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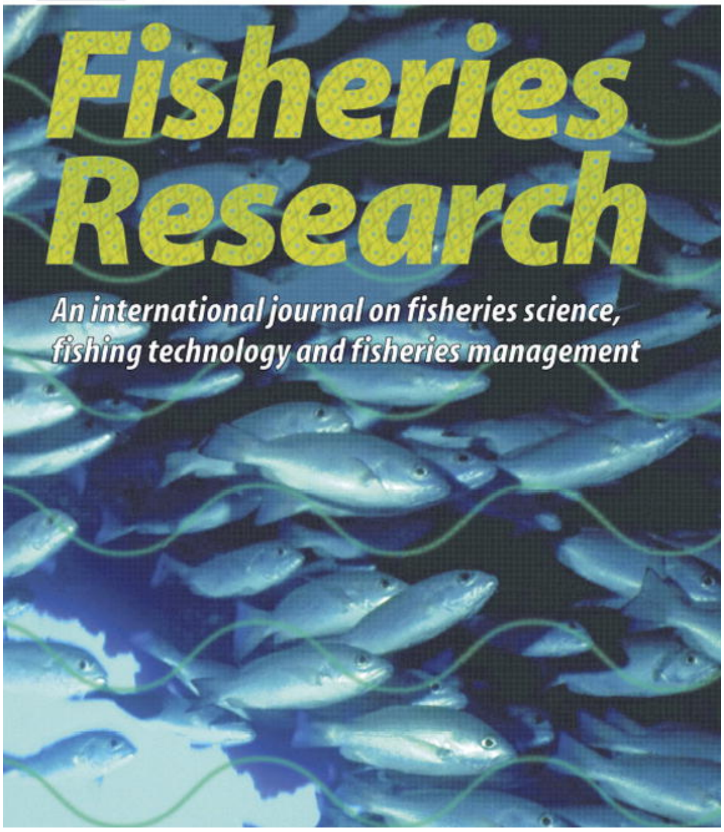

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Using PIT technology to study the fate of hatchery-reared YOY northern pike released into shallow vegetated areas

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Abstract

This study uses passive integrated transponder (PIT) technology to analyse the fate of 192 PIT-tagged hatchery-reared young-of-the-year northern pike *Esox lucius* (mean fork length FL 51.0 mm ± 5.3 S.D.) released into an experimental area located in the Brière Marsh (France), together with 72 untagged individuals for control. Survival and emigration were studied by trapping and using a portable PIT detector from release (20 May) to complete drying out of the grassland (15 June 2005). Only 19.3% and 6.9% of the PIT-tagged and control fish, respectively, successfully emigrated from the experimental area before drying out. Small individuals (FL <50 mm at tagging) suffered a higher mortality rate, and size-dependent effects of cannibalism rather than PIT-tagging procedure on survival were suspected. No evidence of tag loss was found for surviving fish, and individual growth conformed to values reported in literature. The portable PIT antenna detected 71.4% of the PIT-tagged pike in the flooded grassland. More than 30% of tagged fish disappeared from the experimental area throughout the study period, and predation by birds was suspected. Results support the view that more attention should be paid to limiting the detrimental effects of mortality on the stocking success of northern pike.

Keywords: Passive integrated transponder; Portable detector; *Esox lucius*; Survival; Stocking program

1. Introduction

Northern pike (*Esox lucius*) is a predatory keystone species that tolerates a broad range of environmental conditions and is particularly adapted to shallow freshwater environments (Casselman, 1996). For this species, temporary flooded and vegetated areas are critical spawning and nursery habitats, where larvae and juveniles can find protection against predators and adequate food resources (Souchon, 1983; Wright and Shoesmith, 1988). After a short period of development, juveniles have to emigrate from temporary wetlands to permanent habitats before total drying out (review in Inskip, 1982). Juvenile pike survival and growth patterns have mainly been investigated under experimental or semi-natural conditions (e.g. Wright and Shoesmith, 1988; Bry et al., 1995; Le Louarn and Cloarec, 1997; Skov et al., 2003; Skov and Koed, 2004). More recently, survival of young-of-the-year (YOY) pike has been studied in the wild using mass marking (Gronkjaer et al., 2004; Sutela et al., 2004) but mortality causes were not identified. Insights into the early life history of northern pike are still needed for developing proper management policies.

