Artificial floating littoral zones: a promising nursery to support Pike (Esox lucius) in reservoirs

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Short Note

Artificial floating littoral zones: a promising nursery to support Pike (*Esox lucius*) in reservoirs

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Abstract – The use of water resources in reservoirs leads to artificial water level fluctuations sometimes with extreme amplitudes and frequencies. These artificial fluctuations homogenize littoral habitats and often make macrophytes disappear. Consequently, spawning and refuge-nursery habitats become scarce which is critical for phytophilous species such as Northern Pike (*Esox lucius*) whose populations decline. Quite recently, floating artificial structures have emerged as a mitigation solution. However, the design of these structures is relatively simplistic and only consists in a simple 2D-floating mat of vegetation. Their effectiveness to support fish populations, especially pike in regulated reservoir, by providing suitable habitats for spawning, refuge and nursery remains poorly documented. Here we conceived 3D artificial Floating Littoral Zones (FLOLIZ) that mimic a natural littoral zone to support both pike spawning and juvenile growth (helophytes, hydrophytes, specific shelter areas). To assess their effectiveness, three structures of 70 m^2 area and 1 m deep were installed in September 2018 in a French reservoir subject to extreme water level fluctuations. Visual surveys carried out in spring and summer by snorkelling over 2019–2023 highlighted an annual recurrence of juvenile pike in FLOLIZ, but also a higher abundance than in control stations. The maximum number of individuals observed simultaneously on the same structure was 14. Even if it cannot be asserted that pike spawned in FLOLIZ, these results highlight that FLOLIZ can provide refuge and nursery habitats for juvenile fish in reservoirs with poor littoral habitats.

Keywords: Ecological engineering / artificial floating island (AFI) / water level fluctuation (WLF) / mitigation / Phytophilous species

1 Introduction

Northern Pike (*Esox lucius*, Linnæus 1758; hereafter "pike") is widely distributed in the Holarctic region. Pike lives in a variety of freshwater ecosystems and also in brackish ecosystems (Craig, 2008). As an apex predator, it is a keystone species that exerts a top-down control on the structure of fish communities, including its conspecifics (Carpenter *et al.*, 1993; Baum and Worm, 2009). Aquatic vegetation plays a major role during the life cycle of pike for spawning, sheltering and foraging (Bry, 1996), and particularly for juvenile stages (Craig, 2008; Skov and Nilsson, 2018). The reproductive success of pike is highly dependent on both the density and type of vegetation available and the stability of the water level at key periods (Casselman and Lewis, 1996). Specifically, the water level must be stable for at least four weeks after egg-laying for the survival and good development of fry (Mingelbier *et al.*, 2008).

In reservoirs, which are used for hydropower and water resource supply, or in regulated rivers, the water level fluctuates artificially. These water level fluctuations (WLF) considerably differ from natural fluctuations in amplitude, duration and frequency (Coops *et al.*, 2003; Hirsch *et al.*, 2014). As a consequence, adjacent wetlands are disconnected and littoral habitats impoverished because they become homogenized with no or very few aquatic vegetation (Furey *et al.*, 2004; Logez *et al.*, 2016; Foubert *et al.*, 2020). This prevents successful spawning and recruitment of pike and leads to an overall decline in their populations (Wolcox and Meeker, 1992; Kruk and Penczak, 2003; Mingelbier *et al.*, 2008; Crane *et al.*, 2015). In France, pike has been classified as

