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Short-term responses of glass eels transported from UK to small Belgian streams

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Abstract – Restocking of inland waters with glass eels is one of the recovery options to prevent the decline of European eel *Anguilla anguilla* (L.) populations. We studied the growth, dispersion, density and habitat preferences in the imported glass eels from UK and stocked in three typologically different small Belgian streams, using electrofishing surveys around the single release point, 1 year following stocking. Our results clearly support that the recaptured individuals stocked in our streams farther from the sea, survived, grew, dispersed upstream and downstream. Elvers exploited the complete transversal section of stream, with preference for the sheltered microhabitats near the banks with slower water velocity and low depth. Length–weight relationship was different between streams in terms of allometric coefficient (*b*). We assume that microhabitats and food availabilities lead to contrasted results in terms of growth and absolute occurrence. Restocking of glass eels in small middle-land streams was found to be an interesting and unconventional option that requires adequate stream and habitat selection.

Key words: Glass eels / restocking / growth / habitat / dispersion / streams

Introduction

Since the 1970s, the European eel *Anguilla anguilla* (Linnaeus) stock has been declining at all stages of life and throughout its geographical distribution (larvae: Friedland *et al*., 2007; glass eels: Bonhommeau *et al*., 2008; elvers: Lobon-Cervia, 1999; yellow eels: Feunteun, 2002; Ibbotson *et al*., 2002; and silver eels: Bilotta *et al*., 2011). To stop this dramatic eel stock decline, the European Commission (EU) adopted a regulation obligating Member States to develop eel management plans (EU, 2007), with the objective for each river basin district to achieve the escapement to the sea of a biomass of silver eel equivalent to 40% of the best estimate in pristine conditions. One of the recovery options identified by the EU to fulfill the requirements is to test the restocking of inland waters connected to the sea with glass eels, elvers or yellow eels that are less than 120 mm in length.

Stocking is an old practice conducted in Germany since around 1900 (Walter, 1910; Lübbert, 1923) and later in other European countries (Moriarty and McCarthy, 1982; Andersson *et al*., 1991; Wickström *et al*., 1996; Simon and Dörner, 2014). Tributaries, lakes and ponds with low or no natural immigration have been stocked using glass eels and elvers caught in river estuaries (Walter, 1910; Müller, 1975; Klein-Breteler *et al*., 1990; Simon *et al*., 2009) and farm eels (Wickström *et al*., 1996; Pedersen, 1998, 2000, 2009; Simon *et al*., 2013). The annual length increases and survival rates in the stocked eels vary strongly between the stocking environments, the stocking materials (farm and glass eels), the stages (smaller and larger eels) and times after stocking (Bisgaard and Pedersen, 1991; Pedersen, 1998; Lin *et al*., 2007; Simon *et al*., 2013; Simon and Dörner, 2014). In stocked (Pedersen, 2009; Simon *et al*., 2013) and non-stocked (Naismith and Knights, 1990; Lambert *et al*., 1994) eels, the recapture rates improved with increasing age and size. In most studies, the combination of deep environments with the small size of glass eel make recaptures ineffective and complicate the monitoring of restocked individuals (Lambert *et al*., 1994), especially the first year after stocking. This results in a lack of knowledge on short-term adaptation of glass eel into their new environment. Surprisingly, middle-land small streams were never tested as an option for glass eel restocking though this life stage presents enormous phenotypic plasticity in variables such as diet and habitat use (Russel and Potter, 2003). Such diversification of the restocking environments may contribute to better

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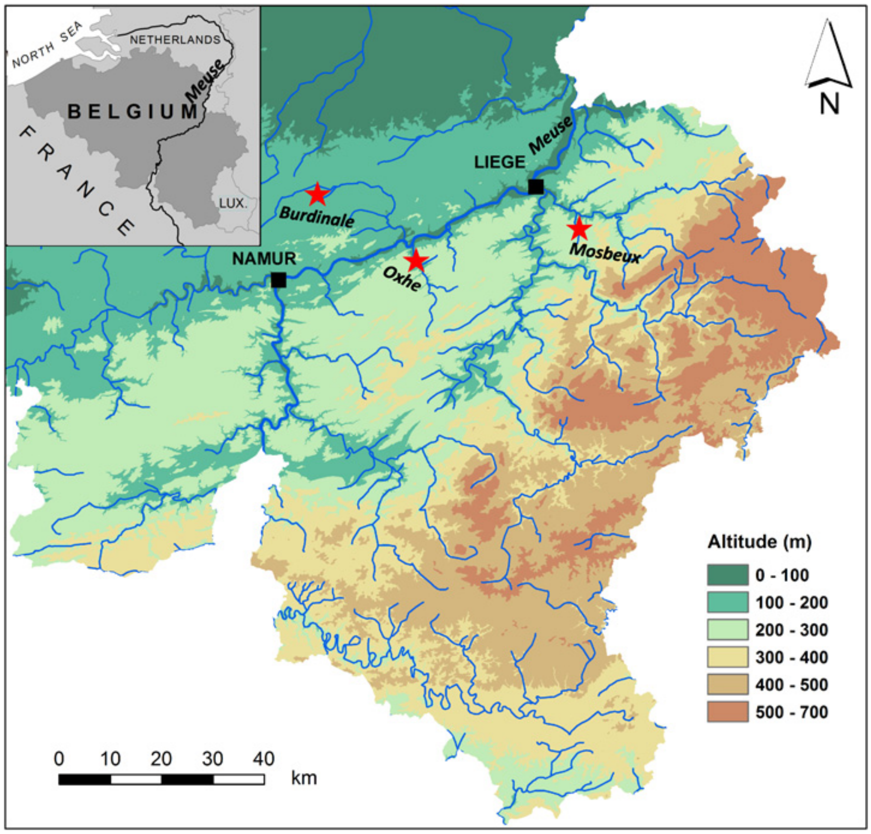

