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ARTICLE

Impacts of External and Surgery-Based Tagging Techniques on Small Northern Pike Under Field Conditions

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Abstract
In Northern Pike *Esox lucius* negligible effects of external tags on growth and survival have commonly been reported, but no studies exist for age-0 fish. We tested the impacts of fin clipping, PIT tags, and three external tags (T-bar anchor, opercular, and streamer tags) on age-0 Northern Pike in a pond. We also examined the impacts of surgically implanted transmitters on small adult Northern Pike in a natural lake. The loss of PIT tags was lowest among all tags and close to 0%. Of the external tags, T-bar anchor tags performed best. Loss of these tags was initially low (on average 5.7% after 195 d) increasing to about 20.0% by 520 d posttagging. Tagging-induced mortality of a few percent was present in all tags tested within the first 195 d posttagging in the pond environment but not present afterwards. The PIT tags, fin clips, and external tags did not affect the growth or condition of surviving fish. Surgically implanted transmitters reduced the growth of small adult Northern Pike with total lengths <480 mm, but no effects were found for larger individuals. We conclude that PIT tagging is the most suitable marking technique for age-0 Northern Pike. If external visibility is required, T-bar anchor tags are also useful, as long as tagging-induced mortality and tag loss rates are accounted for at the analysis stage. Our study raises a cautionary note about surgically implanted transmitters in small adult Northern Pike, as they may negatively affect behavior and fitness.

Tagging is widely used to estimate exploitation rates, abundance, migration, growth, and other key aspects of the ecology and management of fish (e.g., Pine et al. 2003; Pollock et al. 2004). Mark–recapture and biotelemetry studies often assume that tags or transmitters are retained and that tagged and untagged individuals have the same behavior and fitness (e.g., Pine et al. 2003). The violation of these assumptions results in bias that must be accounted for in statistical analyses. For example, in fishery-dependent exploitation studies in which fishers report recovered tags, tag loss must be included in the exploitation models to derive reliable estimates of fishing mortality (Allen and Hightower 2010). Given the wealth of information that can be derived from individually tagged fish in the wild, tagging can be expected to remain an important method in the future (Walters and Martell 2004). The reliability of tagging methods depends on the performance of various tag types in different life stages of the fish and is likely species-specific. This paper focuses on Northern Pike *Esox lucius*.

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A diversity of tagging methods are used in fisheries research (Parker et al. 1990). One of the simplest methods is the partial or complete amputation of one or more fins (e.g., Diana and Wahl 2008). The impact of fin clipping on the health and fitness of the marked fish varies substantially among species (for case studies see Ricker 1949 and O'Grady 1984). In age-0 Muskellunge *Esox masquinongy* <250 mm total length (TL), pelvic fin amputation did not affect growth and survival (McNeil and Crossman 1979; Wagner et al. 2009). The effects of fin clipping on the fitness of age-0 Northern Pike have not been reported.

Batch marking methods such as fin clipping are not suitable when information at the individual level is needed. Passive integrated transponder tags allow for individual-based research. In a range of fish species, mortality caused by PIT tags has been found to be low or absent (e.g., Buzby and Deegan 1999; Baras et al. 2000; Daugherty and Buckmeier 2009). Also, PIT tags did not impair growth or cause lethal effects in juvenile Muskellunge (Wagner et al. 2007; Younk et al. 2010). In terms of tag loss, PIT tags implanted in the dorsal musculature of Muskellunge were retained at nearly 100% (Wagner et al. 2007; Younk et al. 2010; Rude et al. 2011). We are unaware of any studies with PIT tags implanted in the dorsal muscle of age-0 Northern Pike.

For fishers or other stakeholders to participate in tag recovery, externally visible marks are necessary. Accordingly, a wide range of external tags that allow for individual identification have been used in the past (reviewed in McFarlane et al. 1990; Nielsen 1992). The information about the effects of such tags on Northern Pike is rare, and the results are inconsistent. Some authors have reported that external tagging resulted in injuries and reduced condition, growth, and survival of Northern Pike >380 mm TL (Kipling and Frost 1970; Koshinsky 1972; Scheirer and Coble 1991). Others found no detrimental effects on condition and growth of Northern Pike >400 mm TL (Gurtin et al. 1999). Much of this literature was based on mark–recapture studies in the field that omitted control fish (e.g., Scheirer and Coble 1991; Pierce and Tomcko 1993). Further studies are therefore required to determine the impacts of external tags on Northern Pike and to search for alternative marking methods that may be suitable for more sensitive life stages, such as age-0 Northern Pike. T-bar anchor tags are lost at modest rates (0–13%) in adult esocids (Pierce and Tomcko 1993; Gurtin et al. 1999; Rude et al. 2011), but no study has evaluated their performance in age-0 Northern Pike. Because this life stage inhabits complex structured habitats (Grimm 1994; Grimm and Klinge 1996), higher loss rates of external tags might occur than in adult Northern Pike.

Streamer and opercular tags are potential alternatives to T-bar anchor tags that can be used to mark age-0 fish. In previous studies, mortality rates associated with streamer tags varied from 2% in Atlantic Salmon *Salmo salar* (Dempson and Stansbury 1991) to 51% in Zander *Sander lucioperca* (Hansson et al. 1997). No previous investigations on the effects of streamer tags on Northern Pike exist. Opercular tags were included in our study because they are fixed to the head and can be easily recognized by nonscientists. Tags fixed to the operculum may negatively affect condition and growth (Koshinsky 1972) and damage the opercular bones of Northern Pike (Kipling and Frost 1970). However, in other fish species the short-term impacts of opercular tags on survival were negligible (Rainbow Trout *Oncorhynchus mykiss*, Lockard 1968; Common Bream *Abramis brama*, Goldspink and Banks 1971).

Although there are many studies on a range of species on the possible detrimental effects of inserting electronic tags into fish (e.g., Paukert et al. 2001; Zale et al. 2005; Jepsen et al. 2008), little is known about the effects of surgically implanted transmitters on esocids. In an exceptional study, Jepsen and Aarestrup (1999) reported no lethal or sublethal effects on Northern Pike >520 mm TL 1 year after tagging, but the study revealed a short-term growth depression. It is unknown how surgery-based tagging affects smaller adult Northern Pike <500 mm TL.

Our objective was to investigate the impact of commonly used tagging methods on growth, survival, and performance (as assessed by tag loss rate) in small Northern Pike (either age-0 or small adult Northern Pike). We predicted that the detrimental effects of tagging on Northern Pike would increase with the degree of invasiveness of the tagging procedure, i.e., the effects would be least detrimental for fin clipping and PIT tagging and be most detrimental for surgery-based tagging.