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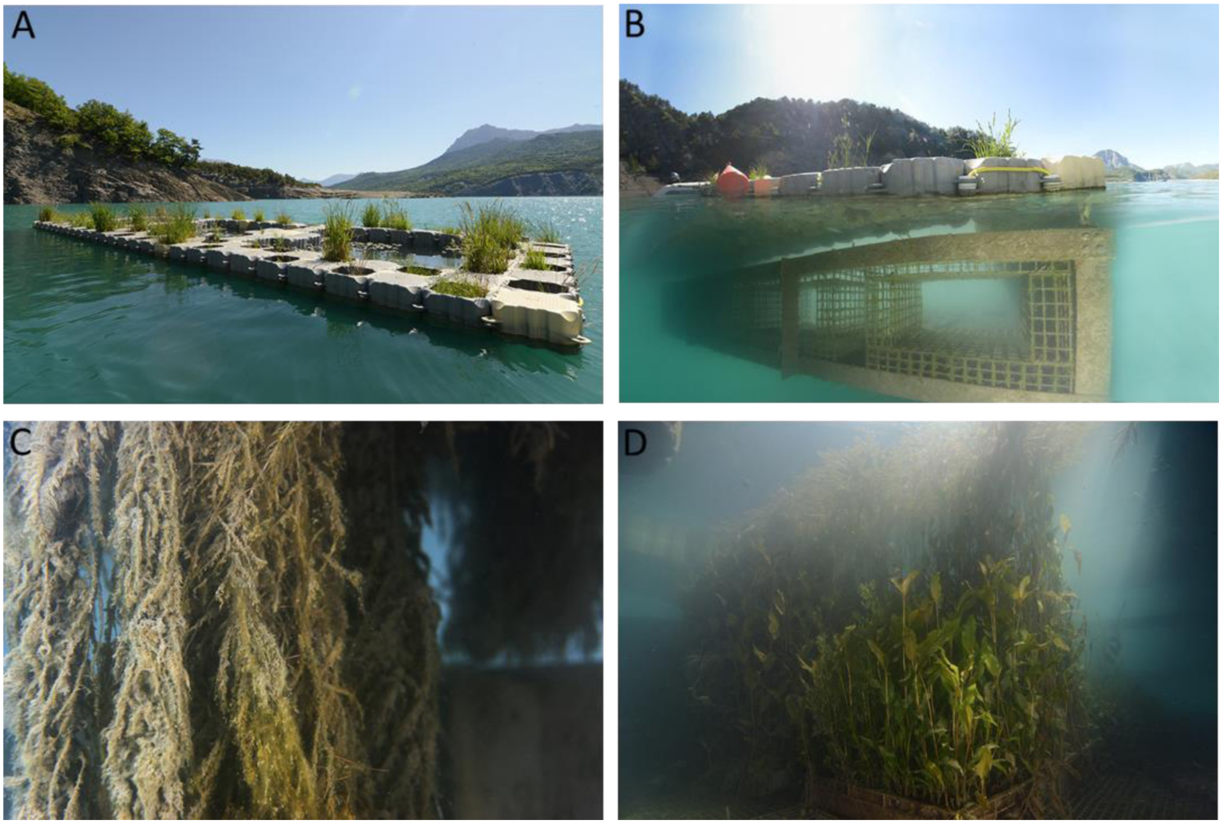

Fig. 1. The different parts of the FLOLIZ. (A) Floating part with helophytes; (B) Aquatic part with wire cages; (C) Helophyte roots and (D) Pondweed bed. Author: Remy DUBAS. ©UROS Project (OFB-INRAE-ECOCEAN).

"Vulnerable" on the Red List of threatened species (UICN Comité français *et al.*, 2019) and benefits from a biotope protection that prohibits the degradation and destruction of eggs and spawning habitats since 1988. To compensate for low abundances, pike is besides very commonly stocked, what has however been shown not to be very efficient (Monk *et al.*, 2020; Daupagne *et al.*, 2021; Guillerault *et al.*, 2021).

Several mitigation measures of artificial WLF impacts have been listed for reservoirs, such as the diversification of aquatic habitats, bank restoration or even flow management to limit water level variations during sensitive periods (Trussart *et al.*, 2002). However, these mitigation measures can be extremely difficult to implement in the field, remain ineffective with high WLF amplitudes and may also conflict with main uses reservoirs have been created for; in the end, they are implemented in very few reservoirs (Santos *et al.*, 2008, 2011; Baumann *et al.*, 2016). To circumvent these issues, habitats not impacted by WLF such as artificial floating islands appear to be a promising mitigation tool (Nakamura and Mueller, 2008; Yeh *et al.*, 2015; Ware, 2020). Some studies have shown that these floating structures were attractive for fish (Hwa-Keun Byeon, 2014; Huang *et al.*, 2017), especially for phytophilous species such as pike (Gillet, 1989; De Moraes *et al.*, 2023), but they remain scarce. Furthermore, the relatively simplistic structures they used (often vegetated 2D floating mat) include habitats suitable for spawning but not for the growth of juvenile fish. Here we conceived a complex 3D floating structure integrating all habitats required for fish and more specifically for pike life cycle, including underwater levels, and tested if it could help to sustain populations in regulated reservoirs.