In the two last decades, the passive integrated transponder (PIT) technology has been developed as a novel method for individually tagging fish (Prentice et al., 1990) and has shown its efficiency in studying fish life-history tactics (e.g. Juanes et al., 2000; Cucherousset et al., 2005a). Stationary PIT antennas have been increasingly used by ichthyologists to study fish habitat use and migration processes (see review in Lucas and Baras, 2000). More recently, portable PIT detectors have been developed to track fish in shallow streams (Roussel et al., 2000; Barbin Zydlewski et al., 2001; Cucherousset et al., 2005b; Hill et al., 2006). Such technological developments have greatly helped to improve our understanding of complex aspects of the early life ecology and behavior of primarily salmonids (e.g. Martin-Smith and Armstrong, 2002; Roussel et al., 2004; Cunjak et al., 2005), but to our knowledge, PIT technology has never been used for the study of YOY northern pike in the wild.

The objective of this work was to investigate the usefulness of PIT technology for studying YOY northern pike in a naturally flooded grassland. We particularly focused on PIT-tag retention,

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post-tagging survival, and the efficiency of a portable PIT detector for studying the fate of hatchery-reared YOY pike after their release in a shallow, still water and vegetated habitat. Such an investigation is crucial since a quantitative assessment of the fate of hatchery YOY pike released in the wild is still needed for improving the effectiveness of stocking programs.

2. Materials and methods

2.1. Study area

The study was carried out in the Brière Marsh (northwest France, Fig. 1), a 7000 ha area composed of a network of permanently flooded ditches and a heterogeneous patchwork of ponds, reed beds and grazed grasslands that are flooded in winter and progressively dry out during spring and summer. The survey was conducted in May and June 2005 in a protected area located in the heart of the Brière Marsh (Fig. 1). A 0.47 ha flooded grassland was subdivided with regularly spaced transect lines in order to delineate 233 rectangular cells (4 m wide and 5 m long). Based on measurements of habitat variables performed in each cell, the substrate consisted exclusively of compact peat with no soft bottom, and the mean water depth was 15.1 cm (±5.6 S.D., maximum water depth 36 cm). Emergent (Poaceae and *Phragmites australis*) and submerged plants (*Ranunculus* spp. and *Callitriche* spp.) covered 47.2% (±28.5 S.D.) of the total area, offering potential spawning substrate for pike (Bry, 1996). The flooded grassland was connected to a temporarily flooded pond by a single connecting point. A fyke net (5 mm mesh) equipped with two wings (1.2 m high and 3 m long) to block the whole water column was set up in a V-shape at this connecting point to trap fish leaving the grassland (Fig. 1). During the experiment, the water level fell down continuously until the grassland dried out totally in late June.

2.2. Fish tagging and stocking

Hatchery-reared YOY pike fed with zooplankton were used for this experiment. A total of 197 YOY pike were anaesthetized

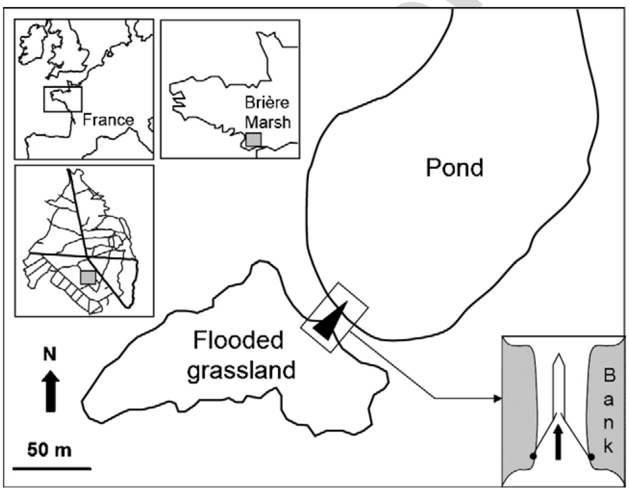

Fig. 1. Map of the study area and description of the trap setting at the single connecting point between the temporarily flooded grassland and the pond.