Fig. 1. The map of the location of the three small streams in the River Meuse Basin: Burdinale, Oxhe and Mosbeux, in southern Belgium.

understand the adaptive capacity of this life stage. Furthermore, the study of their microhabitats preferences in small streams may also provide helpful information to optimize restocking in larger and deeper environments.

In this study, glass eels imported from UK were used to directly restock three typologically different small Belgian streams located more than 350 km upstream of the North Sea. In order to test the hypothesis if restocking of glass eel in small streams is a future management option, this preliminary study aims to examine the short-term (1 year) responses of these translocated glass eels by studying their growth, habitat use, absolute occurrence and dispersion.

Materials and methods

Study areas

The study sites are located in the River Meuse basin in Belgium (Fig. 1), in three small streams, which have a longitudinal length less than 15 km and are located at a distance more than 350 km upstream of the Meuse estuary in the Netherlands (Fig. 1; Table 1). The Mosbeux, Oxhe and Burdinale rivers are typical of the trout zone (Huet, 1949) and were selected based on historical data revealing the past presence of resident eels (Philippart and Vranken, 1983). In Oxhe and Burdinale, the reference site is 400 m long and 260 m long in the Mosbeux due to the choice of a release point 40 m from the River Vesdre. In the Mosbeux, two small physical obstacles were located at +62 and +68 m, with difference in water level of 77 ± 14 and 95 ± 5 cm for the first and the second obstacle, respectively.

The fish biodiversity in the study sites (Table 1) varied from $n = 2$ to $n = 7$ with the bullhead *Cottus rhenanus* the most abundant species in the three streams. Resident eels with a total length of 55–75 cm were caught in both Burdinale (density, 0.005 eels m^{-1}) and Mosbeux (0.02 eels m^{-1}). Potential eel predators such as the brown trout *Salmo trutta* (Kennedy and Fitzmaurice, 1971) and the pike *Esox lucius* (Mann, 1982) were found in the three rivers (Table 1). The three streams and their surroundings were never restocked by glass eels before our study.

The microhabitat availability (substratum, coverage and water depth and velocity) was estimated in the reference sites during low-water regime before electrofishing surveys. The substrate was determined using the Wentworth size scale (Wentworth, 1922). The reference stretch in Mosbeux was heterogeneous with larger stones and blocks (Table 1). The coverage evaluated by identifying the covered (presence of riverine woodlands, aquatic plants and bridges) and uncovered areas in rivers varied from 30 to 80%. River widths ranged from 1.6 to 7.4 m, depths <65 cm and current velocity (Flo-Mate model 2000, Marsh-McBirney INC) < 1.4 m s^{-1}.

Table 1. Description of the three streams, the release point of the stocked glass eels and the fish community in the reference stretches. The bullhead *Cottus rhenanus*, the brown trout *Salmo trutta*, the loach *Barbatula barbatula*, the European eel *Anguilla anguilla*, the stickleback *Gasterosteus aculeatus*, the Eurasian minnow *Phoxinus phoxinus*, the young Atlantic salmon *Salmo salar*, the lamprey *Lampetra planeri* and the pike *Esox lucius*.

Description	Burdinale	Oxhe	Mosbeux
Characteristics of stream			
Direct tributary	Mehaigne	Meuse	Vesdre
Distance from the North Sea (km)	388.8	377	359.3
Length of stream (km)	12	12	7
Length of pilot stretch (km)	0.4	0.4	0.26
Predominant substratum (% of stretch)	Sands, silts or fine organic material (91%)	Fine and large stones (73%)	Large stones and blocks (60%)
Width in m: mean (range)	2.5 (1.6–3.5)	3.9* (2.4–6.5)	2.7 (1.8–7.4)
Coverage in %: mean (range)	80* (40–90)	30 (5–60)	33 (0–85)
Depth in cm: mean (range)	17.6 (1–60)	19.3 (2–65)	15.2 (2.5–65)
Velocity in m s^{-1}: mean (range)	0.2 (0–0.9)	0.3 (0–1.4)	0.3 (0–1.3)
The glass eel release point			
Altitude (m)	130	160	97
Distance from the River Meuse (km)	12.8	7.0	17.0
Distance from the stream mouth (km)	3.5	7	0.04
Number of stocked glass eels (kg)	6232 (1.5 kg)	6232 (1.5 kg)	4155 (1.0 kg)
Fish community			
Species (in decreasing order of importance)	Bullhead, stickleback, loach, eel, lamprey and pike	Bullhead and brown trout	Bullhead, brown trout, loach, eel, stickleback, Eurasian minnow and young Atlantic salmon
Brown trout 2–40 cm (number per m)	–	0.33	0.32
Resident eels 55–75 cm (number per m)	0.005	–	0.02
Electrofishing date in spring 2014			
First	April 1	April 4	March 31
Second	April 8	April 11	April 7

*$P < 0.05$, Kruskal–Wallis (KW) and Mann–Whitney (U) tests.