METHODS

Age-0 Northern Pike culture.—Age-0 Northern Pike were purchased from a commercial hatchery (Fischerei Müritz-Plau GmbH, Germany). Wild spawners were caught with trap nets in Lake Müritz (surface area 11,260 ha; 53°25′0″N, 12°41′0″E) and stripped for eggs and sperm in early spring 2010 and 2011. Fertilized eggs were reared in Zuger glasses until hatching. Hatched yolk sac larvae were transferred to indoor tanks (1 m × 2.5 m) filled with lake water and subsequently stocked as free-swimming fry at the end of yolk sac absorption into nutrient-rich earthen Common Carp *Cyprinus carpio* production ponds. The ponds were drained from November 2–6, 2010, and October 17–19, 2011. Recovered age-0 Northern Pike were held in mesh-covered indoor circular tanks (2.6-m diameter × 1-m height) until experimentation. Northern Pike were fed with small prey fish during the holding period of up to 7 d.

Effects of external and PIT tagging in a largely predator-free environment in age-0 Northern Pike.—To evaluate the loss of external tags and PIT tags and their effects on growth and survival, we used 432 age-0 Northern Pike in 2010, which had a mean ± SD standard length (SL) and weight of 271 ± 23 mm and 156 ± 47 g, respectively. Experimental fish were netted out of the holding tank, anesthetized in 0.4 mL clove oil–ethanol emulsion [(1:9)/L] (Peake 1998; Zaikov et al. 2008), measured to the nearest millimeter SL and weighed (Sartorius BL 12, with an accuracy of ± 1 g; Sartorius AG, Göttingen, Germany). The Northern Pike were randomly assigned in groups of 10

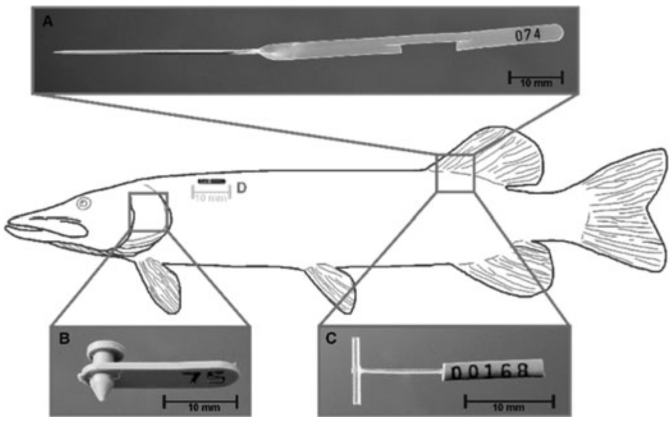

FIGURE 1. The three external tags, the **(A)** streamer tag, **(B)** opercular tag, and **(C)** T-bar anchor tag, and the internal **(D)** PIT tag, showing the anatomical locations where the tags were applied in Northern Pike.

fish to one of the six treatment groups: (1) control group (no marks applied), (2) partial fin clip of the right pelvic fin (fin clip group), (3) partial fin clip of the left pelvic fin and PIT tag (PIT tag group), (4) partial fin clip of the left pelvic fin, PIT and T-bar anchor tag (T-bar anchor tag group), (5) partial fin clip of the left pelvic fin, PIT and opercular tag (opercular tag group), and (6) partial fin clip of the left pelvic fin, PIT and streamer tag (streamer tag group). Fin clips were used to identify fish from the tagging groups in the event of tag loss. The following specifications of the various tags were used (Figure 1):

- The PIT tags (Oregon RFID, Portland, Oregon) were 2.15 mm in diameter, 12 mm in length, and weighed 0.1 g. Tags were inserted in the dorsal musculature on the left side of the fish's nape and approximately 0.5 cm deep, using a modified hypodermic needle.
- The T-bar anchor tags (FD-68BC FF; Floy Tag, Seattle, Washington) were gray and individually numbered. The total tag length was 2.1 cm, which included the 1.1 cm vinyl tube. These tags were injected diagonally forward and laterally through the dorsal pterygiophores on the left side of the anterior base of the dorsal fin (Guy et al. 1996), using a 27-mm needle mounted on a Dennison Mark III fine-fabric tagging gun (Number 10312). The gun was rotated 90° before removing the needle so that the T-bar was perpendicular to the pterygiophores on the dorsal–lateral axis.
- The modified individual violet Minitags (Dalton I.D., Oxfordshire, UK) were fixed in the centre of the left operculum. The tag was modified by stamping out a 5-mm-long piece around the pin. The pin was then attached to the individually numbered complement (20 mm in length × 6 mm in width × 1 mm in height) through a hole punched into the operculum.
- The streamer tags (poly streamer tag, S13; Hallprint Pty, Hindmarsh Valley, South Australia) were a translucent, individually numbered polyethylene film, 3 mm in width × 60 mm in length, welded to a fixed needle. The tag was applied through the musculature under the anterior dorsal fin.

Tagging was conducted between November 8 and 9, 2010, at a water temperature of 7.4°C and a dissolved oxygen concentration of 10.5 mg/L. The SL and relative condition of Northern Pike at tagging did not differ among treatment groups (SL, ANOVA: $F = 1.439$, df = 5, $P = 0.209$; relative condition, ANOVA: $F = 1.165$, df = 5, $P = 0.326$). Before transferring fish into an observation pond, they were allowed to recover for 48 h in two tanks (400 cm in length × 90 cm in width × 80 cm in height), distributed according to the tagging date in equal numbers per treatment. Mean ± SD water temperature and dissolved oxygen concentrations during this period were 7.1 ± 0.3°C and 10.0 ± 0.2 mg/L and 7.1 ± 0.2°C and 11.4 ± 0.6 mg/L, respectively. Five Northern Pike were missing after 48 h with unknown fates (possible intracohort cannibalism or fish jumped out of the tanks and were eaten by terrestrial mammals) and two lost the operculum tag during handling so that in total 425 Northern Pike were released into the pond.

The pond had a surface area of 4.0 ha with an average and maximum depth of 1.0 m and 2.5 m, respectively, and the shoreline was largely covered by Common Reed *Phragmites australis*. The pond was free of other predatory fish, but predation by birds was possible. The pond was stocked with abundant prey fish of the species Roach *Rutilus rutilus*, Rudd *Scardinius erythrophthalmus*, Common Bream, Silver Bream *Blicca bjoerkna*, European Perch *Perca fluviatilis*, and Ruffe *Gymnocephalus cernua* within a consumable size range for age-0 Northern Pike. Age-2 Common Carp were also stocked, but they exceeded the size range of vulnerable prey fish (Nilsson and Brönmark 2000).

Tagging mortality, growth, and tag loss were evaluated after 195 d on April 15, 2011 (overwinter), after 325 d (September 28, 2011, first summer), and after 520 d (April 10, 2012, second winter). Mean ± SD pond water temperatures were 4.5 ± 3.3°C, 19.3 ± 2.0°C, and 5.7 ± 3.6°C during overwinter 2010–2011, summer 2011, and overwinter 2011–2012, respectively. Water temperatures were documented once every hour using two HOBO Pendant temperature data loggers (type 64K-UA-001-64, accuracy ±0.53°C). Values were averaged.