2 Material and methods

We designed a 70 m^2 three-dimensional floating structure (Floating Littoral Zone "FLOLIZ", 14 m long × 5 m wide) that mimics a natural littoral zone with helophytes, aquatic stages with different depths and vegetated with hydrophytes, and different types of shelter (Fig. 1). In detail, it is composed of a terrestrial part made up of floating caissons (MarineFloor©) and helophyte planters (the roots can grow in water). This floating part supports the frame made up of three extruded aluminium structures (one central structure 0.8 m deep and two edge structures 0.5 m deep). Steel mesh cages containing an inert mineral substrate (recycled oyster shells, Misapore©) cover their bottom and two sides. Grass-like hydrophytes were planted (*Stuckenia pectinata, Myriophyllum spicatum*, Chara sp) in the 0.5 m deep structures and pondweeds (*Potamogeton nodosus, Potamogeton lucens, Potamogeton coloratus*) in the 1 m deep structure. Grass-like plants recreated an aquatic lawn that is highly appreciated by pike for egg deposition (Franklin and Smith Jr., 1963; Mccarraher and Thomas, 1972) whereas the dense pondweed beds provided refuge-nursery areas (Cook and Bergersen, 1988; Raat and Nations, 1988; Walton-Rabideau *et al.*, 2020). Finally, empty wire cages, 2.5 cm mesh size, were placed along the width of the

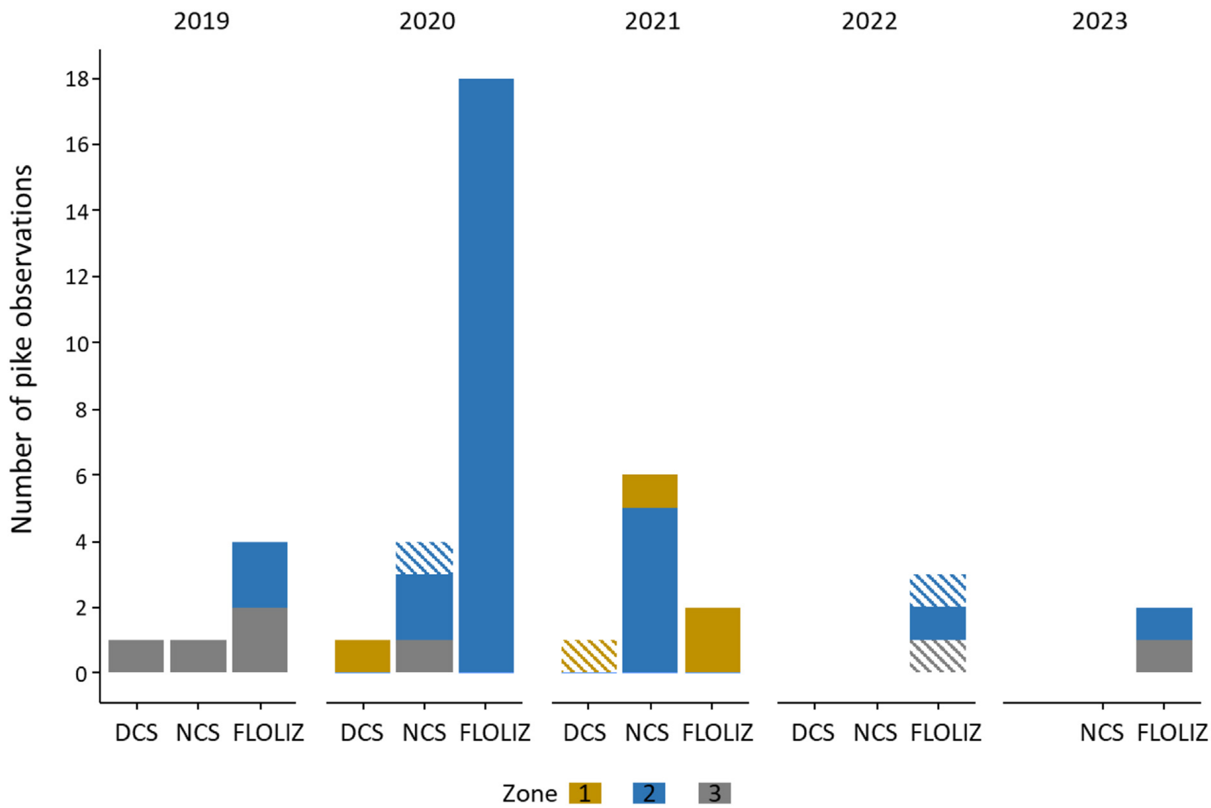

Fig. 2. Number of pike individuals observed in the different type of station (DCS, NCS, FLOLIZ) over 2019–2023. The colours correspond to the zone (3 replicates for each station type). The hatched rectangles correspond to adults, while the filled rectangles correspond to juveniles. DCS could not be sampled in 2023.