The water temperature (Onset® data loggers) was quite similar between the three streams in terms of the daily mean temperature (Mosbeux 9.8 °C, Oxhe 10.1 °C and Burdinale 10.4 °C). However, considering that the threshold temperature for active swimming is higher than 8 °C in glass eels (Gascuel, 1986; Dekker, 1998; Linton *et al.*, 2007) and elvers (Hvidsten, 1983; McGovern & McCarthy, 1992), the duration of the periods with the temperature above 8 °C was found to be relatively longer in Mosbeux (263 days of the 361 days with a daily mean temperature of 11.1 °C) than Burdinale (250 days, 12.7 °C) and Oxhe (239 days, 12 °C).

Stocking and post-stocking assessments

The wild glass eels that were stocked in the three small streams (May 22, 2013) were imported by plane from UK through a commercial eel trade company (UK Glass Eels Ltd, Gloucester, UK). They were captured by hand net in freshwater environment in UK and held several days in tanks before shipping. $N = 50$ individuals were measured (70 ± 3.5 mm) and weighed (0.26 ± 0.07 g) once arrived in Belgium. Pigmentation stages of these imported glass eels were generally dominated by stages VIA1-2 according to Elie *et al.* (1982). Burdinale and Oxhe were stocked with 1.5 kg of glass eel (approximately 6232 glass eels) and Mosbeux with 1.0 kg (approximately 4155 glass eels). The single point restocking sites (point "0") is located at variable distances from the stream mouth and sea due to accessibility for electrofishing (Table 1).

Samples of restocked eels were captured DC electrofishing (EFKO, 3.0 kVA) using landing nets measuring 40×40 cm in diameter with 2×2 mm mesh. During electrofishing campaigns, each captured elver was anesthetized (eugenol 1/10 in alcohol, 0.3 mL L^{-1}), measured (in mm) and weighed (in 0.01 g). During the first campaign, the eel were tagged with a visible implant elastomer (VIE) tag (Northwest Marine Technology Inc., Shaw Island, WA, USA) and released at the precise catch point. The VIE tag was injected into the transparent body part located at the posterior position to the genital papilla along the caudal fin (Imbert *et al.*, 2007), making it easy to distinguish the tagged and untagged elvers at the second campaign (as an indication of electric fishing efficiency).

The growth was studied in terms of the relation between the length and the weight and the length distribution in the three streams (Boulenger *et al.*, 2015).

The dispersion pattern was examined with respect to the longitudinal distance from release point 0, and laterally from the banks (left-bank, right-bank or middle of the stream).

To evaluate the microhabitat use, each individual catch was accompanied by the identification of the physical characteristics of its habitat (the substratum, coverage, water depth and velocity) considered as significant

Table 2. Results of the elvers caught at first and second electrofishing surveys in reference stretches of the three streams in spring 2014.

Stream	Glass eels stocked	Elvers caught/ tagged at first fishing, A	Elvers caught at second fishing, B	Tagged elvers caught at second fishing, C	Total number of elvers caught, A + B	Total of elvers caught (%)	Density (elver m^{-2})
Mosbeux	4155	25	74	5	99*	76.4*	0.134*
Burdinale	6232	8	11	1	19	14.6	0.018
Oxhe	6232	4	8	1	12	9.0	0.0071
Three streams	16 619	37	93	7	130	100	0.038

*$P < 0.0001$, Fisher Exact Probability (FEP) test.

Table 3. Descriptive statistics and estimated length–weight relationships of elvers for the three streams: sample size (*n*); confidence limits (95% CL); coefficient of determination (R^2); *P* value (*P*); intercept (*a*); slope (*b*).

Stream	*n*	Length range (mm)	Weight range (g)	*b*	95% CL of *b*	*A*	95% CL of *a*	R^2	*P*
Mosbeux	99	75–175	0.3–9.7	3.27	3.01–3.53	− 3.17	− 3.43 to − 2.91	0.866	< 0.01
Burdinale	19	77–175	0.5–6.9	3.02	2.51–3.53	− 2.88	− 3.39 to − 2.37	0.901	< 0.00001
Oxhe	12	76–103	0.5–1.3	2.53	2.00–3.06	− 2.46	− 2.96 to − 1.96	0.919	< 0.00001
All	130	75–175	0.3–9.7	3.12	2.98–3.41	− 3.09	− 3.31 to − 2.88	0.871	< 0.01

variables for eel (Laffaille *et al.*, 2004). For each physical characteristic, the microhabitat use was examined in terms of utilization rates (UR, the proportion of elvers in a specific physical characteristic), the preference index (PI, the UR divided by availability, *i.e.,* the proportion of the same physical characteristic in the reference stretch) and the body length distribution.