At each evaluation period, the pond was drained and recovered Northern Pike were held for 1–2 d in circular tanks (2.6-m diameter × 1-m height). The fish were anesthetized, measured, weighed, and checked for the presence or absence of tags and afterwards held in tanks and released back into the pond.

We analyzed the mortality, tag loss, growth, and condition of Northern Pike from tagging to each draining event. In a second approach, data were analyzed separately for each of the three periods between sampling (day 0–195, day 195–325, and day 325–520 posttagging). In this period-based analysis, we investigated mortality, growth, and condition only for fish that retained their tag at the beginning of the respective period. For the overwinter period 2011–2012, we failed to assign a distinct untagged control. In this particular case, we used the fin clip group as the most appropriate reference group for tag effect comparisons.

The growth of different groups was calculated as the relative daily growth rate (RDGR; Wagner et al. 2007) based on SL information as follows:

$$\text{RDGR} = [(L_2 - L_1)/L_1] \times \Delta t^{-1} \times 100,$$

where L_1 was the mean initial SL of the treatment group from a pooled sample, L_2 was the final individual SL at sampling, and Δt was time elapsed (days) for each period of observation. We used pooled samples and an average size at tagging in all treatment groups because the control groups could not be differentiated at the individual level.

The relative condition (K_n; Le Cren 1951) was estimated for each individual and observation period as follows:

$$K_n = (W/W') \times 100,$$

where W was the individual fish weight and W' was the SL-specific weight predicted from a $\log_{10}$ transformed length–weight regression ($y = 3.336x - 13.673$, $R^2 = 0.903$) of the entire sample of fish at tagging. Relative condition calculations for distinct periods were based on a $\log_{10}$ transformed length–weight regression of the control group for the first ($y = 3.213x - 12.951$, $R^2 = 0.947$) and second sampling ($y = 3.159x - 12.682$, $R^2 = 0.977$) to predict W'. For the last sampling, W' was calculated from the $\log_{10}$ transformed length–weight regression of the fin-clipped treatment group ($y = 3.804x - 16.499$, $R^2 = 0.914$).

Additive effects of fin clipping in externally tagged age-0 Northern Pike in a high-predation-risk environment.—The 2010 study indicated an effect of the combination of partial fin clips and external tagging on the survival of Northern Pike (see Results). However, in the first experiment all externally tagged fish also had a fin clip and thus it was not possible to differentiate between a fin clip and an external-tagging effect. Moreover, in 2010 the observation pond was largely predator-free and fin clips might be particularly harmful under predation risk if they affect flight responses (e.g., Ricker 1949). Therefore, the potential for an additive effect on the survival of Northern Pike caused by fin clips on top of carrying an external tag was reinvestigated in 2011 using a pond stocked jointly with predatory adult Northern Pike. In total, 258 age-0 Northern Pike, which had a mean ± SD SL of 336 ± 35 mm and weight of 325 ± 107 g, were anesthetized and tagged with PIT and T-bar anchor tags on October 20, 2011, using the same methods as in 2010. Northern Pike were then held in a mesh-covered circular tank (2.6-m diameter × 1-m height) for 19 d to recover. Fish were netted out of the holding tank and assigned alternatively to one of the two treatment groups: (1) PIT and T-bar anchor tag without any fin clipping ($N = 115$) and (2) total fin clip of the right pelvic fin at the base of the fin in addition to PIT and T-bar anchor tags ($N = 114$). The fin clipping happened on November 8, 2011. Initial SL (t-test: $t = 0.279$, df = 227, $P = 0.780$) and relative condition factor (t-test: $t = -0.700$, df = 227, $P = 0.485$) of age-0 Northern Pike were not different between groups. Fish were allowed to recover before they were transferred to the pond (see pond description above) and were stocked with the surviving age-1 Northern Pike ($N = 185$) from the experiment that had started in 2010. Adult Northern Pike ($N = 65$, size range = 400–810 mm TL) large enough to prey on tagged age-0 and age-1 fish were stocked as well to introduce predation pressure into the experiment. The pond was drained on April 10, 2012, and survival, growth, and tag loss were evaluated for both treatment groups as previously described.

Surgery-related tagging effects in adult Northern Pike.—Experimental Northern Pike were caught in Kleiner Döllnsee, Germany (52°599 N; 13°349 E), by rod-and-line fishing and with a battery-powered DC electrofishing unit (Type EFGI 4000, 4 kW, Bretschneider Spezialelektronik, Chemnitz, Germany) between September 8 and November 12, 2009. Fish were anesthetized and individually marked with PIT tags using the previously described procedures. Body weight (g) and TL (mm) were measured. Fish were assigned to the control (immediately released after anesthesia without transmitter implantation) or the treatment group, in which combined radio-acoustic transmitters (Lotek Wireless, Newmarket, Ontario; for dimensions see below) were surgically implanted into the body cavity through a 2–3-cm incision, 3 cm behind the base of the left pelvic fin left dislocated from the linea alba. The external antenna was funneled through the lateral body wall between the pelvic and anal fin using a 15-cm-long blowing needle. The incision was closed by three interrupted sutures using absorbable suture material (PDS*II 3-0 FS-1, ETHICON; Johnson & Johnson Medical, Livingston, Scotland). Aerated water, containing a maintenance dose of anesthesia, was pumped though the gills during surgery. The mean ± SD surgery time was 6 ± 1 min ($N = 24$). Following full recovery in aerated lake water, fish were released back into the lake.

Northern Pike were categorized into three length-classes ($N = 20$ in each) with a mean ± SD TL and wet weight of 411 ± 44 mm and 397 ± 135 g, 537 ± 48 mm and 903 ± 266 g, and 681 ± 74 mm and 1,922 ± 567 g, respectively. The smallest fish were tagged with type CH-TP 11–25 transmitters (11 mm in diameter, 65 mm in length, and 12.0 g air weight), medium-sized fish with CH-TP 16–25 (16 mm in diameter, 55 mm in length, and 26.0 g air weight), and large fish with CH-TP 16–33 (16 mm in diameter, 63 mm in length, and 32.0 g air weight). Mean ± SD tag weight/body mass ratio was 2.8 ± 1.2% (range, 1.1–5.6%).

An effort was made to recapture control (PIT tag) and transmitter-tagged Northern Pike in 2010 using a battery-powered DC electrofishing unit and rod-and-line fishing. To evaluate whether Northern Pike equipped with a combined radio-acoustic transmitter had impaired growth and condition compared with untagged Northern Pike, daily growth increment and relative condition were computed for fish caught in autumn 2009 and recaptured in 2010. Comparisons were made between fish that were of similar sizes (had overlapping size ranges), resulting in a final sample size of $N = 8$ for the control and $N = 11$ for the transmitter-tagged Northern Pike (mean ± SD TL and wet weight of 486.8 ± 61.2 mm, 594.1 ± 215.7 g and 526.9 ± 53.9 mm, 878.2 ± 272.1 g, respectively).