with eugenol (0.04 mL L^{-1}), measured (fork length, ±1 mm) and weighed (±0.1 g). The mean fork length and weight were 51.0 mm (±5.3 S.D.) and 0.86 g (±0.3 S.D.), respectively. A PIT tag was inserted into the peritoneal cavity using a sterile needle mounted on an injector, and the left pelvic fin was clipped to assess tag loss. The PIT tags used were 11.5 mm long and 2.1 mm in diameter (ID 100; EID Aalten B.V., Aalten, The Netherlands). In addition, a group of 74 control fish (mean fork length = 54.9 mm ± 4.2 S.D.) were subjected to the same procedure but not PIT-tagged, the right pelvic fin being clipped to distinguish them from PIT-tagged individuals. Fish were given 6–8 h to recover before being transported in plastic bags in groups of 13–15 individuals by boat to the study area (2 h), similarly to local stocking practises. Mortality, cannibalism and tag loss were checked at the end of the recovery period and before release in the grassland. Tagged and control fish were released randomly into the experimental area at 9 p.m. on 20 and 25 May, 2005, respectively. The stocking density (0.06 ind m^{-2}) was similar to the density of wild YOY pike usually observed in the Brière Marsh (Cucherousset, unpublished data), but below stocking densities reported in the literature (e.g. 1–3.3 ind m^{-2} in Lucchetta, 1983 and 0.4–3.6 ind m^{-2} in Sutela et al., 2004) to prevent exacerbation of cannibalism (Bry et al., 1992).

2.3. Fyke net and PIT detection survey

The fyke net was checked once or twice a day; trapped pike were anaesthetized with eugenol (0.04 mL L^{-1}), measured (fork length, ±1 mm), and checked for PIT tags and fin clips. Then, fish were released into the adjacent pond (Fig. 1). A portable PIT detector was also used once a day in search for lost PIT tags inside and under the fyke net; each transponder detected was picked up by the operator. The detector is composed of one RFID reader (LID 650; EID Aalten B.V., Aalten, The Netherlands) interfaced with a LCD screen and powered by a 12 V battery. The reader is connected to a waterproof antenna (ANT 612; EID Aalten B.V., Aalten, The Netherlands) which is mounted on a 3 m-long aluminium pole. When a PIT tag is detected by the antenna, the tag code is displayed and a piezoelectric buzzer sounds a loud tone to alert the operator. The maximum tag detection distances range from 30 to 36 cm, depending on the orientation of the PIT tag. A thorough description of the portable PIT detector and its performance is given in Cucherousset et al. (2005b). From 21 May to 7 June, the portable PIT detector was used every 3–4 days to check for the presence and location of PIT-tagged fish in the experimental area. The operator (J. Cucherousset) manoeuvred the antenna above the water surface by wading between two transects and the entire wetted area was scanned in 8–10 h. When a PIT tag was detected, its exact position was plotted in relation to the rectangular cells delineated by the transect lines. After June 7, more than 60% of the initial flooded area had completely dried out and the scanning operations were stopped. On 15 June, the fyke net dried out; two 40–50 m^2 pools (mean water depth = 4.97 cm ± 4.1 S.D.) persisted but were disconnected from the pond. These pools were electrofished but no pike were caught. After total drying out, additional operations were performed on 19 July to recover PIT tags remaining in the study site. Each rectangular cell delineated by the transect lines was carefully scanned, the entire experimental area being scanned three times consecutively. Each PIT tag detected was picked up and removed; its position was recorded for comparisons with the previous locations. During the third and final scanning, no transponders were found.

2.4. Data analysis

The efficiency of the portable PIT detector was calculated as the proportion of fish detected by the operator during the first scanning survey (21 May). Only fish trapped in the fyke net during the subsequent days were considered to ensure that the detection efficiency was calculated on living fish.