Data analysis

To check the significant differences in the length of elver body size between dispersion patterns and between habitat uses, the preference index of elvers for microhabitats and the physical characteristics of habitats within and between streams, a Kruskal–Wallis (KW) test was performed and followed when necessary by a Mann–Whitney (U) test for multiple paired comparisons. The availability and utilization of elver microhabitats, the proportions of elvers caught and the proportions of elvers by dispersion patterns were examined using the Fisher Exact Probability (FEP) test. The comparisons of longitudinal and lateral dispersion patterns in elvers for each stream were examined using the chi square (χ^2) test. The linear regression was used to test the relationship between the length and the weight of the elvers caught. The length–weight relationships were calculated using the equation $P = a \times Lt^b$ and logarithmically transformed into $\log_{10}(P) = \log_{10}(a) + \log_{10}(Lt)$, where *P* and Lt are, respectively, the body weight in grams and total length in centimeters, *a* is a coefficient relative to body form, and *b* the allometric coefficient indicating isometric growth when equal to 3.0 (Froese, 2006). For all statistical analyses, the significance level was set at $P < 0.05$.

Results

Catch and growth of elvers

$N = 37$ elvers were caught and tagged at the first electric fishing in the three streams. During the second capture event, 93 elvers were caught, including 7 recaptured elvers, varying from $n = 1$ (Burdinale and Oxhe) to $n = 5$ (Mosbeux). Between streams, Mosbeux showed higher number and density of elvers caught than Burdinale and Oxhe (Table 2).

The 130 caught elvers ranged from 75 to 175 mm (median of 92 mm) (Table 3). The values of *b* and *a* in the length–weight relationships differed between streams, with the allometric coefficient (*b)* that indicates faster growth in weight than in length in the Mosbeux ($b = 3.27$), slower growth in weight than in length in the Oxhe ($b = 2.53$) and an isometric growth in the Burdinale ($b = 3.02$).

Longitudinal and lateral dispersion

The profile of the longitudinal dispersion of the 130 elvers caught showed an almost complete occupation of the reference stretches in the three streams, from + 155 m to − 192 m (Table 4). The longitudinal profile of the elver dispersion varied between streams. Mosbeux having two small physical obstacles showed elvers less dispersed (90% on a stretch 81 m long, 66% over 49 m from the release point to a site downstream of the foot of the first obstacle) than in the two other streams. A longer distance of the maximum elver dispersion was observed in Oxhe.

The lateral dispersion profile of elvers was similar in the three streams (Table 4). The elvers exploited a complete

Table 4. Longitudinal and lateral dispersions of elvers for the three streams from late March to April 2014. Values of dispersion distance in the column or lateral dispersion in each stream with a common superscript do not differ significantly (χ^2, $P < 0.05$).

		Longitudinal dispersion from the release point of glass eels (m)		Lateral dispersion (%)		
Stream	*n*	Range (distance)	90% (distance)	Left-bank	Right-bank	Middle of stream
Mosbeux	99	+ 155 to − 48 (203^a)	+ 58 to − 23 (81^a)	52.5^b	42.4^b	5.1^a
Burdinale	19	+ 143 to − 112 (255^b)	+ 80 to − 101 (181^c)	47.4^a	31.6^a	21.0^a
Oxhe	12	+ 144 to − 192 (336^c)	+ 144 to − 5 (149^b)	58.4^b	33.3^{ab}	8.3^a
All	130	+ 155 to − 192 (347)	+ 144 to − 101 (245)	52.8	35.8	11.4

transversal section of the streams, with higher occurrence near the banks (88.6% of the 130 elvers) than in the middle of streams (11.4%) ($\chi^2 = 153.85$, $P < 0.0001$). In each stream, longitudinal and lateral dispersion patterns did not significantly affect the growth of elvers (KW test, $P > 0.05$).

Habitat use

The three streams showed similar preference of elvers for habitat use. The sediment, vegetation and stones were the most widely used substrates (Fig. 2(a)). The concrete of the bridges was used in Burdinale with a higher preference index, but this substratum was much less available. The sheltered zones by the bridges and riparian woodlands were significantly preferred by elvers (Fig. 2(b)). Similarly, greater preference of elvers for shallow areas with water depth < 22 cm was observed than deeper areas > 22 cm (Fig. 2(c)). Elvers exploited more areas with slower water velocity < 0.2 m s^{-1} than those with water velocity > 0.2 m s^{-1} (Fig. 2(d)). However, the exploitation of a specific habitat by elvers in each stream did not significantly impact their growth (KW test, $P > 0.05$).

Discussion

The glass eels imported and immediately stocked in middle-land streams survived, grew, dispersed upstream and downstream and exploited the complete transversal profile of the stream, with preference for the sheltered microhabitats with low water velocity and shallow areas mostly located on the banks. All the recapture individuals were in good health with no external signs of diseases.