Relative daily growth rate of transmitter-tagged and untagged Northern Pike between the capture event in 2009 and the recapture event in 2010 was calculated as mentioned above. To compare RDGR between treatment and control fish in the year before capture and tagging, length at age of each fish at the beginning of the growing season in 2008 and at the beginning of the growing season in 2009 was back-calculated from scales (Francis 1990, based on the scale-proportional hypothesis). Furthermore, the relative condition of transmitter-tagged and control Northern Pike at capture in 2009 and recapture in 2010 was estimated as mentioned above. To calculate relative condition, the SL-specific weight W' was estimated based on a $\log_{10}$ transformed length–weight regression ($y = 3.062x - 12.463$, $R^2 = 0.991$, $N = 1481$) of Northern Pike (size range of 143–870 mm TL) sampled from the Kleiner Döllnsee Northern Pike population from 2008 to 2010.

Statistical analyses.—In the first experiment, differences in initial SL and relative condition factor among treatments were assessed by one-way ANOVA. Multiple comparisons were conducted using Tukey's honestly significant difference post hoc test at homogeneous variances and Dunnet's T3 post hoc test for heterogeneous variances. The Levené tests were conducted to test homogeneity of variances. Univariate general linear models (analysis of covariance [ANCOVA]) were conducted to test for growth differences between treatment groups with initial SL as the covariate. Treatment mortality and its sampling variance were estimated using procedures outlined by Wilde et al. (2003) utilizing control fish as the reference category. Further, we applied logistic regression analysis to model treatment effects on mortality and tag loss.

In the second experiment, differences among treatment groups were tested using *t*-tests. Growth differences were tested as described above using initial SL as the covariate. Logistic regression analysis was used to model the effect of a total fin clip on the mortality of age-0 Northern Pike.

We used general linear models (GLMs) to identify the potential effects of surgically implanted combined radio-acoustic transmitters on the relative condition and RDGR of Northern Pike. The first GLM was used to test for differences in relative condition between the two groups of fish about 1 year after transmitter implantation. As independent variables, the group of fish (tagged and untagged individuals), the TL at recapture ($TL_{recapture}$), and their interaction term were added to the model. To test for differences in the relative condition at the onset of the study, the relative condition at tagging between subsequently tagged and untagged fish was also compared. Further, GLMs were used to compare the RDGR of Northern Pike over approximately 1 year. To fulfill normality assumptions and homogeneity of variances, data were cube-root transformed before analyses. The group of fish (tagged and untagged individuals), the TL at the time of tagging ($TL_{tagging}$), and their interaction term were added as independent variables. To exclude potential differences in growth between the two groups of fish in the year before tagging, back-calculated RDGRs were compared using a GLM. Again, RDGR values were cube-root transformed prior to analyses. To control for differences in the initial size of the fish, TL at the beginning of the reference year and the interaction term of group and initial size were added to the model. The time (days) between capture of Northern Pike in 2009 and recapture in 2010 was compared between the two groups of fish using ANOVA. All statistical analyses were performed using Predictive Analysis SoftWare version 17.0 at a type-1 error probability of $\alpha = 0.05$.

RESULTS

Effects of External and PIT Tagging in a Largely Predator-Free Environment in Age-0 Northern Pike

Only one fish in our study lost a PIT tag, and it was lost between 325 and 520 d after tagging (Table 1). Tag loss of the T-bar anchor and streamer tags after the first winter (195 d posttagging) was <7.5%, but 98% of the opercular tags were lost (Figure 2; Table 1). Consequently, a logistic regression (overall model: $\chi^2 = 141.805$, df = 3, $P < 0.001$) revealed a significantly elevated probability of losing the external tags during the first 195 d posttagging for opercular tags ($\beta = 6.762$, $P < 0.001$), while no elevated tag loss existed for streamer tags ($P = 0.893$) compared with T-bar anchor tags. Tag loss rates of

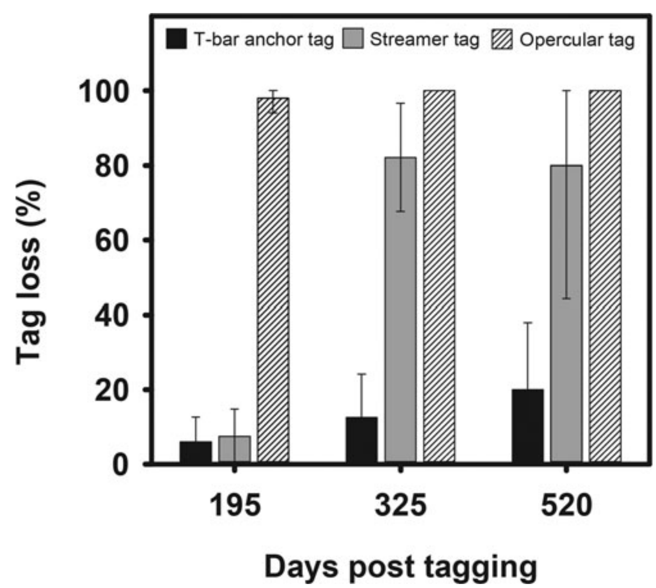

FIGURE 2. Temporal development of tag shedding of T-bar anchor, streamer, and opercular tags over the study period of 520 d. Whiskers indicate 95% CIs.

TABLE 1. Mortality (%) and tag loss rates (%) of age-0 Northern Pike 195, 325, and 520 d posttagging in an experimental pond. The corrected treatment mortality was assessed by subtracting the control fish mortality from the treatment group mortality according to Wilde et al. (2003). Data refer to the number of Northern Pike initially tagged at the onset of the study (indicated by *N*).

	Sampling event (days posttagging)		
Variable	195	325	520
Control ($N = 70$)			
Number of survivors	66	38	[c]
Control mortality ± 95% CI	5.7 ± 5.5	45.7 ± 11.9	[c]
Partial fin clip[a] ($N = 71$)			
Number of survivors	58	30	21
Corrected treatment mortality ± 95% CI	12.6 ± 10.7	12.0 ± 16.7	70.4 ± 10.8[d]
PIT tag + partial fin clip[b] ($N = 71$)			
Number of survivors	57	31	18
Corrected treatment mortality ± 95% CI	14.0 ± 11.0	10.6 ± 16.7	4.2 ± 15.0[e]
Tag loss ± 95% CI	0.0	0.0	5.6 ± 10.8
T-bar anchor tag + PIT tag + partial fin clip[b] ($N = 72$)			
Number of survivors	50	32	20
Corrected treatment mortality ± 95% CI	24.8 ± 12.2	9.8 ± 16.7	1.8 + 15.1[e]
Tag loss ± 95% CI	6.0 ± 6.7	12.5 ± 11.7	20.0 ± 17.9
Opercular tag + PIT tag + partial fin clip[b] ($N = 70$)			
Number of survivors	50	32	22
Corrected treatment mortality ± 95% CI	22.9 ± 12.1	8.6 ± 16.8	0.0 + 15.5[e]
Tag loss ± 95% CI	98.0 ± 4.0		
Streamer tag + PIT tag + partial fin clip[b] ($N = 71$)			
Number of survivors	53	28	5
Corrected treatment mortality ± 95% CI	19.6 ± 11.7	14.8 ± 16.6	22.5 + 12.4[e]
Tag loss ± 95% CI	7.5 ± 7.3	82.1 ± 14.5	80.0 ± 35.8

[a]Partial fin clip of the left pelvic fin.
[b]Partial fin clip of the right pelvic fin.
[c]Failed to assign control group.
[d]Value represents calculated mortality.
[e]Corrected by mortality of the partial fin clip group.