Individual growth was estimated based on fish trapped in the fyke net. The expected weight at recapture was calculated based on a length–weight relationship at tagging:

$$W = 0.0397\,e^{0.0589\mathrm{FL}}$$

where W is the weight in g and FL is the fork length in mm ($n = 192$, $R^2 = 0.88$). We used two indicators of growth performance (Bry et al., 1991): the increment in fork length (IFL, in mm day^{-1}) and the specific growth rate (SGR, in % day^{-1}) using the formulae:

$$\mathrm{IFL} = \frac{\mathrm{FL_f} - \mathrm{FL_i}}{t}$$

$$\mathrm{SGR} = \left[\frac{\ln\, W_\mathrm{f} - \ln\, W_\mathrm{i}}{t}\right] \times 100$$

where $\mathrm{FL_i}$ and W_i are the fork length and the weight at tagging, $\mathrm{FL_f}$ the measured fork length, W_f the back-calculated weight at recapture and t is the time spent in the grassland.

The fate of each individually PIT-tagged YOY pike was inferred from recapture events at the fyke net and PIT tag locations within the experimental area (scanning surveys with the portable PIT detector). Each individual was assigned to one of the four following groups. Fish that were trapped in the fyke net belong to group I. Group II corresponds to transponders found inside or under the fyke net, whereas transponders collected in the grassland after complete drying out belong to group III. For group III fish, we assume that death or tag loss occurred when the transponder started to be consistently detected in the same rectangular cell until complete drying out (i.e. no movement). Finally, group IV corresponds to PIT tags that were detected at least once during the scanning operations, but the fish were not recaptured in the fyke net, and the transponders were not found after total drying out. PIT tag disappearance was assumed to occur the day after the transponder was detected for the last time in the experimental area.

Recapture rates of PIT tagged and control fish in the fyke net were compared using the Fisher's exact test. Since deviations from normality were detected in the dataset, differences in fish fork length at tagging between the groups and differences in growth performances (IFL and SGR) between different size classes of survival fish were tested using non-parametric analysis of variance (Kruskal–Wallis test). A rejection level of 0.05 was used in all tests.

3. Results

3.1. Mortality at tagging, tag retention and portable PIT detector efficiency

Among the 197 PIT-tagged fish, five individuals died during the recovery period (2.5%). Fish that died were small (FL range 43–52 mm; mean FL = 46.2 mm ± 3.5 S.D.) compared to the survivors (FL range 42–65 mm, average FL = 51.1 mm ± 5.2 S.D.). No PIT tag was rejected and no act of cannibalism occurred before stocking. Similarly, two control fish died (2.7%) and control fish that died were small (FL range 49–50 mm; mean FL = 49.5 mm ± 0.7 S.D.) compared to the survivors (FL range 47–68 mm, average FL = 55.1 mm ± 4.1 S.D.). The mortality rate of control fish before stocking was not significantly different from PIT-tagged fish (Fisher's exact test, $p > 0.99$). On morning of 21 May, two of the 192 PIT-tagged fish released the day before were captured in the fyke net. Afterwards, 35 individuals were recaptured in the fyke net throughout the survey. Among these 35 individuals, 25 have been detected within the experimental area by the operator during the first scanning survey; the efficiency of the portable PIT detector was 71.4%.

3.2. Fate of PIT-tagged fish after release

Among the 192 PIT-tagged YOY pike that were released in the grassland, 37 individuals were captured in the fyke net (group I, see Table 1), 28 transponders were found inside and under the fyke net (group II), 68 transponders were collected on the ground after complete drying out (group III), and 59 transponders disappeared from the experimental area (group IV). All trapped fish with the left pelvic fin clipped had a transponder, indicating 100% tag retention for the surviving fish (group I).