The low recapture rate is a general problem on glass eel studies (Simon and Dörner, 2014) and the catch rate rises with increasing age and size (Naismith and Knights, 1990; Lambert *et al.*, 1994; Simon *et al.*, 2013). The number of stocked glass eels recaptured by electrofishing 1 year following stocking at elver stage was low in the three streams probably due to this issue of small amount of glass eel stocked, the size of the individuals (median length, 9 cm) and the low efficiency of electric fishing for this life stage. Nevertheless, such qualitative precocious monitoring is important to better understand the stocking process and glass eel adaptations. The dispersion outside our limited study site probably occurred by swimming with and against the current or passive migration by flooding rather than only higher natural mortality (Beaulaton and Castelnaud, 2005; Bureau du Colombier *et al.*, 2009). Considering the migration rate of elvers to be 0.64 km per day observed in non-tidal rivers (White and Knights, 1997), some individuals in the stocked young eels in the three streams may leave the reference stretches in just 1 day, as already noted by Pedersen (2009). In our study, the choice of a single release point was adopted to increase precision on dispersion pattern, as the quantities of restocked eels were quite limited. But this practice may have increased dispersal by density dependence mechanism and maybe, by extension, raise the mortality rate. The observation of bi-directional movements is an important point demonstrating that despite their capture during the beginning of the colonization phase, the glass eel restocked in middle-land streams exploited the available habitats in both directions. The ontogenetic colonization of the larger rivers in the hydraulic network may thus also operate from upstream to downstream.

The use of electric fishing in our small streams was feasible but more complicated and tedious and less effective than with traditional species, not making possible the extension of the study area and a rigorous approach of the survival rate. However, the higher absolute recapture rate was observed in the Mosbeux River, despite its lower stocking rate, suggesting a lower mortality rate in this stream. The higher availability of microhabitats observed in Mosbeux such as underbanks; large substratum; crevices between rocks, stones and roots; and sheltered areas may have played a major role and provided higher protection to earlier-stage eels with cryptic behavior which prefer to hide in quiet and shallow areas, as also suggested by Pedersen (2009). Likewise, organic effluent discharges from domestic sources observed in this stream, as well as a longer time period with temperature $> 8\,°$C may have favored the accessibility of various food resources as well as the development of several live preys, All these observations probably explain the better absolute efficiency observed in Mosbeux, showing the major importance of the habitat's carrying capacity in stream selection during the restocking practices as well as the importance of both eel density and stream typology. In Danish river system, (Pedersen 2009) reported that the disappearance rate of elvers including emigration and natural mortality raise with increasing the stocking density. For Huertas and Cerda (2006), differences in eel density may lead to different life strategies such as territorial, gregarious and less active fish for elvers maintained at a low surface density versus active

