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The use of native piscivorous fishes for the eradication of the invasive Chinese Sleeper, *Perccottus glenii*

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Abstract – The chief aim of invasive species management is to prevent biological invasions by taking measures for suppressing or eradicating potential invaders. Biological control as a management tool is frequently implemented to reduce the population size, adverse ecological impacts, and dispersal of invasive species. The efficacy of biological control measures in managing the *Perccottus glenii* population was assessed in four small lakes of Lithuania. The biocontrol was carried out by introducing the native piscivorous fishes *Esox lucius* and *Perca fluviatilis* into the invaded water bodies for two successive reproductive seasons. The stocking of these fishes led to an instant reduction in *P. glenii* abundances, and the outcome of the repeated stocking was complete disappearance of the species from the water bodies investigated. Our study proves that native predator fishes can be successfully used for eradicating well-established *P. glenii* populations in small eutrophic lakes. We hope the current study results will contribute to developing risk-commensurate methodologies for the control of invasive *P. glenii* populations in small water bodies.

Keywords: biological control / fish community / invasion management / *Perca fluviatilis* / *Esox lucius*

Résumé – L'utilisation de poissons piscivores indigènes pour l'éradication du dormeur chinois envahissant, *Perccottus glenii*. L'objectif principal de la gestion des espèces envahissantes est de prévenir les invasions biologiques en prenant des mesures pour supprimer ou éradiquer les envahisseurs potentiels. La lutte biologique en tant qu'outil de gestion est souvent mise en œuvre pour réduire la taille des populations, les impacts écologiques négatifs et la dispersion des espèces envahissantes. L'efficacité des mesures de lutte biologique dans la gestion de la population de *Perccottus glenii* a été évaluée dans quatre petits lacs de Lituanie. Le biocontrôle a été effectué en introduisant les poissons piscivores indigènes *Esox lucius* et *Perca fluviatilis* dans les plans d'eau envahis pendant deux saisons successives de reproduction. L'empoissonnement de ces espèces a entraîné une réduction instantanée de l'abondance de *P. glenii*, et l'empoissonnement répété a entraîné la disparition complète de l'espèce des plans d'eau étudiés. Notre étude prouve que les poissons prédateurs indigènes peuvent être utilisés avec succès pour éradiquer les populations bien établies de *P. glenii* dans les petits lacs eutrophes. Nous espérons que les résultats de l'étude actuelle contribueront à l'élaboration de méthodologies adaptées au risque pour le contrôle des populations invasives de *P. glenii* dans les petits plans d'eau.

Mots-clés : lutte biologique / communauté de poissons / gestion des invasions / *Perca fluviatilis* / *Esox lucius*

1 Introduction

In Europe, the Chinese Sleeper *Perccottus glenii*, Dybowski, 1877, has been recognized as a highly invasive fish species since its first introduction from East Asia in 1912 (Reshetnikov, 2004). The ongoing species invasion is probably the outcome of deliberate and non-deliberate stocking, which is thought to be facilitated by *P. glenii* opportunism, flexible life-history characteristics, and aggressive behaviour as well as by its ability to survive in degraded environmental conditions (Ćaleta *et al.*, 2011; Reshetnikov and Ficetola, 2011). The ability of *P. glenii* to effectively use trophic resources ranging from ciliates to vertebrates (Reshetnikov, 2003; Koščo *et al.*, 2008; Grabowska *et al.*, 2009; Kati *et al.*, 2015) coupled with the prolonged reproductive period allows the coexistence of

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Table 1. Characteristics of studied lakes: coordinates, surface area (*S*); mean depth (*H*); maximal depth (H_{max}); dissolved oxygen at 1 m depth (February) (DO).

Lakes	Latitude, N	Longitude, E	*S* (ha)	*H* (m)	H_{max} (m)	DO (mg/L)	
						2010	2013
Beržuvis	26.1905100	55.1671831	11.7	1.4	2.2	0.1	0.6
Bevardis	25.0470127	54.6469167	3.6	1.5	2.3	0.1	0.3
Cirkliškis	26.1471849	55.1203970	1.1	1.3	2.4	0.2	0.4
Stūgliai	26.2205717	55.1803079	2.7	1.6	2.1	0.8	1.3

Table 2. Dates of piscivorous fish stocking into bioregulated lakes in 2013–2014 and numbers of the piscivorous fish individuals stocked. Age of the stocked fish: 0+: one-summer-old fish; 1+: two-summer-old fish; etc.