Table 1
The fate after complete drying-out of the PIT tags from the 192 YOY pike released into the experimental flooded grassland

Group	Fate of the PIT tag	N	Fork length at tagging (in mm)	
			Mean (±S.D.)	[minimum; maximum]
I	PIT-tagged fish trapped in the fyke net	37	52.2 (±5.9)	[44; 65]
II	PIT tags found inside or under the fyke net	28	52.3 (±5.3)	[42; 64]
III	PIT tags recovered in the grassland after complete drying out	68	49.4 (±4.2)	[43; 63]
IV	PIT tags disappeared from the grassland during the survey	59	51.8 (±5.4)	[43; 63]

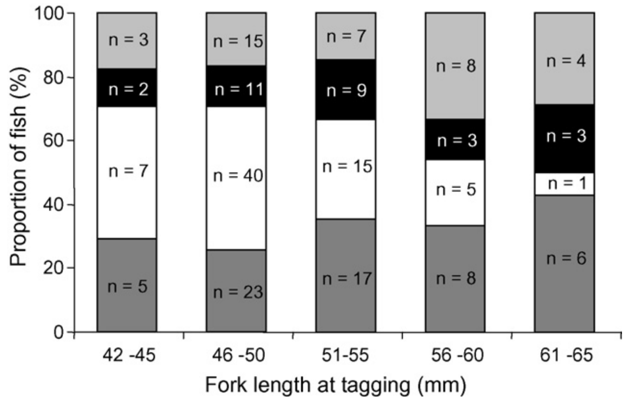

Fig. 2. Proportions and numbers of the 192 PIT-tagged pike belonging to group I, (▒, PIT-tagged fish trapped in the fyke net), group II (■, PIT tags found inside or under the fyke net), group III (□, PIT tag recovered in the grassland after the complete drying-out) and group IV (▓, PIT tag disappeared from the grassland during the survey) for each 5 mm fork length class at-tagging.

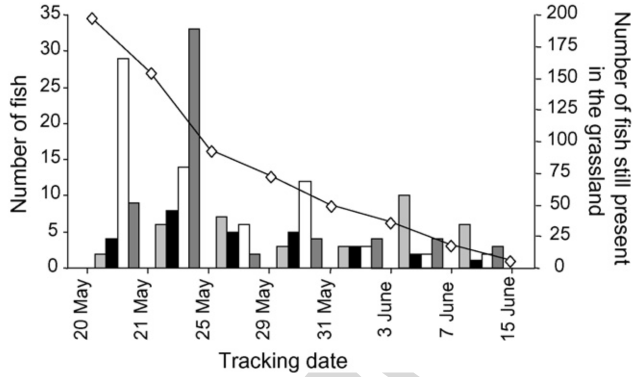

Fig. 3. Number of PIT-tagged YOY pike in the grassland throughout the survey (◊) and number of fish belonging to group I, (▒, PIT-tagged fish trapped in the fyke net), group II (■, PIT tags found inside or under the fyke net), group III (□, PIT tag recovered in the grassland after the complete drying-out) and group IV (▓, PIT tag disappeared from the grassland during the survey).

The frequency distributions of fish fork length at tagging (5 mm size classes, see Fig. 2) indicated that higher survival rates (14.6–33.3%) were observed for fish larger than 50 mm FL. Conversely, fish that died in the experimental area (group III) were significantly smaller at tagging (FL 49.4 mm ± 4.2 S.D.) compared with groups I, II and IV (Table 1; Kruskal–Wallis test, KW = 11.79, $p = 0.0081$). This trend is confirmed by the frequency distributions of fish fork length at tagging (Fig. 2), which indicate that 44.3% of fish smaller than 50 mm FL at tagging belong to group III. The proportion of fish in group II (11.8–21.4%) was quite constant whatever fish size at tagging (Fig. 2), whereas the proportion of PIT-tags that disappeared from the experimental area tented to be higher (42.9%) for fish larger than 60 mm FL.