Table 1. Kruskal-Wallis test of differences in pike abundance between station types (FLOLIZ and control stations) over different periods. NS = No significant difference; * means a significant difference at 5% threshold; χ2 = Kruskal-Wallis Chi Squared; df = Degree of freedom; *P* = *P*-value (Kruskal and Wallis, 1952).

		DCS vs FLOLIZ	NCS vs FLOLIZ	DCS vs NCS
Whole sampling period				
	Season	$\chi2 = 3.9$, df = 1, $P = 0.049$ *	NS	NS
	Spring	$\chi^2 = 4.3$, df = 1, $P = 0.037$ *	NS	NS
	Summer	NS	NS	NS
Year				
	2019	NS	NS	NS
	2020	NS	NS	NS
	2021	NS	NS	NS
	2022	$\chi2 = 3.7$, df = 1, $P = 0.055$	$\chi2 = 3.7$, df = 1, $P = 0.055$	NS
	2023	No data	NS	No data

aluminium structures to create shelter for fry. FLOLIZ functionality for pike life cycle (from spawning to growth of juvenile fish) has been tested over 2019-2023 in Serre-Ponçon reservoir (France, 44° 31' 38.23" N ; 6° 22' 52.04" E, area 28 km^2, volume 1270 million m^3 and maximum depth 110 m). Over 2019-2022, annual WLF ranged in [17; 49] m and daily WLF in [–1.67; + 1.23] m (Data EDF). Three FLOLIZ have been installed in September 2018 in three downstream bays of the reservoir. For a full description of Serre-Ponçon reservoir and FLOLIZ, refer to Salmon *et al.* (2022).

Pike were recorded by snorkelling from the beginning of the spawning period (May for Serre-Ponçon reservoir) to the end of summer from 2019 to 2023. This sampling method has already proved its effectiveness for counting pike in lake, especially for age 0+ (Turner and Mackay, 1985; Brosse *et al.*, 2001). In these clear waters, visual census was suitable to detect potential egg-layings in hydrophytes and to record all pike life stages (from larvae to adults) that could be approached closely (<1 m) without escaping. It was conducted by two qualified divers to identify pike, estimate their size and life stage, both in FLOLIZ and in control stations. Control stations