Lake	Date	*E. lucius* (ind./ha)	*P. fluviatilis* (ind./ha)
Beržuvis	2013.10.04	0+ (600)	2+–5+ (250)
	2014.10.02	0+ (300)	2+–5+ (125)
Bevardis	2014.10.11	0+ (300)	2+–5+ (125)
	2015.10.04	0+ (300)	2+–5+ (125)
Cirkliškis	2013.10.21	1+ (200)	–
	2014.04.25	1 (100)	–
Stūgliai	2013.10.21	0+ (600)	–
	2014.10.09	0+ (250)	2+–5+ (125)

individuals of multiple sizes. The species is able to escape competition and predation by inhabiting water bodies unsuitable for most other freshwater fishes in Northern Europe. It has been suggested that isolated water bodies with abundant macrophytes, thick mud layer and repetitive oxygen-deficit events are the optimal habitat for this species (Jurajda *et al.*, 2006; Reshetnikov and Chibilev, 2009). Furthermore, *P. glenii* dramatically affects invaded communities by reducing diversity of local macroinvertebrate, amphibian and fish species (Reshetnikov, 2003), thus eventually affecting functioning of the whole ecosystem (Reshetnikov, 2013). Disease transmission and facultative parasitism cause additional concern (Kvach *et al.*, 2013, 2016; Sokolov *et al.*, 2014).

The current research into *P. glenii* invasion biology is primarily focused on the elucidation of threats and the underlying mechanism of species invasions rather than on provision of sustainable and practical solutions for management of this invasive species (Grabowska *et al.*, 2011; Reshetnikov and Ficetola, 2011; Nehring and Steinhof, 2015). Besides preventive measures, such as trade legislation, there is a need for effective methods for the eradication or suppression of local *P. glenii* populations and the hold-up of their further establishment and wider dispersal in Europe (Nehring and Steinhof, 2015). So far, only a limited number of programmes for *P. glenii* eradication, mainly involving the use of chemical methods (Reshetnikov and Ficetola, 2011), have been reported.

The objective of this study was to investigate the potential of native piscivorous fishes, such as the Northern pike *Esox lucius* Linnaeus, 1758, and the European perch *Perca fluviatilis* Linnaeus, 1758, to eradicate or suppress populations of *P. glenii* in small eutrophic lakes.

2 Materials and methods

2.1 Study site

Biocontrol experiments were performed in 2012–2017 in natural lakes Beržuvis, Bevardis, Cirkliškis and Stūgliai pond, located in eastern Lithuania. All the water bodies studied are similar in their physical characteristics: they are all shallow, have a thick (> 3 m) sediment (sapropel) layer and the littoral zone that is densely overgrown with macrophytes. All the four water bodies are subjected to irregular oxygen depletion events during prolonged ice cover (Tab. 1).

The first official record of *P. glenni* in Lake Bevardis (as well as in Lithuania) dates back to 1986 (Virbickas, 2000). According to anglers, the presence of *P. glenni* in the other water bodies studied was recorded before 2000 (personal communication). The preliminary analysis performed in 2010 showed that already at that time the species was well established in the water bodies surveyed and dominant in their fish communities. At that time *Perccottus glenii* constituted 66–95% of the total fish number in all the water bodies investigated (more than 300 ind./100 m^2).

2.2 Biocontrol

Lakes were repeatedly stocked in the spring or autumn of 2013, 2014 and 2015. The stocking material was provided by local fish farms. The largest numbers of *E. lucius* and *P. fluviatilis* specimens per unit area were stocked into Lake Beržuvis, followed by those into Bevardis and Stūgliai. Lake Cirkliškis was stocked only with *E. lucius*, the number of stocked fish individuals per unit area being the smallest among the lakes studied (Tab. 2). According to piscivorous fish stocking dates, the whole study period was subdivided into the following three periods: pre-stocking (2012–2013), transitional (2014–2015), and post-stocking (2017) periods.

2.3 Analysis of fish communities

The composition of fish communities was investigated during the vegetation season in 2012–2015, and in 2017. Fish were sampled using battery-powered electric fishing gear

(Samus Special Electronics, Samus-725 mp). Electric fishing using the same gear and fishing mode was performed from a boat in the water depth range of 0.2–2.0 m. For catch per unit of effort (CPUE), 10 min of actual operational electrofishing was applied. All fish were identified to species level and counted. Pursuant to state fishing laws and sampling licensing, after sampling, all native fish were released into the same water bodies, except for the representative number of *E. lucius* and *P. fluviatilis* specimens from Lake Beržuvis, which were intended for diet analysis, and all non-indigenous *P. glenii*. All fish were killed by overdosing on anaesthetics (1.5–2.0 $mL \cdot L^{-1}$ solution of 2-phenoxyethanol for 5 min).