T-bar anchor tags were 20.0% at the completion of our study (520 d). Tag loss rates differed significantly between streamer (≥80%; Table 1) and T-bar anchor tags 325 d ($\chi^2 = 31.182$, df = 2, $P < 0.001$) and 520 d ($\chi^2 = 29.367$, df = 2, $P < 0.001$) after tagging. No opercular tags were observed after 325 d at liberty.

Overwinter mortality ± 95% CI after the first 195 d posttagging corrected by the mortality rate of the control group was 12.6 ± 10.7% and 14.0 ± 11.0% for the fin clip and PIT tag treatment groups, respectively. Because the CIs of mortality did not envelop 0%, these data indicated significantly elevated mortality rates of 2–3% resulting from fin clipping and PIT tag implantation. The control-fish-corrected mortality ranged between 19.6 ± 11.7% and 24.8 ± 12.2% in the externally tagged fish (Table 1). The logistic regression model (overall model: $\chi^2 = 20.810$, df = 6, $P = 0.002$) revealed a significant ($P < 0.025$) elevated mortality probability in all treatment groups relative to controls. Although the additional mortality caused by external tags relative to untagged controls (8–12% per type of tag) was greater than the 2–3% elevated mortality caused by fin clipping and PIT tags, these differences were not significant using logistic regression analyses when the lethal effects of external tags were assessed relative to the fin clip group (logistic regression: $\chi^2 = 4.469$, df = 4, $P = 0.346$) or to the fin clip and PIT tag group (logistic regression: $\chi^2 = 3.901$, df = 4, $P = 0.420$).

After the first summer (325 d at liberty), there was no increase in mortality of tagged fish compared with controls (overall model: $\chi^2 = 6.808$, df = 6, $P = 0.339$), and similarly no significant differences existed after two winters (520 d posttagging) (Table 1; overall model: $\chi^2 = 2.665$, df = 5, $P = 0.751$).

The mortality of control fish was highest during the first summer between 195 and 325 d posttagging (42.4 ± 12.2%), while it was low in the first 195 d posttagging (5.7 ± 5.5%). The control-fish-corrected treatment mortalities caused by external tagging were low because of the high mortality of the control group over the first summer posttagging and ranged from 0.0% to 5.9% (Table 2). Period-specific analyses did not reveal any tagging-induced mortality increase in the first summer after tag implementation (195–325 d posttagging) (logistic regression: $\chi^2 = 6.363$, df = 6, $P = 0.343$). Standard length at tagging was

TABLE 2. Mortality rates (%) of age-0 Northern Pike between sampling events (observation period: 195–325 d and 325–520 d posttagging, for values between 0 and 195 d see Table 1). Percent mortality was calculated using fish alive and retaining tags at the onset of each of the observation periods. The corrected treatment mortality was assessed by subtracting the control fish mortality from the treatment group mortality according to Wilde et al. (2003).

Variable	Observation period (days posttagging)	
	195–325	325–520
Control		
Number of Northern Pike at the onset of new period	66	38
Number of survivors	38	[c]
Control mortality ± 95% CI	42.4 ± 12.2	[c]
Partial fin clip[a]		
Number of Northern Pike at the onset of new period	58	30
Number of survivors	30	21
Corrected treatment mortality ± 95% CI	5.9 ± 14.2	30.0 ± 16.7[d]
PIT tag + partial fin clip[b]		
Number of Northern Pike at the onset of new period	57	31
Number of survivors	31	18
Corrected treatment mortality ± 95% CI	3.2 ± 17.9	11.9 ± 24.4[e]
T-bar anchor tag + PIT tag + partial fin clip[b]		
Number of Northern Pike at the onset of new period	47	28
Number of survivors	32	20
Corrected treatment mortality ± 95% CI	0.0 + 18.2	0.0 + 23.9[e]
Opercular tag + PIT tag + partial fin clip[b]		
Number of Northern Pike at the onset of new period	1	
Number of survivors	0	
Corrected treatment mortality ± 95% CI	0.0 + 18.2	
Streamer tag + PIT tag + partial fin clip[b]		
Number of Northern Pike at the onset of new period	49	5
Number of survivors	28	5
Corrected treatment mortality ± 95% CI	4.7 ± 18.3	0.0 + 16.7[e]

[a]Partial fin clip of left pelvic fin.
[b]Partial fin clip of right pelvic fin.
[c]Fail to assign control group.
[d]Value represents calculated mortality.
[e]Corrected by mortality of the partial fin clip group.

unrelated to mortality and tag loss in any of the models ($P > 0.05$ in all models) that were tested. Tagging also did not affect the relative condition (ANOVA: $P > 0.54$, in all comparisons) or RDGR (ANCOVA: $P > 0.15$, in all comparisons) of the age-0 Northern Pike at any point during the experiment (Table 3).

Additive Effects of Fin Clipping in Externally Tagged Age-0 Northern Pike in a High-Predation-Risk Environment

The T-bar anchor tag loss ± 95% CI of surviving age-0 Northern Pike was low in the second experiment under high predation risk. After 153 d, 3.3 ± 3.3% and 10.0 ± 5.6% of T-bar anchor tags were lost in externally tagged fish with and without fin clips, respectively. All PIT tags were retained. Total mortality after 153 d was high, but treatment mortality ± 95% CI was not significantly different between fish without (73.9 ± 8.25%) and with fin clips (73.7 ± 8.2%) (logistic regression: $\chi^2 = 0.013$, df = 1, $P = 0.908$). Survival of Northern Pike was positively correlated with SL at tagging ($\beta = 0.015$, $P = 0.002$). Fin clipping of tagged age-0 Northern Pike on top of external tagging caused no decrease in relative condition (t-test: $t = 0.140$, df = 58, $P = 0.889$) nor did it affect the RDGR compared with fish that were only externally tagged and that carried a PIT tag without an additional fin clip (ANCOVA: $F = 1.322$, df = 2, $P = 0.275$; Table 4).