Only five of the 72 control fish (right pelvic fin clipped) survived and were recaptured in the fyke net. The recapture rate in the fyke net was significantly lower for control fish (6.9%) compared with PIT-tagged fish (19.3%, Fisher's exact test, $p = 0.014$). The small number control fish that were recaptured precluded any comparison of individual growths between untagged and PIT-tagged fish. For PIT-tagged fish trapped in the fyke net, the mean SGR was 11.3% day^{-1} (±1.59 S.D.), ranging from 8.18% to 14.7% day^{-1}; the mean IFL was 1.92 mm day^{-1} (±0.27 S.D.) and ranged from 1.39 to 2.5 mm day^{-1}. Additionally, no differences in growth performances (SGR and IFL) were found between fish smaller and fish larger than 50 mm FL at tagging (Kruskal–Wallis test, KW > 186.5, $p > 0.637$).

The number of PIT-tagged fish captured in the fyke net (group I) and the number of transponders collected in and under the fyke net (group II) did not show explicit trends throughout the study period (Fig. 3). For group III, 50% of the 68 transponder were consistently detected in the same location from the first scanning survey to their final picking up (19 July), and were assumed to die or to reject their transponder the day after release. For group IV, 42 of the 59 transponders (72%) had disappeared from the experimental area within 5 days after release (Fig. 3).

4. Discussion

4.1. Effect of PIT-tagging

Several studies have been conducted to determine the minimum fish size for PIT-tagging, results being largely variable depending on species and individuals (e.g. Baras et al., 2000; Sigourney et al., 2005; Mueller et al., 2006). According to investigations that were mostly conducted on salmonids (Prentice et al., 1990; Ombredane et al., 1998), tag rejection is usually low if fish body size is not too small. In the present study, no instantaneous tag rejection was observed after a 6 h recovery period and no evidence of tag loss was found among individuals recaptured in the fyke net while emigrating from the grassland (i.e. all left pelvic fin-clipped fish captured in the fyke net had a PIT tag). A formal experiment under controlled conditions is now needed to confirm results on tag retention by young-of-the-year pike. Under a certain size threshold, PIT-tagging can have negative short-term effects on survival and growth (Sigourney et al., 2005; Hill et al., 2006). Most of the transponders that were recovered on the ground after complete drying out (group III) had been inserted into fish smaller than 50 mm FL and a size-dependent effect of PIT-tagging procedure on YOY survival can be suspected. Unfortunately, the low number of control fish recaptured ($n = 5$) precludes any unambiguous estimation of detrimental effect of tagging on fish. However, it is noteworthy that the growth of PIT-tagged pike in the present study (IFL of 1.92 mm day^{-1} and SGR of 11.3% day^{-1} on average) fell within the range of values reported in the literature, i.e. IFL ranging from 1.2 to 5.6 mm day^{-1} under natural or semi-natural conditions and SGR of 15.2% day^{-1} ranging from 9.8% to 25.0% day^{-1} under experimental conditions of near-maximum growth (see review in Bry et al., 1991). Moreover, we did not detect any differences in growth performance according to individual body size at tagging. This indicates that PIT-tagging did not affect the growth of small fish predominantly, as it would have been expected in our experiment if the effect of tagging was size-dependent. Cannibalism in YOY pike is known to be size-selective (Bry et al., 1992) and Skov et al. (2003) demonstrated that it can potentially cause a 60% reduction in stocked pike density, at least within the first 7 days after release. Despite the low stocking densities, it is possible that cannibalism occurred in our experimental area, and the low survival observed for small PIT-tagged and control pike might be due to predation by larger individual rather than PIT-tagging procedure. The contribution of each mortality source (cannibalism versus tagging) would deserve for more observations under controlled conditions, as well as possible changes in fish behaviour after tagging (Baras et al., 2000).

4.2. The use of PIT technology on YOY pike

This work was a first attempt at using PIT technology to study the fate of YOY pike after stocking in naturally flooded grassland. While searching for PIT-tagged YOY pike with the portable detector, the detection efficiency (71.4%) corresponded to values already obtained in the literature for salmonid species, i.e. 25–85% (Morhardt et al., 2000; Roussel et al., 2000; Barbin Zydlewski et al., 2001; Cucherousset et al., 2005b; Hill et al., 2006). The high detection efficiency is not surprising since water depth in the experimental area never exceeded the maximum reading distance of the portable PIT detector. The fish that were not detected were likely to escape from the antenna while being moved above the water by the operator. This result indicates that portable PIT detectors can be used to successfully track small-bodied fish such as YOY pike in shallow, vegetated and open temporary flooded areas. However, some taxa may be more likely to escape from the antenna compared to the YOY northern pike, and preliminary tests on detection efficiency are always recommended.