The total number and weight were determined for the *P. glenii* specimens caught per each unit of effort (CPUE), whereas the total body length (TL) and age were assessed only for fish specimens from representative sub-samples (up to 30 specimens per each CPUE). The age of *P. glenii* specimens was estimated from scales (Thoresson, 1993). In addition, we measured TL (to the nearest mm) and body weight (to the nearest 0.1 g) of all the *E. lucius* and *P. fluviatilis* specimens intended for diet analysis. All fish sampling and examination procedures were carried out in strict accordance with regulations of the Republic of Lithuania. The fish taxonomy used in the present study follows the one provided in FishBase (Froese and Pauly, 2018).

2.4 Analysis of piscivorous fish diet

Analysis of the piscivorous fish diet was carried out on fish individuals sampled from Lake Beržuvis during the transitional period (2014–2015) of piscivorous fish stocking. Piscivorous fish from standardized catches, *i.e.* *E. lucius* ($n = 28$, $TL = 33.0 \pm 10.3$) and large-sized individuals of *P. fluviatilis* ($n = 8$, $TL = 19.6 \pm 0.8$), were subjected to gut content analysis. Stomachs of selected fish were removed and preserved in 10% formaldehyde solution until examination in the laboratory. Stomach contents were weighed to the nearest 0.1 mg using an electronic balance (ABJ 120-4M, Kern and Sohn GmbH) to obtain wet weight. Then food items were extracted, identified, grouped and again wet-weighed, their proportions in weight of the total gut content being assessed.

2.5 Statistical analyses

Non-parametric Mann-Whitney U-tests were used to test for differences in the numbers of fish species sampled during biocontrol periods. As the data obtained did not meet the normality assumption for parametric methods (Shapiro-Wilk's tests, $P < 0.05$), we used non-parametric tests. The analyses were performed using STATISTICA 12.0 software. The significance level of $P < 0.05$ was specified for all statistical analyses *a priori*.

3 Results

3.1 Pre-stocking period

Before the piscivorous fish stocking, fish assemblages in the studied lakes were poor in terms of species richness and consisted of two or three species (Tab. 3). The mean number of fish per standard CPUE ranged from 39.3 to 138.9. *Perccottus glenii* dominated fish assemblages in all the lakes studied, on average accounting for 80.9–97.7% of total fish communities. The total body length of the sampled *P. glenii* specimens ranged from 3.2 to 26.0 cm (0+–11+ year old). The mean number of *P. glenii* specimens per CPUE varied from 31.8 to 135.7 ind. and their body weight from 17.2 to 22.1 g (Tabs. 3 and 4). Meanwhile, the total catch of other fish species accounted for less than 20% of the total pre-stocking fish catch in all the lakes studied (Tab. 3).

Table 3. Catch per unit of effort (CPUE) of different fish species in studied water bodies during 2012–2017 (mean ± SD): pre-stocking period 2012–2013 (Pre), transitional period 2014–2015 (Transitional), and post-stocking period 2017 (Post).