Surgery-Related Tagging Effects in Adult Northern Pike

The time elapsed between capture and recapture of the Northern Pike in Kleiner Döllnsee did not differ between fish with and without electronic transmitters (mean ± SD = 336 ± 33 d and 329 ± 17 d, respectively; ANOVA: $F = 0.316$, df = 1, $P = 0.581$). Relative condition also did not differ between tagged and control fish at the time of tagging in 2009 (GLM: $F = 1.130$, df = 3, $P = 0.369$) or about 1 year after tagging (GLM: $F = 1.117$, df = 3, $P = 0.374$). However, fish that were <480 mm TL at tagging grew less than their untagged conspecifics (mean ± SE RDGR = 0.0032 ± 0.0016%/d and

TABLE 3. Sample size (N; surviving Northern Pike), mean standard length (SL), relative condition (K_n), and relative daily growth rate (RDGR) of experimental fish within the six treatment groups at tagging and 159, 325, and 520 d posttagging.

Treatment	N	SL ± SD (mm)	K_n ± SD	RDGR ± SD (%/d)
At tagging and start of observation period				
Control	72	269 ± 25	1.00 ± 0.09	
Partial fin clip[a]	72	277 ± 22	1.00 ± 0.10	
PIT tag + partial fin clip[b]	72	269 ± 19	0.99 ± 0.09	
T-bar anchor tag + PIT tag + partial fin clip[b]	72	274 ± 23	0.99 ± 0.10	
Opercular tag + PIT tag + partial fin clip[b]	72	271 ± 21	1.00 ± 0.08	
Streamer tag + PIT tag + partial fin clip[b]	72	268 ± 29	0.99 ± 0.08	
At recovery 195 days posttagging				
Control	66	288 ± 32	1.00 ± 0.08	0.038 ± 0.008
Partial fin clip[a]	58	298 ± 20	1.00 ± 0.08	0.041 ± 0.005
PIT tag + partial fin clip[b]	57	285 ± 20	1.00 ± 0.14	0.031 ± 0.005
T-bar anchor tag + PIT tag + partial fin clip[b]	50	295 ± 25	1.00 ± 0.12	0.039 ± 0.007
Opercular tag + PIT tag + partial fin clip[b]	50	292 ± 21	0.99 ± 0.08	0.040 ± 0.006
Streamer tag + PIT tag + partial fin clip[b]	53	285 ± 22	0.98 ± 0.09	0.032 ± 0.006
At recovery 325 days posttagging				
Control	38	403 ± 54	1.00 ± 0.06	0.155 ± 0.010
Partial fin clip[a]	30	404 ± 37	0.99 ± 0.06	0.142 ± 0.007
PIT tag + partial fin clip[b]	30	390 ± 46	1.00 ± 0.20	0.143 ± 0.010
T-bar anchor tag + PIT tag + partial fin clip[b]	33	408 ± 44	1.00 ± 0.06	0.150 ± 0.009
Opercular tag + PIT tag + partial fin clip[b]	32	386 ± 46	1.00 ± 0.10	0.130 ± 0.009
Streamer tag + PIT tag + partial fin clip[b]	28	386 ± 41	1.00 ± 0.07	0.136 ± 0.009
At recovery 520 days posttagging				
Control				
Partial fin clip[a]	21	414 ± 38	1.00 ± 0.10	0.096 ± 0.006
PIT tag + partial fin clip[b]	18	425 ± 70	1.00 ± 0.10	0.111 ± 0.012
T-bar anchor tag + PIT tag + partial fin clip[b]	20	437 ± 43	0.99 ± 0.10	0.113 ± 0.007
Opercular tag + PIT tag + partial fin clip[b]	22	405 ± 43	0.99 ± 0.10	0.096 ± 0.007
Streamer tag + PIT tag + partial fin clip[b]	25	402 ± 47	1.00 ± 0.10	0.096 ± 0.007

[a]Partial fin clip of the left pelvic fin.
[b]Partial fin clip of the right pelvic fin.

0.0214 ± 0.0065%/d, respectively; Table 5; Figure 3). By contrast, transmitter implantation into Northern Pike >480 mm TL did not affect growth increment (mean ± SE RDGR = 0.0133 ± 0.0038%/d and 0.0095 ± 0.0095%/d for tagged and control fish, respectively). The mean ± SE RDGR the year before transmitter implantation did not differ between experimental fish (that were subsequently tagged) and control fish (0.0550 ± 0.0009%/d and 0.0560 ± 0.0013%/d, respectively; GLM: F = 0.46, df = 1, P = 0.508; Table 5), demonstrating an effect of surgical transmitter implantation on growth rates of small

TABLE 4. Mean SL, relative condition (K_n), and relative daily growth rate (RDGR) of age-0 Northern Pike at tagging and after the first winter posttagging under high predation risk.

Treatment	N	SL ± SD (mm)	K_n ± SD	RDGR ± SD (%/d)
At tagging and start of observation period				
PIT tag + T-bar anchor tag	115	337 ± 35	0.99 ± 0.10	
Fin clip + PIT tag + T-bar anchor tag	114	335 ± 33	1.00 ± 0.10	
172 days posttagging (overwinter)				
PIT tag + T-bar anchor tag	30	349 ± 35	1.00 ± 0.10	0.0011 ± 0.0080
Fin clip + PIT tag + T-bar anchor tag	30	348 ± 32	1.00 ± 0.10	0.0008 ± 0.0125

TABLE 5. General linear models to predict (1) the effects of surgically implanted combined radio-acoustic transmitters (Group), total length at tagging ($TL_{tagging}$), and their interaction on cube-root transformed relative daily growth rates (RDGR) of Northern Pike over 1 year and (2) cube-root transformed RDGR of tagged and untagged Northern Pike (Group) over 365 d the year before tagging as a control, considering total length at the beginning of the reference year ($TL_{reference\ year}$) and the interaction term as a covariate. The two models include the same individual Northern Pike (N = 11 tagged fish and N = 8 untagged fish). Bold italicized P-values indicate significant effects.

Model	Effect	Estimate	SE	df	F	P	R^2
Transmitter implantation							0.286
	Intercept	0.914	0.28	1	1.96	0.182	
	Group[a]	−1.254	0.41	1	9.35	***0.008***	
	$TL_{tagging}$	−0.001	0.01	1	0.37	0.554	
	Group × $TL_{tagging}$	0.002	0.01	1	8.98	***0.009***	
Control period prior to transmitter implantation							0.836
	Intercept	0.725	0.05	1	352.70	< ***0.001***	
	Group[a]	−0.051	0.07	1	0.46	0.508	
	$TL_{reference\ year}$	−0.001	0.00	1	87.65	< ***0.001***	
	Group × $TL_{reference\ year}$	0.000	0.00	1	1.82	0.197	

[a]Reference is untagged fish.

Northern Pike. Relative transmitter weight (range = 1.8–4.9%) was not correlated with RDGR of the tagged fish (P = 0.358, R^2 = 0.006).

