tagger × implant and tagger × implant × time). For larger fish, SGR was neither affected by the tagger nor the implantation method ($p > 0.10$).

4. Discussion

This experiment showed contrasted effects of tagger and implantation method on survival, tag retention and growth of age-0 brown trout according to fish size. Survival differed between taggers for small fish but not for larger ones. Survival rates of tagged fish from both size classes remained close to those of the control at 30 days, and then smaller fish displayed a lower survival than the control at 60 days. These results are in accordance with Acolas et al. (2007), who estimated a survival rate above 95% for fish >52 mm fork length (approximately equivalent to 54 mm TL) using logistic regressions. Other experiments focusing on age-0 salmonids did not show any negative effects of tagging on fish survival. Prentice et al. (1990a) reported high survival (95–98%) of juvenile Chinook salmon after four months, and Ombredane et al. (1998) did not show any difference in survival between tagged and untagged brown trout released in a natural stream and recaptured seven months later. However in these studies, only a few fish <60 mm were marked, and the mean length at tagging was never below 65–70 mm.

Baras et al. (1999) showed a higher survival rate of juvenile Nile tilapia *Oreochromis niloticus* (weights ranging between 1.9 and 13.7 g) with surgery than with injection (respectively 78–100% and 10–50%) within 10 days after tagging. Investigations on silvery minnows (mean ± SE standard length = 66.3 ± 0.7 mm) also highlighted a higher survival rate over 32 days after surgical incision (87 ± 6%) than needle injection (50 ± 5%) (Archdeacon et al., 2009). Gries and Letcher (2002) recommended surgical implantation for the tagging of 0+ Atlantic salmon (mean ± SD fork length = 115.1 ± 0.4 mm), showing a survival rate of 94.3%, although fish <60 mm were not tagged. Unlike these studies, our results did not show any advantage on survival of surgical implantation over injection. Both methods have benefits: surgical implantation may limit damage to organs (Baras et al., 1999), whilst injection requires a shorter handling time (Gries and Letcher, 2002). Though Bateman and Gresswell (2006) did not show any effect of handling time on fish survival when implanting 23 mm PIT tag in juvenile steelhead (73–97 mm FL), the longer time required for tagging with surgery inevitably decreases the effective tagging rate. Gries and Letcher (2002) reported an hourly tagging rate of 80–100 juvenile Atlantic salmon using surgical implantation, whilst at least twice as much could be marked with injection (Prentice et al., 1990b).

Most PIT tags were shed in the first 20 days post-tagging, prior to the complete healing of the wound. Tag retention rate did not significantly differ between the two length classes in our study, which can be explained by the narrow range of lengths (50–63 mm). Indeed, the probability of tag loss is reported to decrease with increasing fish length. Navarro et al. (2006) showed that gilthead seabream *Sparus auratus* less than 3 g displayed higher tag loss rates than larger fish. This trend was confirmed for brown trout by logistic regression between PIT Tag retention probability and juvenile length (Acolas et al., 2007): tag retention was 80% for fish ≥57 mm FL at tagging, and decreased to 70% for fish ≥52 mm FL at tagging. The mean retention rate in our study is consistent with Acolas et al. (2007). For small fish, tag retention was higher after injection than after incision. Archdeacon et al. (2009) found similar retention rates between the two implantation methods, but silvery minnows were larger (mean standard length ± SE = 64.4 ± 0.03 mm). The lower tag retention with surgical incision may be due to the relative larger cut on small fish, which can increase the probability of tag loss. Though it was proved to prevent tag losses (Baras et al., 2000; Roussel et al., 2000), we did not suture the wound, as it would have considerably increased the handling time.

Tagged fish showed lower mean length and weight than control at one month post-tagging, especially for small fish. This result contrasted with Acolas et al. (2007), who did not show any effect of tagging on length and weight of fish, at 13 and 27 days post-tagging. Sigourney et al. (2005) did not detect significant differences in weight between PIT tagged Atlantic salmon and control, but noticed a slight reduction in growth of tagged fish after two months. In our study, large fish (>55 mm) were smaller than control at 30 days, and this was compensated during the second month after tagging, when specific growth rates increased. For small fish, growth rates differed according to taggers and no growth compensation occurred during the time of the experiment. Prentice et al. (1990a) observed similar short-term decrease in growth of juvenile Chinook salmon within 20 days after tagging, which was compensated by an increased growth after two months. In our experiment, all treatments were mixed, and one might be inclined to think that a potential dominance of untagged fish on tagged fish could confound our results. We did not find evidence for such interaction on fish >55 mm (i.e. no difference in final survival and growth between tagged and untagged fish). We therefore assumed that the lower survival and growth of smaller fish more probably are the consequence of a negative effect of PIT tagging rather than that of a dominance of untagged fish.

The fish ≥56 mm corresponded to a maximum initial tag-to-body weight ratio in air of 6.3%, which is very close to 5.9% (or 3.4% in water) reported by Acolas et al. (2007). Albeit a tag-to-body weight ratio of 2% was commonly considered as an upper limit for fish tagging (Winter, 1983), Brown et al. (1999) demonstrated that it could be extended to 6–12% on juvenile rainbow trout (5–10 g) without alteration of the swimming performance. In practice, for small age-0 salmonids, we do not recommend tagging fish when PIT tag weights more than 6% of fish weight.

Our results provided new insights for the generalization of a PIT tagging technique on age-0 salmonids. We recommend a minimum fish size of 55 mm TL for tagging with 12-mm tags. Over this size, either surgical implantation or direct injection can be performed by different taggers without altering survival, tag retention and growth. This enables large-scale tagging to be done by different taggers once fish size reaches 55 mm. However, we still highly advise scientists to practice and carry out preliminary tests in hatchery.

Acknowledgements

We kindly thank Cyrille Chataigner and the team of Rive's hatchery (Thonon-les-Bains, France) for providing all the facilities and the fish for this study. We are also grateful to Anne-Sophie Reymond, Irène Nègre and Laurent Espinat for their assistance for tagging fish, together with Nicole Chavaz-Cirilli, David Grimardias, Benjamin Bergerot and Shane Vatland for statistical advice or useful comments. This research was supported by the University of Applied Sciences of Western Switzerland (hepia), the French National Institute for Agronomic Research (INRA), and the Swiss Federal Office for Environment (OFEV).

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