Fish species	Pre	Transitional	Post
Beržuvis			
C. gibelio	1.1 ± 1.3	3.5 ± 6.2*	–
E. lucius	–	2.5 ± 2.0	3.7 ± 0.6
L. delineatus	8.7 ± 15.3	113.1 ± 125.4	–
P. fluviatilis	–	54.9 ± 72.5	–
P. glenii	68.4 ± 34.1	1.5 ± 2.1*	–
R. rutilus	–	0.1 ± 0.3	–
T. tinca	–	0.1 ± 0.3	–
Total	77.9 ± 32.7	175.7 ± 182.8	3.7 ± 0.6*
CPUE *n*	**10**	**11**	**4**
Bevardis			
C. gibelio	12.6 ± 8.2	1.7 ± 2.5*	51.7 ± 85.2
E. lucius	–	2.0 ± 1.4	4.7 ± 1.2
P. fluviatilis	–	0.3 ± 0.5	55.0 ± 51.7
P. glenii	94.0 ± 33.8	48.2 ± 48.2	–
Total	106.6 ± 36.1	52.2 ± 49.8	111.3 ± 129.9
CPUE *n*	**9**	**9**	**3**
Cirkliškis			
C. gibelio	–	0.2 ± 0.4	–
E. lucius	–	0.1 ± 0.3	1.0 ± 1.0
L. delineatus	2.5 ± 2.5	–	355.3 ± 327.4*
P. glenii	135.7 ± 30.0	42.5 ± 37.4*	7.0 ± 3.6*
C. carassius	0.7 ± 1.2	0.3 ± 0.6	–
Total	138.9 ± 28.8	43.0 ± 37.0*	363.3 ± 325.6
CPUE *n*	**3**	**11**	**3**
Stūgliai			
C. gibelio	2.3 ± 1.3	2.4 ± 3.5	2.3 ± 1.0
E. lucius	–	1.3 ± 1.1	1.0 ± 0.8
L. delineatus	5.3 ± 6.4	192.8 ± 190.1*	404.0 ± 11.4*
P. fluviatilis	–	1.0 ± 1.6	0.5 ± 0.6
P. glenii	31.8 ± 19.4	6.8 ± 10.2*	–
Total	39.3 ± 13.6	204.3 ± 197.6	407.8 ± 12.4*
CPUE *n*	**4**	**11**	**4**

Note: Numbers of performed CPUE in each water body are given in bold (CPUE *n*).
* Significant value changes (Mann-Whitney U test, $P < 0.05$) compared to the pre-stocking period.

3.2 Transitional period

In the transitional biocontrol period, the mean number of *P. glenii* per standard CPUE decreased significantly in all the water bodies studied except one, ranging from 1.5 to

Table 4. Metrics of *Perccottus glenii* populations in studied water bodies during 2012–2017: pre-stocking period 2012–2013 (Pre), transitional period 2014–2015 (Transitional), and post-stocking period 2017 (Post).

Population metrics	Pre	Transitional	Post
Beržuvis			
Abundance, %	87.8	0.9	0.0
TL max, cm	26.0	14.1	–
Age, min–max	0+–11+	0+–4+	–
Mean weight, g	18.5 ± 36.9	8.1 ± 9.3	–
Bevardis			
Abundance, %	88.2	92.3	0.0
TL max, cm	24.5	15.9	–
Age, min–max	0+–10+	0+–4+	–
Mean weight, g	22.1 ± 28.3	10.7 ± 12.1	–
Cirkliškis			
Abundance, %	97.7	98.8	1.9
TL max, cm	22.2	17.9	18.0
Age, min–max	0+–9+	0+–5+	0+–5+
Mean weight, g	20.7 ± 25.2	5.11 ± 10.8	16.0 ± 27.2
Stūgliai			
Abundance, %	80.9	3.3	0.0
TL max, cm	20.2	20.9	–
Age, min–max	0+–7+	0+–7+	–
Mean weight, g	17.2 ± 14.2	28.4 ± 32.7	–

42.5 ind. (Tab. 3) (Figs. 1A, 1C and 1D). *P. glenii* numbers per standard CPUE in Lake Bevardis also declined (from 94.0 ± 33.8 ind. in the pre-stocking period to 48.2 ± 48.2 ind. in the transitional biocontrol period (Fig. 1B), but this change was not significant (Mann-Whitney U test: $Z = 1.86$, $P = 0.06$). Overall, all *P. glenii* populations underwent drastic changes as the mean body weight of *P. glenii* per standard CPUE remarkably decreased. The average body weight of *P. glenii* decreased more than two-fold ranging from 5.1 to 10.7 g in all the water bodies studied except one. In Stūgliai pond, the mean body weight of *P. glenii* specimens was found to increase from 17.2 g in the pre-stocking period to 28.4 g in the transitional biocontrol period (Tab. 4). The change observed in the maximum length and age of the captured *P. glenii* specimens followed the same pattern. After piscivorous fish stocking, both characteristics markedly decreased in the lakes studied; meanwhile in Stūgliai pond, they remained similar (Tab. 4). Overall, although suppressed, *P. glenii* populations were still dominant in Bevardis and Cirkliškis lakes. Meanwhile, fish assemblages of the other studied water bodies (Tab. 3) were dominated by belica *Leucaspius delineatus* (Heckel, 1843).