DISCUSSION

We found that all tagging methods, even a partial fin clip or a PIT tag, significantly elevated overwinter mortality in age-0 Northern Pike. While PIT tagging, fin clipping, or external tagging did not affect the growth and condition of age-0 Northern Pike, surgically implanted transmitters, which were the most invasive tagging procedure examined, negatively affected growth of small Northern Pike (<480 mm TL) in a natural lake. The reduced ability to cope with environmental stressors and inflammations after the stress experienced during handling and tagging (Arlinghaus et al. 2009) likely contributed to the tagging-induced mortality and growth depression observed in our experiment. Collectively, our results raise a cautionary note that almost all tagging methods will negatively influence Northern Pike performance, at least within the first few months after tagging. These impacts seem inevitable and have to be accounted for in the statistical analysis or interpretation of tagging-generated data.

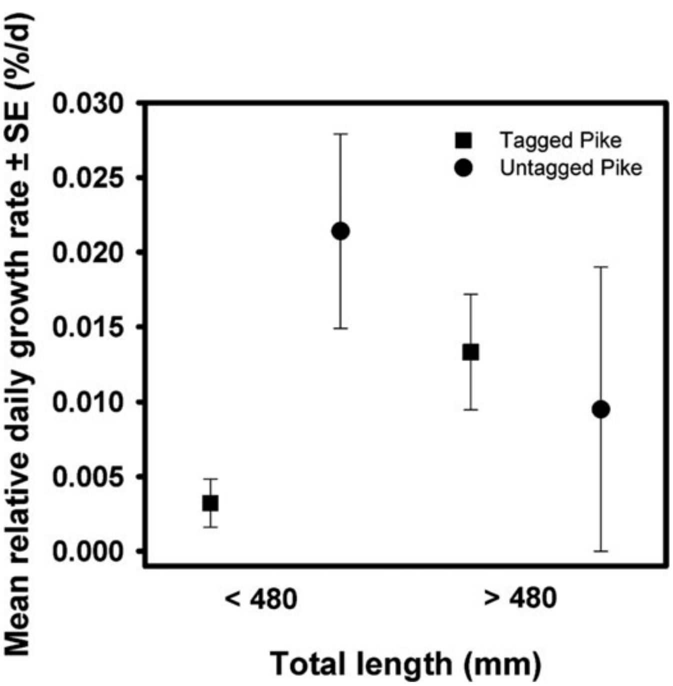

FIGURE 3. Relative daily growth rates of radio-acoustic-tagged and untagged Northern Pike of different size-classes (small, ≤480 mm; large, ≥481 mm) over 1 year. Transmitters were surgically implanted into the body cavity. Relative transmitter weight did not differ between size-classes.

Fin clipping has often been found to have no effect on the survival of fish, including esocids (e.g., Koshinsky 1972; Pratt and Fox 2002; Wagner et al. 2009). By contrast, we found that fin clipping elevated age-0 Northern Pike mortality by a few percent (2–3%) relative to control fish. In line with these findings, several authors reported reduced survival caused by fin clips in a range of species (e.g., Ricker 1949; Shetter 1951; O'Grady 1984). Reduced ability to evade predators was proposed as a possible reason (e.g., Coble 1967; Pratt and Fox 2002). The fin-clipped and control fish showed similar growth and condition in our study despite their different mortalities, and therefore altered prey capture efficiency (Wagner et al. 2009) caused by fin clipping was unlikely to be responsible for the significantly elevated mortality. Although, it is possible that it only negatively affected fish that died.

Fin clipping did not further elevate the mortality already induced by external tagging, even under conditions of high predation risk by adult Northern Pike. Although the additional mortality caused by external tagging in Northern Pike that were also fin-clipped was more than double (8–12%) that of Northern Pike that were only fin-clipped (2–3%), these differences were not significant. There were also no fin clip effects on mortality in the second experiment, in which fish that were already externally tagged were also fin-clipped. The risk of predation was much greater in the second experiment, as indicated by a disproportionate mortality among Northern Pike in the second experiment (73.7% compared with 24.8% in the first experiment). This probably contributed to the lack of fin clip effects on mortality in the second portion of our study.

We found that PIT tags performed very well in age-0 Northern Pike. The very low PIT tag loss rates in our study (often 0%) were in line with findings by other authors studying Muskellunge (e.g., Wagner et al. 2007; Younk et al. 2010; Rude et al. 2011). We injected PIT tags into the anterior dorsal muscle, a place with minor motion intensity in the body because of the lateral curvature of the body that forms a wave running from the head to the tail (Videler 1993). The dorsal musculature can thus be recommended for the application of PIT tags in age-0 Northern Pike. The small overwinter mortality caused by PIT tags was about 3% relative to control fish and similar to fin-clipped fish. Our findings were in agreement with studies by Wagner et al. (2007) and Younk et al. (2010) who found a 1.0–3.0% increase in mortality in age-0 Muskellunge carrying PIT tags in the dorsal musculature compared with controls. Collectively, these studies and the present work indicated that PIT tags cause some mortality in the first weeks posttagging, but loss rates of tags are very low and no impacts on growth are to be expected for age-0 Northern Pike.

The low overwinter tag loss rates for T-bar anchor tags that we observed were in agreement with several other studies (e.g., Brook Trout *Salvelinus fontinalis*, Carline and Brynildson 1972; Northern Pike, Pierce and Tomcko 1993; Muskellunge, Rude et al. 2011). The loss of T-bar anchor tags often accelerates over time (Buzby and Deegan 1999; Rude et al. 2011), but other external tags have comparable loss rates (e.g., Lockard 1968; Koshinsky 1972; Hansson et al. 1997; this study). Gurtin et al. (1999) found that the loss rate of T-bar anchor tags in Northern Pike (254–740 mm TL) was 8% within the first year of tagging, increasing to 13% after the first winter. Even lower tag loss rates were reported by Pierce and Tomcko (1993) who found a low annual tag loss rate of 1.8% for T-bar anchor tags in Northern Pike ranging from 380 to 727 mm TL. Because the annual tag loss in our study was higher (about 24%), it appears that tag loss might be higher in smaller than in larger Northern Pike. These higher loss rates could be a result of the more frequent use of structured habitat by age-0 Northern Pike (Grimm and Klinge 1996) and might have been facilitated by their faster growth rate. The greater shedding rates of all external tags found in our study than those found in previous Northern Pike studies might also have been influenced by multiple events of handling and netting the Northern Pike over the study period. Based on our study and others, notable tag loss should be expected in T-bar anchor tagging programs in age-0 Northern Pike and must be accounted for in the analysis of tag return data.