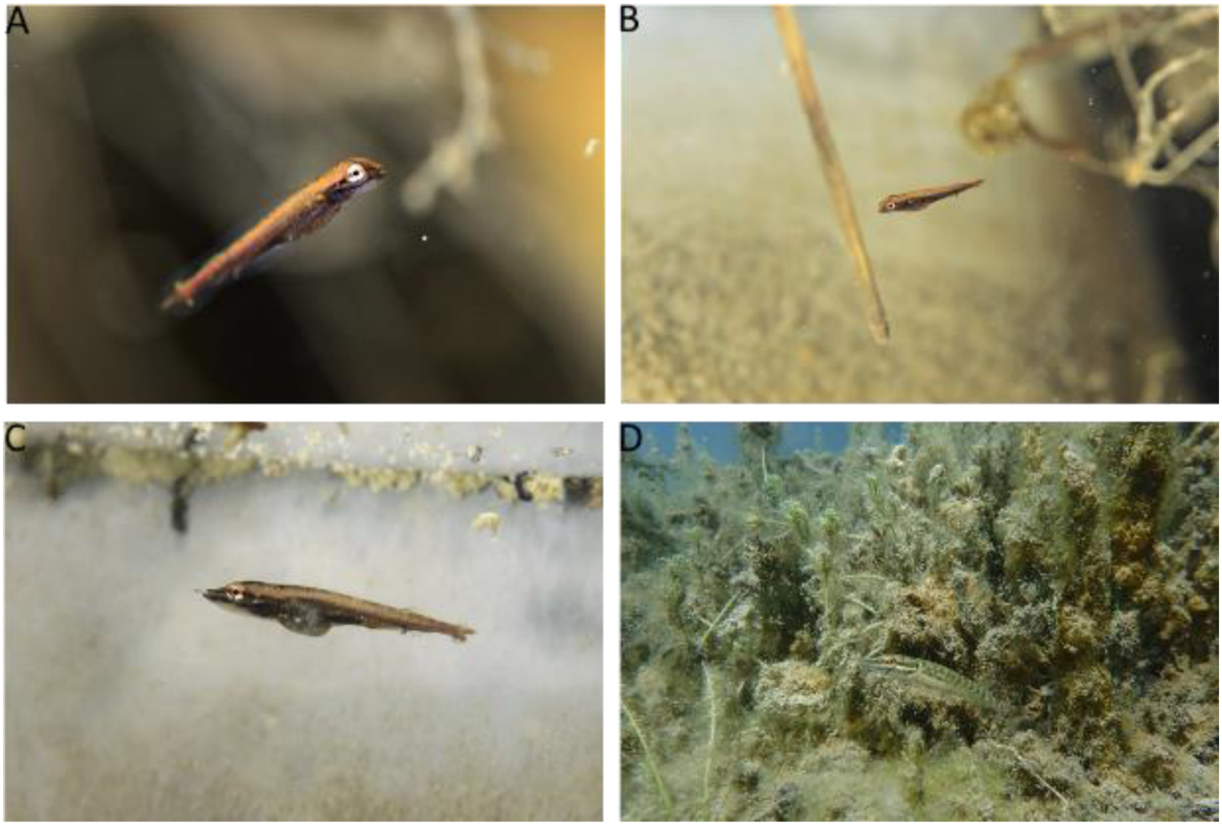

Fig. 3. Pictures of juvenile pike in FLOLIZ during the sampling period. (A) 15 mm individual (May 2019); (B) 20 mm individual (May 2019); (C) 25 mm individual (May 2019); (D) 70 mm individual (June 2020). Sizes have been estimated visually. The author of photos A to C is Remy DUBAS. The author of photo D is Julien DUBLON. ©UROS Project (OFB-INRAE-ECOCEAN).

were of two kinds: a portion of natural littoral zone in the same bay as FLOLIZ, approximately 50 m away from FLOLIZ (NCS for Nearby Control Stations), and another one in a neighbouring bay with similar hydro morphological characteristics to NCS (DCS for Distant Control Stations). Shallow depth being a main feature of juvenile pike habitat (Chapman and Mackay, 1984), due to steep banks control stations consisted in 70 m long, 1 m wide (*i.e.* 70 m^2) and up to 1 m deep areas. The trio of sampling stations (FLOLIZ, NCS, and DCS) was replicated in three zones of the reservoir (for details, see Salmon *et al.*, 2022). The choice of two kinds of control station aimed to evaluate the influence of FLOLIZ in its surrounding, its attractiveness possibly leading to more pike observations in NCS than in DCS. Each diver sampled half a FLOLIZ in roughly 20 minutes by swimming into and around the FLOLIZ. In control stations, each diver sampled a 35 m-long and 1 m-wide linear in 20 minutes as well. Differences in pike abundance between stations were tested according to different periods: over the entire sampling period 2019–2023, by season (spring corresponds to May–June and summer to July–September) and by year (2019, 2020, 2021, 2022 and 2023). Non-parametric two-by-two comparisons were used to highlight differences in abundance. Tests were performed using the "kruskal.test" function in the « Stats » package (R Core Team, 2022). The analysis was carried out in Rstudio software version 2022.12.0-353.

3 Results

No egg laying was observed neither in FLOLIZ nor in control stations during the sampling period. A total of 43 observations of pike were recorded among which 39 corresponded to juveniles and 4 to adults (Fig. 2). In FLOLIZ, pike were observed in each year totalling 29 observations (2 adults and 27 juveniles). For the control stations, only 3 observations (1 adult and 2 juveniles) in the DCS and 11 observations (1 adult and 10 juveniles) in the NCS were made over the sampling period. The mean abundance of pike was significantly higher in FLOLIZ than in DCS over the whole sampling period (0.6 ± 2.2 in FLOLIZ and 0.07 ± 0.3 in DCS, P-value = 0.049) and also in spring (1.4 ± 3.3 in the FLOLIZ and 0.1 ± 0.3 in DCS, P-value = 0.037) Table 1. Abundances in NCS and DCS did not differ.