Total fish numbers per CPUE remained unchanged during the transitional period in all the water bodies studied except Lake Cirkliškis (Tab. 3). After *E. lucius* stocking into this lake, the mean fish number per CPUE sharply decreased, from 138.9 ± 28.8 ind. in the pre-stocking period to 43.0 ± 37.0 ind. in the transitional biocontrol period (Mann-Whitney U test: $Z = 2.57$, $P = 0.010$). The number of fish species increased in all the lakes and ranged from four to seven species.

3.3 Post-stocking period

After the biocontrol period, the number of species in fish assemblages of the studied lakes dropped and was comparable with that in the pre-stocking period (Tab. 3). In the post-stocking period, *P. glenii* disappeared from the investigated fish assemblages in most cases, suggesting that the biocontrol process was successful (Tab. 3). However, *P. glenii* remained in the fish catches landed from Lake Cirkliškis, though significantly reduced (1.9% of a total fish catch) compared with the pre-stocking period (Mann-Whitney U test: $Z = 1.96$, $P = 0.04$) (Fig. 1C). The surviving *P. glenii* specimens remained in this lake and reached the age of maturity. The largest specimens reached up to 18.0 cm in length and were 5+ year old (Tab. 4). Overall, in the post-stocking period, native species dominated fish assemblages in all the lakes studied, but fish community diversity remained poor.

3.4 Piscivorous fish diet

The diet analysis of *E. lucius* and large-sized *P. fluviatilis* specimens (TL > 17 cm) showed that small *P. fluviatilis* (TL < 5 cm), constituting more than 47 and 63% of the diet of piscivorous *E. lucius* and *P. fluviatilis*, respectively, were the dominant prey item. *Leucaspius delineatus* made up a substantial part (38%) of *E. lucius* diet, but was not found in the diet of *P. fluviatilis*. Surprisingly, only 14.3% of all the analysed *E. lucius* specimens consumed *P. glenii*. The contribution of *P. glenii* to the diet of *E. lucius* reached only 14%. On the contrary, its share in the diet of *P. fluviatilis* was significant and constituted 38%, as 37.5% of the analysed *P. fluviatilis* specimens consumed *P. glenii*. Additionally, larvae of dragonfly (Odonata) constituted 0.7% of the *E. lucius* diet, meanwhile only two prey-species (*P. glenii* and *P. fluviatilis*) were found in the diet of *P. fluviatilis*.

4 Discussion

The development of effective management programmes for invasive species control is a challenge currently facing invasion biology (Hulme, 2006, 2009). Despite some important initiatives, the geographical expansion of *P. glenii* is still continuing and there is an urgent need for cost-efficient strategies for containing, suppressing or eradicating *P. glenii* populations (Nehring and Steinhof, 2015). The native piscivorous fish stocking experiment carried out on a lake level during our study proved effectiveness of piscivorous fish in controlling *P. glenii* populations. Within a four-year period of biocontrol measures' implementation, the initially abundant populations of *P. glenii* were eradicated in three of the studied water bodies and highly suppressed in one of them.

During the transitional period, the number of *P. glenii* individuals decreased 2–46 fold. Only small-sized *P. glenii* specimens remained in dense vegetation, while elder (> 5+ year old) individuals were eradicated during the first year of biocontrol implementation in all the lakes except one. After four years of biocontrol implementation, *P. glenii* was no longer recorded in CPUEs in the studied lakes, except for Lake Cirkliškis, where the population of *P. glenii* was strongly suppressed, but not eradicated. It should be pointed out that