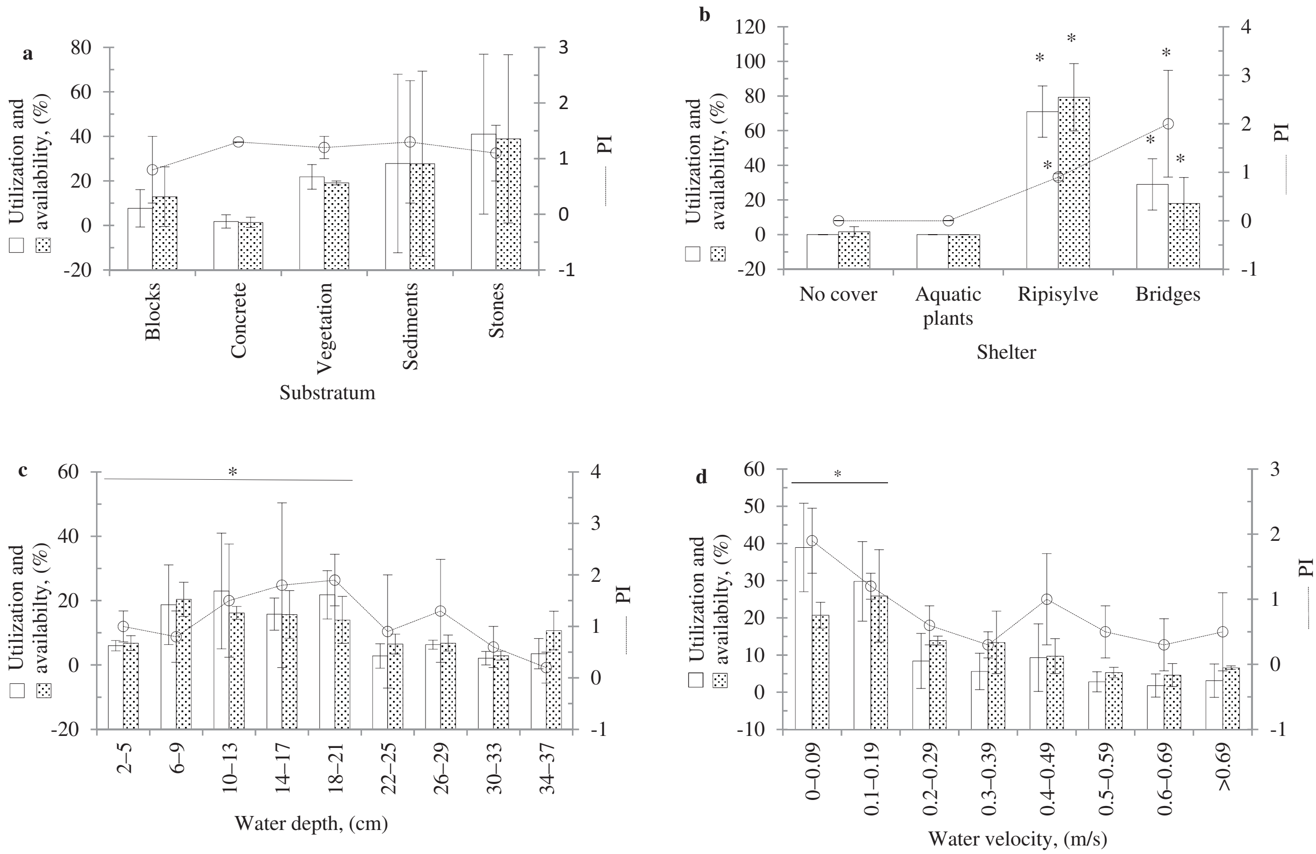

Fig. 2. The preference index of elvers for habitats in the three combined streams: substratum (a), shelter (b), water depth (c) and velocity (d). $*P < 0.05$, FEP test for availability in streams for habitats used by elvers and utilization of habitats by elvers and KW and U tests for the preference index of elvers for habitats. Concrete means footings of concrete bridge. Mean and standard deviation of the three streams; $n = 99$, 19 and 12 elvers for Mosbeux, Burdinale and Oxhe, respectively. Abbreviations: FEP, Fisher Exact Probability; KW, Kruskal–Wallis; U, Mann–Whitney.

swimmer individuals enhancing aggressive behavior and stimulating the intake of food for elvers kept at high density. The higher utilization of banks observed during the study may be related to the more readily available microhabitats offering many potential shelters and shallow areas with slower flow, which provide optimal living conditions in terms of bioenergetics and the maximum efficiency in food intake, as well as protection against predators, as it was also observed at the yellow eel stage (Ovidio *et al.*, 2013). This behavior in the earlier eel stage may be regarded as a tradeoff between the foraging needs and the vulnerability to predation of these young eels with limited swimming performance and a morphology similar to earthworms, making them an important food item for many predators such as piscivorous birds (Žydelis and Kontautas, 2008) as well as other fish such as intercohort conspecifics (Jessop, 2000) and heterospecifics (Kennedy and Fitzmaurice, 1971; Mann, 1982). In such contexts, rivers should be stocked by spreading the young-stage eels in shallow zones with available shelters along the banks, which may be a serious management option to improve the success of eel survival in terms of conservation.

From the median size of 7 cm in the stocked wild glass eels, the annual median growth of the elvers in this study was 2.2 cm per year, but with an important individual variability (range: 0.5–10.5 cm per year). These observed growth rates were comparable with those found in lake and larger river environments (Bisgaard and Pedersen, 1991; Pedersen, 2000). In a small eutrophic Danish lake, the mean length increase of 3.6–5.1 cm (range, 0.9–7.1 cm) per year was observed 6–8 years post-stocking (Pedersen, 2000) versus 2.3–9.3 cm per year in four German lakes 1 year after stocking. Bisgaard and Pedersen (1991) reported eels growing 2–5 cm a year in a Danish stream. The reasonable growth performance observed may be a signal of the food availability, and therefore the restocked streams, may be considered as suitable growth habitats for the stocked early eel developmental stage. Considering that the observed slopes and intercepts in the length–weight relationships of elvers were significantly different using separate stream datasets, this could demonstrate the differences in body condition between streams. Elvers in Mosbeux showed a better growth in weight than in length. In contrast, elvers in Oxhe showed a better growth in length than in weight, probably because of the low food resource availability.

The lack of a significant difference in growth between the elvers caught upstream of the migrating obstacles on the Mosbeux and the growth of elvers captured downstream may indicate that some individuals in the young stage of this species in a novel habitat condition are able to display greater upstream migratory activity and a greater ability to ascend barriers independent of body size. As a consequence, although the size of elvers may be a good indicator of the energetic status (shorter elvers being lighter), the density dependence in this eel species is probably the only plausible explanation for the climbing behavior observed. In agreement with Huertas and Cerda (2006), higher density in the elvers observed downstream of obstacles would have made elvers more active swimmers seeking a novel growth area. The density-dependence argument rather than energetic status is also supported by the lack of difference in growth between individuals upstream and downstream of the release site.

This study provides insight into the typology of microhabitats and macrohabitats likely to be stocked using the earlier eel life stage caught near estuaries and immediately released in streams to enhance the local eel populations. Stocking in small middle-land (Alt. 97–160 m) streams results growth rates comparable with those found in lakes, suggesting that such open environment is a potential stocking option in countries or regions farther from the sea, whose upstream populations have declined after the escapement of the last silver eels. In order to affirm that such practice is ecologically beneficial, an estimation of the survival rate at longer time scale (> 2 years) with a better electric fishing efficiency will be the next step of our researches. The ecological interest of such practice should be considered because the glass eels restocked in small streams probably suffer less piscivorous predation. However, once they become silver eel they will migrate over longer distances downstream to reach the sea, which may cause delays and mortality (Verbiest *et al.*, 2012). Another point to consider further is the impact of such restocking practices in upper rivers on the future sexual differentiation of the restocked individuals (Geffroy and Bardonnet, 2015).