Two adults (total length > 700 mm) were observed in 2022 in two different FLOLIZ, one in May, just after the spawning season. By year, the minimum and maximum numbers of pike recorded were [2; 18] for FLOLIZ, [0; 1] for DCS and [0; 6] for NCS (Fig. 2). The maximum number observed in one station and during one sampling campaign was 14 in FLOLIZ, 5 in NCS and 1 in DCS. Individuals were mainly observed near the surface inside FLOLIZ, either hidden in the roots of helophytes or under floating wood branches (Fig. 3). In control stations, individuals were observed below the surface at a maximum depth of approximately 0.3 m, without any close physical structure. The smallest individuals (~15 mm-long) observed in FLOLIZ still had yolk sac. One hunting event of pike fry (~25 mm-long) was observed on cyprinid larvae (~15 mm-long) in FLOLIZ. The tail of the cyprinid larvae protrudes from the mouth of the juvenile pike (Fig. 3C).

4 Discussion

No previous study had investigated the effectiveness of artificial floating structure to support pike populations in reservoirs with high WLF. This study experimentally tested, for the first time, the attractiveness and effectiveness of a complex floating structure (3D design) as an alternative nursery for pike in reservoirs. From 2019 to 2023, we systematically observed juvenile pike in FLOLIZ but not in littoral control stations. Over the whole sampling period, a higher pike abundance was observed in FLOLIZ than in DCS, but not than in NCS; however, this was not verified in each year. This could strengthen a possible influence of FLOLIZ beyond its own area and illustrate its ability to support the population. The attractiveness of FLOLIZ could be related to the complexity and diversity of habitats they provide. Indeed, many studies have shown that early fish stages are highly dependent on complex habitats such as aquatic vegetation (Rozas and Odum, 1988; Grenouillet *et al.*, 2002; Weber and Brown, 2012; Massicotte *et al.*, 2015). Casselman and Lewis (1996) indicate that spawning habitats are less critical than macrophyte cover, which is more critical as a nursery habitat for juvenile pike. In particular, the aquatic vegetation offers to juvenile pike shelter from predators (Skov and Berg, 1999), including conspecifics (Craig, 2008). It also provides places to ambush zooplankton, macroinvertebrates and other fish (Nilsson *et al.*, 2023). In addition, food resources were available in FLOLIZ, with both a high abundance of macroinvertebrates (Salmon *et al.*, 2022) and cyprinid fry (Field Data). These refuge-nursery habitats enabled juvenile pike to grow, from roughly ~20 mm to ~60 mm from early May to end of June (Figs. 3A–3C), what enhances their chances of survival and recruitment (Rozas and Odum, 1988). As pike has been shown to exhibit natal homing and fidelity to spawning site (Miller *et al.*, 2001; Larsson *et al.*, 2015), individuals that have grown in FLOLIZ might return in FLOLIZ to spawn once they become mature. Although no egg laying was recorded, the observation of fixed pike larvae with yolk sac as well as mature adults makes very plausible that these larvae hatched in the FLOLIZ. Pike eggs are small (1.5 mm to 3 mm diameter), scattered in dense vegetation (Murry *et al.*, 2008), and hatch in about 10 days at this period (120 °C-days from Frost and Kipling, 1967), what makes them difficult to observe. Due to the complex habitats in FLOLIZ in which juvenile pike can easily hide, we can also reasonably suppose that the number of individuals has been under-estimated in comparison to control stations. As regards to the limited size of FLOLIZ compared to space requirements of pike spawning grounds (1500 m^2 according to Chancerel, 2003) and home range (Cook and Bergersen, 1988; Sandlund *et al.*, 2016) given in literature, they could probably host only a few adults and would be more adapted to sustain populations in small artificial lakes. Even though FLOLIZ area is relatively small, which could limit the number of spawners they can host, they offer suitable habitats for larvae and juvenile fish (up to 14 individuals observed simultaneously in a FLOLIZ). This could enhance recruitment that has been shown to be much more efficient than restocking to support populations (Skov *et al.*, 2011; Hühn *et al.*, 2014; Hühn *et al.*, 2023). Finally, even if further experiments in different contexts are needed, these results obtained over a five-year period give a promising insight in the effectiveness of FLOLIZ to provide functional refuge and nursery habitats for pike, which could have positive effects on populations in reservoirs or artificial lakes.

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