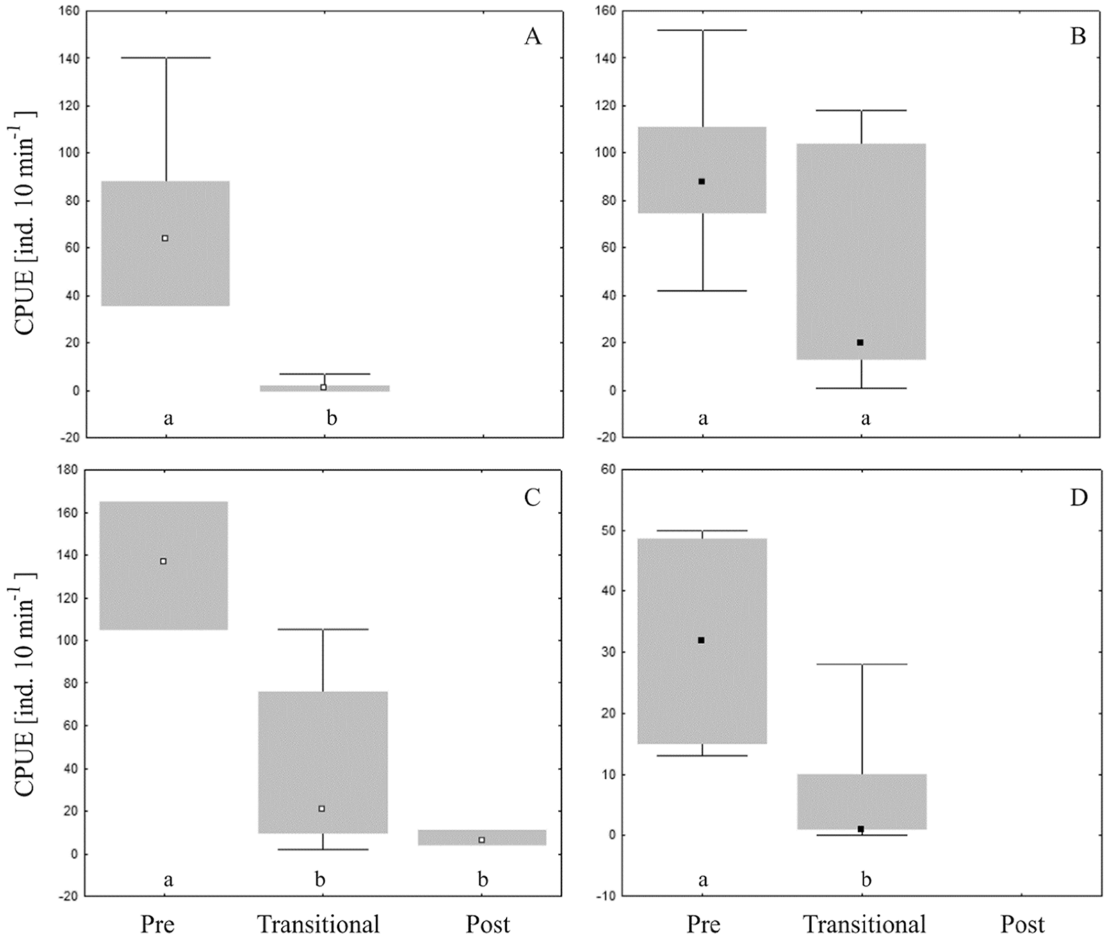

Fig. 1. Catch per unit of effort (CPUE) of *Perccottus glenii* in lakes Beržuvis (A), Bevardis (B), Cirkliškis (C), and Stūgliai (D) studied before (Pre: 2012–2013), during (Transitional: 2014–2015), and after (Post: 2017) the implementation of biocontrol measures, *i.e.* the introduction of native piscivorous fish species (median, quartiles, range). Small letters (a, b) denote homogeneous groups according to Mann-Whitney U tests.

this lake was stocked only with *E. lucius*, and fish stocking numbers per unit area were the lowest among all the lakes studied (see Tab. 2).

The analysis of piscivorous fish diet in Lake Beržuvis showed that the contribution of *P. glenii* to the diet of *E. lucius* was unexpectedly low, but it constituted a substantial part of the diet of large-sized *P. fluviatilis* specimens. This fact somehow contradicts the findings obtained in other studies, showing that *P. glenii* may be preferable prey for *E. lucius* (Litvinov and O'Gorman, 1996; Telcean and Cicort-Lucaciu, 2016), whereas the ability of *P. fluviatilis* to regulate the abundance of *P. glenii* has not been studied yet. The existing sparse data indicate that *P. fluviatilis* is capable of preying on *P. glenii* although its share in perch diet is trivial, (Litvinov and O'Gorman, 1996; Didenko and Gurbyk, 2016; Mérö, 2016). According to our observations, *P. fluviatilis* alone is not capable of eradicating *P. glenii*, which is proved by the fact that in several lakes of Lithuania, both species have been coexisting for decades (unpublished data).