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References

Andersson J., Sandström O. and Hansen H.J.M., 1991. Elver (*Anguilla anguilla* L.) restockings in a Swedish thermal effluent – recaptures, growth and body conditions. *J. Appl. Ichthyol.*, *7*, 78–89.

Beaulaton L. and Castelnaud G., 2005. The efficiency of selective tidal stream transport in glass eel entering the Gironde (France). *Bull. Fr. Pêche Piscic*, *378–379*, 5–21.

Bilotta G.S., Sibley P., Hateley J. and Don A., 2011. The decline of the European eel *Anguilla anguilla*: quantifying and managing escapement to support conservation. *J. Fish Biol.*, *78*, 23–38.

Bisgaard J. and Pedersen M.I., 1991. Mortality and growth of wild and introduced cultured eels *Anguilla anguilla* (L.) in a Danish stream, with special reference to a new tagging technique. *Dana*, *9*, 57–69.

Bonhommeau S., Chassot E. and Rivot E., 2008. Fluctuations in European eel (*Anguilla anguilla*) recruitment resulting from environmental changes in the Sargasso Sea. *Fish. Oceanogr.*, *74*, 1891–1914.

Boulenger C., Acou A., Trancart T., Crivelli A.J. and Feunteun E., 2015. Length-weight relationships of the silver European eel, *Anguilla anguilla* (Linnaeus, 1758), accross its greographic range. *J. Appl. Ichthyol.*, *31*, 427–430.

Bureau du Colombier S., Bolliet V. and Bardonnet A., 2009. Swimming activity and behavior of European *Anguilla anguilla* glass eels in response to photoperiod and flow reversal and the role of energy status. *J. Fish Biol.*, *74*, 2002–2013.

Dekker W., 1998. Long-term trend in the glass eels immigrating at Den Oever, The Netherland. *B. Fr. Peche Pisc.*, *349*, 199–214.

Elie P., Lecomte-Finiger R., Cantrelle I. and Charlon N., 1982. Définition des limites des différents stades pigmentaires durant la phase civelle d'Anguilla anguilla (L.). *Vie Milieu*, *32*(3), 149–157.

EU, 2007. Establishing measures for the recovery of the stock of European eel. Council regulation (EC) No 1100/207 of 18 September 2007. *O. J. E. U.*, *248*, 17–23.

Feunteun E., 2002. Management and restoration of European eel population (*Anguilla anguilla*): an impossible bargain. *Ecol. Eng.*, *18*, 575–591.

Friedland K.D., Miller M.J. and Knights B., 2007. Oceanic changes in the Sargasso Sea and declines in recruitment of the European eel. *ICES J. Mar. Sci.*, *64*, 519–530.

Froese R., 2006. Cube law, condition factor and weight–length relationships: history, meta-analysis and recommendations. *J. Appl. Ichthyol.*, *22*, 241–253.

Gascuel D., 1986. Flow carried and swimming migration of the glass eel (*Anguilla anguilla*) in the tidal area of a small estuary on the French Atlantic coast. *Helgoläender Meeresun*, *40*, 321–326.

Geffroy B. and Bardonnet A., 2015. Sex differentiation and sex determination in eels: consequences for management. *Fish Fish.*, doi:10.1111/faf.12113.

Huertas M. and Cerda J., 2006. Stocking density at early developmental stages affects growth and sex ratio in the European eel (*Anguilla Anguilla*). *Biol. Bull.*, *211*, 286–296.

Huet M., 1949. Aperçu de la relation entre la pente et les populations piscicoles des eaux courantes. *Schweiz. Z. Hydrol.*, *11*, 332–351.

Hvidsten N.A., 1983. Ascent of elvers (*Anguilla anguilla*) in the stream Imsa Norway. *Rep. Inst. Freshw. Res.*, *62*, 71–74.

Ibbotson A., Smith J., Scarlett P. and Aprahamian M.W., 2002. Colonisation of freshwater habitats by the European eel. *Anguilla anguilla*. *Freshw. Biol.*, *47*, 1696–1706.

Imbert H., Beaulaton L., Rigaud C. and Elie P., 2007. Evaluation of visible implant elastomer as a method for tagging small European eels. *J. Fish Biol.*, *71*, 1546–1554.

Jessop B.M., 2000. Estimates of population size and instream mortality rate of American eel elvers in a Nova Scotia River. *T. Am. Fish. Soc.*, *129*, 514–526.

Kennedy M. and Fitzmaurice P., 1971. Growth and food of brown Trout *Salmo trutta* (L.) in Irish waters. *P. Roy. Irish Acad. B.*, *71*, 269–352.

Klein-Breteler J.G.P., Dekker W. and Laminens E.H.R.R., 1990. Growth and production of yellow eels and glass eels in ponds. *Int. Revue Ges. Hydrobiol.*, *75*, 189–205.

Laffaille P., Baisez A., Rigaug C. and Feunteun E., 2004. Habitat preferences of different European eel size classes in a reclaimed marsh: a contribution to species and ecosystem conservation. *Wetlands*, *24*, 642–651.