The literature is inconsistent in terms of mortality rates induced by T-bar anchor tags. For example, in Brook Trout (Carline and Brynildson 1972) and Largemouth Bass *Micropterus salmoides* (Tranquilli and Childers 1982) T-bar anchor tags did not negatively influence survival. However, a high mortality rate of 32% after 120 d was reported by Mourning et al. (1994) in Rainbow Trout. Application of the T-bar anchor tag always results in injuries and, due to the movement of the tag, in open wounds. These can cause chronic inflammation and potentially lead to death. We occasionally observed chronic inflammation caused by external tags in surviving Northern Pike. Further, oscillating and colored tags can attract predators and induce elevated or tag-selective predation (e.g., Lawler and Smith 1963; Catalano et al. 2001). We used colorless and camouflaged tags to reduce the risk of tag-selective predation, but it is possible that the tagged fish were still more vulnerable to predation. This might explain the significantly increased mortality of externally tagged fish relative to control fish. The trend for increased mortality in the externally tagged Northern Pike was only observed over the first winter posttagging in an environment free of piscivorous fish. Selective predation by piscivorous birds (e.g., Cormorants *Phalacrocorax carbo*) on potentially weakened (or more visible) tagged individuals might have occurred. We therefore speculate that the mortality of about 8–12% of T-bar-anchor-tagged age-0 Northern Pike relative to controls observed in our study could be caused by secondary infections, impaired evasion of fish that were not only tagged but also fin-clipped, elevated visibility of tagged individuals to predators, or a combination of these. By contrast, growth was not impaired in age-0 Northern Pike tagged with external tags, rendering these tags potentially problematic in terms of survival but not in terms of growth for surviving fish.

A limitation of our study design was that fish that were externally tagged were also fin-clipped and carried a PIT tag. Hence, on strict statistical grounds the reduced survival of externally tagged fish relative to controls in our first experiment could not be differentiated from the cumulative effect of multiple markings. However, the second experiment showed that fin clipping did not further elevate mortality of already externally tagged fish, indicating a lack of additive effects from fin clipping. It is also possible that the external tag had "absorbed" most of the negative tagging effects in the high-predation-risk environment, such that the additional fin clip did not exert any influence in the second experiment. Because we found a doubling of mortality caused by external tags, including T-bar anchor tags, compared with fin clipping in the first experiment, we suspect that external tagging likely had some additive effects on age-0 Northern Pike. Unfortunately, we did not have any external-tagging-only treatment in the first experiment, which would have allowed us to unambiguously disentangle the effect of external tagging only compared with the effects of multiple markings. More research is needed to fully address this question.

Loss of the tags fixed through the operculum of age-0 Northern Pike was particularly high in our study. Overwinter tag loss was about 98.0%, and there was a complete loss of all tags after 325 d. For other tag types attached to the operculum, lower tag loss rates have been reported (Lockard 1968; Goldspink and Banks 1971). An unstable operculum in age-0 Northern Pike or a diameter of the fixation button that was too small to hold the tag at the operculum could be possible reasons for the poor performance of our opercular tags. Moreover, inflammation from tagging might have exacerbated these issues. Injuries and increased visibility may also have been reasons for the elevated mortality, relative to the control treatment group, in fish with opercular tags in our study.

Our study was the first to analyze the performance of streamer tags for Northern Pike. Overwinter tag loss of streamer tags was 7.5%. By contrast, streamer tag shedding occurred very fast in juvenile Barramundi *Lates calcarifer*, for which 100% tag loss in just 77 d was reported (Russel and Hales 1992). The long-term performance of the streamer tag in the present study was similarly weak, which is consistent with high shedding rates of streamer tags in anadromous Brown Trout *Salmo trutta* (Bartel et al. 1987) and Atlantic Herring *Clupea harengus* (Nakashima and Winters 1984). The overwinter mortality of the streamer-tagged age-0 Northern Pike was similar to that of age-0 Northern Pike with T-bar anchor tags. Because of the high long-term tag loss rates, we do not recommend the use of streamer tags in Northern Pike.

We found that the growth and condition of Northern Pike in the first experiment was unaffected by any of the tagging methods used. This is similar to the findings of McNeil and Crossman (1979), Gurtin et al. (1999), and Wagner et al. (2007, 2009) in other esocids. By contrast, Scheirer and Coble (1991) found that Northern Pike with T-bar anchor tags grew 44% less than untagged controls in the first year following tagging. The authors reported that the tag did not impair the condition of the fish and suggested that fish consumed enough to maintain their condition but not enough to grow. Scheirer and Coble (1991) assessed growth of tagged and untagged Northern Pike in different ways, i.e., the growth increment of untagged fish was based on back-calculated lengths while direct measurements of TL were used in tagged individuals. Perhaps these calculations affected their results. As we found only one exceptional study in our literature review, we conclude that tagging with methods explored in our study do not impair the growth and condition of age-0 Northern Pike.

We showed that small adult Northern Pike (<480 mm TL) carrying combined radio-acoustic transmitters grew less than untagged conspecifics. However, larger Northern Pike (>480 mm TL) did not show any growth impairment, which is consistent with the study by Jepsen and Aarestup (1999) who also studied larger-sized Northern Pike (>520 mm TL) implanted with radio transmitters. Further, Koed et al. (2006) reported increased body lengths and no impaired condition of large (570–1,130 mm TL) radio-transmitter-tagged Northern Pike after about 1 year at liberty. Northern Pike density in Kleiner Döllnsee is relatively high compared with other systems (Pagel 2009); hence, intraspecific competition for space and food resources is likely strong. Possibly the smaller individuals suffered from greater disadvantages caused by the surgery and could not easily compensate for the energy loss resulting from the surgery and impaired feeding after the stress event (see also Edeline et al. 2010).

One explanation for the reduced growth only found in small Northern Pike is that the antenna length of the combined radio-acoustic transmitter disproportionately impacted small fish, especially for species that inhabit complex habitats like Northern Pike. Entangled, free-moving, and trailing antennas can cause inflammation and necrosis at the antenna exit site (e.g., Knights and Lasee 1996; Adams et al. 1998). Furthermore, Bauer and Loupal (2007) reported an adverse effect on liver tissue in Common Carp because of granulation tissue that encapsulated the transmitter as a foreign body. Additionally, the damage to organs that are important for metabolism might have contributed to the reduced nutritional status and reduced growth of small Northern Pike in our work. Further work testing the effects of surgically implanted transmitters with and without antennas would be needed to provide conclusive answers.

Our results help to identify the most suitable tagging methods for age-0 Northern Pike. An optimal tagging method has minimal effects on the fish, while still serving the research purpose. Therefore, if external visibility is not an issue, our research suggests that PIT tags will be the most suitable tagging method for age-0 Northern Pike. For batch marking, fin clips can be used as well, but some mortality should be expected. Among the externally visible tags, T-bar anchor tags were found to be most useful tag in age-0 Northern Pike. Surgery-based combined radio-acoustic transmitters are probably harmful to small Northern Pike and thus will only yield unbiased data in larger fish. Their impact is largely independent of the transmitter/fish size ratio and may be caused by antennas. Overall, our findings raise a cautionary note that small Northern Pike are less resilient to tagging than previously assumed. This is not a trivial result because many methods using marks depend critically on the assumption that the fitness and behavior of the marked fish are not affected and are similar to untagged wild fish. This does not call into question the results achieved with marking in fish but constitutes a challenge for researchers to consider tagging-induced study effects and control for them as much as possible.

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