The low number of *P. glenii* in the diet of *E. lucius* may be attributed to the time lag between the first predatory fish stocking and their diet analysis. The average share of *P. glenii* in the total fish catch during the piscivorous fish diet sampling was only 0.1%. This fact indicates that the majority of *P. glenii* individuals had been already consumed by that time. The surviving small-sized *P. glenii* specimens were possibly suppressed by large-sized individuals of *E. lucius* in a very shallow littoral zone overgrown with dense macrophytes, *i.e.* in the habitats where large-sized *E. lucius* cannot easily hunt due to the limited space for ambush-type predation (Pers. observation). Apparently, piscivorous *P. fluviatilis* were still able to prey on small-sized *P. glenii* individuals in shallow waters overgrown with macrophytes, while larger individuals of *E. lucius* switched to feeding on *L. delineatus* and *P. fluviatilis* in open waters.

Overall, *E. lucius* and *P. fluviatilis* are predators with pronounced opportunism and feeding plasticity. Both species consume the prey that is available, easy to catch and is suitable as food owing to its size (Rakauskas *et al.*, 2010; Pedreschi *et al.*, 2015). Unfortunately, to date, there is no information on how selective *E. lucius* and *P. fluviatilis* are in their predation on *P. glenii*, and to what extent these predators display preference for feeding on *P. glenii* compared with other prey-fish species. Owing to the specific structure of its snout and larger body size, *E. lucius* should be better at controlling larger *P. glenii* specimens, while *P. fluviatilis* has proved to be able to effectively prey on small *P. glenii* individuals. Predating strategies of these two species also differ. *E. lucius* usually stays in solitude and relies on ambush predation (Harper and Blake, 1991; Eklöv, 1992), while *P. fluviatilis* actively seeks for prey and hunts in a group (Eklöv, 1992; Turesson and Brönmark, 2004). Therefore, the use of these both predators simultaneously produced the best biocontrol effect and might be an explanation, why the eradication of *P. glenii* in Lake Cirkliškis, stocked solely with *E. lucius*, was not successful.

The results of the present biocontrol experiment provide evidence that the native piscivorous fish *E. lucius* and *P. fluviatilis* can strongly contribute to the effective suppression of invasive *P. glenii*, at least on a scale of small eutrophic shallow lakes. In comparison with eradication programmes involving the use of chemical biocides and other direct measures such as netting, electrofishing or draining of habitats, the reintroduction of native piscivorous fish species is a feasible, cost-effective, uncontroversial, and sustainable management approach. The use of fish as biocontrol agents has generally been applied for managing mosquitoes (Martinez-Ibarra *et al.*, 2002; Pyke, 2008), invasions of non-native crayfishes (Musseau *et al.*, 2015), or invasions of non-indigenous amphibians (Louette, 2012). Previous studies have also shown that *E. lucius* and *P. fluviatilis* can negatively affect populations of the invasive stone moroko *Pseudorasbora parva* (Temminck and Schlegel, 1846), reducing its abundance and biomass, without affecting native species (Davies and Britton, 2015; Lemmens *et al.*, 2015). However, there are no reports on large-scale biocontrol programmes that have successfully utilized piscivorous fish to suppress the invasion of *P. glenii* populations (Britton *et al.*, 2011). Furthermore, extensive understanding of how to enhance and manage *E. lucius* populations, given the longstanding tradition of pike stocking in the restoration of shallow ponds and lakes, is available (Skov and Nilsson, 2007; Jeppesen *et al.*, 2012). Results of this study show that there is a considerable potential for suppressing populations of small, invasive fishes such as *P. glenii*. Although such biocontrol action is less immediate than fish removals, it has the potential benefit of negligible long-term management costs. Therefore, we believe that stocking of *E. lucius* and *P. fluviatilis* can be a valuable measure in specific cases, *e.g.* when the aim is to eradicate populations of invasive *P. glenii* in small eutrophic lakes.

However, the possibility of a strong effect on a local fish assemblage should also be considered. The experiments performed revealed that the local fish community of Lake Beržuvis, which was initially strongly unbalanced by *P. glenii* invasion, was finally exterminated as a result of piscivorous fish stocking in the fourth year of biocontrol implementation. It is worth noting that Lake Beržuvis was stocked with the largest number of predators. However, it remains unclear, whether it was the result of mass-stocking of predators or the outcome of the oxygen depletion observed at the end of the winter in 2016.