Lambert P., Feunteun E. and Rigaud C., 1994. Eel study in freshwater marshes. First analysis of catch probability observed during electric fishing operations. *Bull. Fr. Pêche Piscic.*, *335*, 111–122.

Lin Y.-J., Lozys L., Shiao J.-C., Iizuka Y. and Tzeng W.-N., 2007. Growth differences between naturally recruited and stocked European eel *Anguilla anguilla* from different habitats in Lithuania. *J. Fish Biol.*, *71*, 1773–1787.

Linton E.D., Jonsson B. and Noakes D., 2007. Effect of water temperature on the swimming and climbing behaviour of glass eels, *Anguilla* spp. *Environ. Biol. Fish.*, *78*, 189–192.

Lobon-Cervia J., 1999. The decline of eel *Anguilla anguilla* (L.) in a river catchment of northern Spain 1986–1997. Further evidence for a critical status of eel in Iberian waters. *Arch. Hydrobiol.*, *144*, 245–253.

Lübbert H., 1923. Der Aufstieg von Glasaalen in der Elbe im Jahre 1923. *Allg. Fisch. Ztg.*, *48*, 107–108 (in German).

Mann R.H.K., 1982. The annual food consumption and prey preferences of pike (*Esox lucius*) in the River Frome, Dorset. *J. Anim. Ecol.*, *51*, 81–95.

McGovern P. and McCarthy T.K., 1992. Elver migration in the river Corrib system, western Ireland. *Ir. Fish. Investig.*, *36*, 25–32.

Moriarty C. and McCarthy D., 1982. *Eel*. In: European Inland Fisheries Advisory Commission, ed. Report of the Symposium on stock enhancement in the management of freshwater Fisheries. *EIFAC Technical Paper No*. 42. pp. 3–6.

Müller H., 1975. *Die Aale*, A. Ziemsen Verlag, Wittenberg, Germany, p. 200 (in German).

Naismith I.A. and Knights B., 1990. Studies of sampling methods and of techniques for estimating populations of eels. *Anguilla anguilla* L. *Aquac. Res.*, *21*, 357–367.

Ovidio M., Seredynski A., Philippart J.C. and Nzau Matondo B., 2013. A bit of quiet between the migrations: the resting life of the European eel during their freshwater growth phase in a small stream. *Aquat. Ecol.*, *17*, 291–301.

Pedersen M.I., 1998. Recapture rate, growth and sex of stocked cultured eels *Anguilla anguilla* (L.). *Bull. Fr. Pêche Piscic.*, *71*, 153–162.

Pedersen M.I., 2000. Long-term survival and growth of stocked eel, *Anguilla anguilla* (L.), in a small eutrophic lake. *Dana*, *12*, 71–76.

Pedersen M.I., 2009. Does Stocking of Danish lowland streams with Elvers increase European Eel Populations? *Am. Fish Soc. Symp.*, *58*, 149–156.

Philippart J.-C. and Vranken M., 1983. Atlas des poissons de Wallonie. Distribution, écologie, éthologie, pêche, conservation. *Cah. Ethol. Appl.*, *3*, 55–61.

Russel I.C. and Potter E.C.E., 2003. Implications of the precautionary approach for the management of the European eel, *Anguilla anguilla*. *Fisheries Manag. Ecol.*, *10*, 395–401.

Simon J. and Dörner H., 2014. Survival and growth of European eels stocked as glass- and farm-sourced eels in five lakes in the first years after stocking. *Ecol. Fresh. Fish*, *23*, 40–48.

Simon J., Dörner H. and Richter C., 2009. Growth and mortality of European glass eel *Anguilla anguilla* marked with oxytetracycline and alizarin red. *J. Fish Biol.*, *74*, 289–295.

Simon J., Dörner H., Scott R.D., Schreckenbach K. and Knösche R., 2013. Comparison of growth and condition of European eels stocked as glass and farm sourced eels in lakes in the first four years after stocking. *J. Appl. Ichthyol.*, *29*, 323–330.

Verbiest H., Breukelaar A., Ovidio M., Philippart J.C. and Belpaire C., 2012. Escapement success and patterns of downstream migration of female silver eel *Anguilla anguilla* in the River Meuse. *Ecol. Freshw. Fish*, *21*, 395–403.

Walter E., 1910. Der Flußaal, eine biologische und fischwirtschaftliche Monographie, Verlag J. Neumann, Neudamm, Germany, p. 346 (in German).

Wentworth, C.K., 1922. A scale of grade and class terms for clastic sediments. *J. Geol., 30*, 377–392.

White E.M. and Knights B., 1997. Dynamics of upstream migration of the European eel *Anguilla anguilla* (L.), in the Rivers Severn and Avon, England, with special reference to the effects of man-made barriers. *Fish. Manage. Ecol.*, *4*, 311–324.

Wickström H., Westin L. and Clevestam P., 1996. The biological and economic yield from a long-term eel stocking expetiment. *Ecol. Freshw. Fish*, *5*, 140–147.

Žydelis R. and Kontautas A., 2008. Piscivorous birds as top predators and fishery competitors in the lagoon ecosystem. *Hydrobiologia*, *611*, 45–54.