4.3. The fate of YOY pike after stocking

Hatchery-reared and PIT-tagged YOY pike had a high mortality rate and only 19.3% of individuals released (192 in total) were recaptured in the fyke net before drying out completed. A low survival rate for YOY hatchery pike has already been reported under natural or semi-natural conditions by others (5–17%, Lucchetta, 1983; 2–12%, Gronkjaer et al., 2004; 34%, Bry et al., 1995), and survival after stocking is known to depend on age at release and environmental variables such as temperature, food availability, time of stocking, and pike density (Bry et al., 1995; Skov et al., 2003; Gronkjaer et al., 2004; Sutela et al., 2004). Among possible mortality causes, the occurrence of transponders that were collected inside and under the fyke net (group II) is unusual. It is unlikely that the lost transponders or dead fish could have been transported to the net by water currents because of the absence of water movement at the fyke net and the high vegetation density in the grassland. Flooding and drying-out in the Brière Marsh is exclusively due to precipitation and evaporation processes. However, the abundance of the invasive red swamp crayfish (*Procambarus clarkii*) in the experimental area was very high, and a total of 4764 juveniles (40–70 mm long) were caught in the fyke net throughout the experiment. This species is well known to prey upon small fish (Gutierrez-Yurrita et al., 1998), and we suspect that predation by crayfish on YOY pike in the fyke net could have been enhanced by the presence of high crayfish numbers in a small water volume/area (fyke net), particularly at the beginning of the survey. Indeed, none of these PIT tags were found in intact but dead fish or alone within/around the fyke net. Predation by crayfish in the fyke net could also explain the very low recovery rate of control fish. The extent to which crayfish could have killed YOY pike in the grassland and contributed to high number of transponders collected on the ground after completed drying out (group III) remains unknown.

More than 30.7% of the fish disappeared after release in the grassland (group IV) and we were unable to find the transponders in the grassland even after complete drying out. The water depth in the experimental area was lower than the maximum reading distance of the portable PIT detector at the beginning of the experiment and continuously decreased throughout the study period. Moreover, due to the compactness of the bottom of the experimental area, it is unlikely that some transponders were accidentally buried by the operator stepping on lost PIT tags while scanning for fish. Although the fyke net blocked the whole water column, the hypothesis that some fish escaped while the operator was checking the trapping system (1–2 min day^{-1}) cannot be totally rejected. However, many bird species breed in the Brière Marsh, and grey herons *Ardea cinerea*, sacred ibis *Threskiornis aethiopicus* and black terns *Chlidonias niger* were frequently observed in the study site. These three species are known to prey upon small fish (Del Hoyo et al., 1992; Beintema, 1997), and were occasionally observed fishing in our experimental area. We therefore suspect bird predation to be the major cause of PIT tag disappearance and YOY pike mortality in our experiment. One otter *Lutra lutra*, was also observed in our experimental area, and might have preyed upon PIT-tagged pike in the grassland.

5. Conclusion

PIT technology provides effective tools for studying YOY northern pike in shallow and vegetated habitat in which they live during their early life period. We found that 11 mm-long transponders can be used to tag YOY northern pike, but complementary investigations under experimental conditions are needed to test the effects of PIT tagging on individual behaviour. Portable PIT detectors can efficiently detect the position of PIT-tagged YOY pike provided that water depth does not exceed the maximum reading distance. Using such technology, frequent scanning of the experimental area can be used to monitor survival and movements of PIT-tagged individuals after release. Finally, the temporal pattern of mortality observed throughout the experiment suggests the existence of a critical period just after release, when YOY pike are highly vulnerable to predators. This could be a severe drawback for YOY pike stocking programs.

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