5 Concluding remarks

The current study suggests that both *E. lucius* and *P. fluviatilis* should be stocked in order to completely exterminate *P. glenii*. These species are able to forage on different-sized prey (different gape size limitation). *Esox lucius* shows a tendency to prey on larger-sized *P. glenii* specimens, while *P. fluviatilis* tends to forage on small *P. glenii* individuals in very shallows waters. Piscivorous fish should be stocked annually, at least for several successive years, so as to avoid the possible impact of unpredictable winter oxygen depletion events or other impacts that may significantly reduce abundance of stocked fish and their predation effect on *P. glenii* populations. In addition, permanent stocking for several successive years should help to prevent maturation and reproduction of the surviving *P. glenii* individuals, which usually occurs in the 2nd or 3rd year of their life, when TL reaches 6–8 cm (Froese and Pauly, 2018). To extend the period of predation on *P. glenii* and to reduce losses of stocked fish in the case of unpredictable winter oxygen depletion, it seems more expedient to carry out piscivorous fish stocking in Northern Europe countries in spring. Introduction of a large amount of piscivorous fish into *P. glenii*-invaded lakes might also lead to undesirable consequences for native fish assemblages. It is known that invaded communities, especially those with a low species diversity, are more susceptible to any kind of alterations. Stocked piscivorous fish may either increase the species richness of top predators or replace the local ones. This can cause additional predation pressure on native fish communities, increasing top-down effects (Eby *et al.*, 2006). Our results indicate that after such intense native piscivorous fish stocking, fish communities remain unbalanced and species diversity therein is low. Thus on completion of biocontrol actions, it may be necessary to restock fish assemblages with the native species that are suitable for such habitats.

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References

Britton JR, Gozlan RE, Copp GH. 2011. Managing non-native fish in the environment. *Fish Fish* 12: 256–274.

Ćaleta M, Jeli D, Buj I, Zanella D, Marčić Z, Mustafić P, Mrakovčić M. 2011. First record of the alien invasive species rotan (*Perccottus glenii* Dybowski, 1877) in Croatia. *J Appl Ichthyol* 27: 146–147.

Davies GD, Britton JR. 2015. Assessing the efficacy and ecology of biocontrol and biomanipulation for managing invasive pest fish. *J Appl Ecol* 52: 1264–1273.

Didenko AV, Gurbyk AB. 2016. Spring diet and trophic relationships between piscivorous fishes in Kaniv Reservoir (Ukraine). *Folia Zool* 65: 15–26.

Eby LA, Roach WJ, Crowder LB, Stanford JA. 2006. Effects of stocking-up freshwater food webs. *Trends Ecol Evol* 21: 576–584.

Eklöv P. 1992. Group foraging versus solitary foraging efficiency in piscivorous predators: The perch, *Perca fluviatilis*, and pike, *Esox lucius*, patterns. *Anim Behav* 44: 313–326.

Froese R, Pauly D. 2018. FishBase. World Wide Web electronics publication. Available from www.fishbase.org, version (02/2018).

Grabowska J, Grabowski M, Pietraszewski D, Gmur J. 2009. Non-selective predator – The versatile diet of Amur sleeper (*Perccottus glenii* Dybowski, 1877) in the Vistula River (Poland), a newly invaded ecosystem. *J Appl Ichthyol* 25: 451–459.

Grabowska J, Pietraszewski D, Przybylski M, Tarkan A, Marszał L, Lampart-Kałuzniacka M. 2011. Life-history traits of Amur sleeper, *Perccottus glenii*, in the invaded Vistula River: Early investment in reproduction but reduced growth rate. *Hydrobiologia* 661: 197–210.

Harper DG, Blake RW. 1991. Prey capture and the fast-start performance of northern pike *Esox lucius*. *J Exp Biol* 155: 175–192.

Hulme PE. 2006. Beyond control: Wider implications for the management of biological invasions. *J Appl Ecol* 43: 835–847.

Hulme PE. 2009. Trade, transport and trouble: Managing invasive species pathways in an era of globalization. *J Appl Ecol* 46: 10–18.

Jeppesen E, Søndergaard M, Lauridsen TL, Davidson TA, Liu Z, Mazzeo N, Trochine C, Özkan K, Jensen HS, Trolle D. 2012. Biomanipulation as a restoration tool to combat eutrophication: Recent advances and future challenges. *Adv Ecol Res* 47: 411–487.

Jurajda P, Vassilev M, Polacik M, Trichkova T. 2006. A first record of *Perccottus glenii* (Perciformes: Odontobutidae) in the River Danube in Bulgaria. *Acta Zool Bulgar* 58: 279–282.

Kati S, Mozsár A, Árva D, Cozma NJ, Czeglédi I, Antal L, Nagy SA, Erős T. 2015. Feeding ecology of the invasive Amur sleeper (*Perccottus glenii* Dybowski, 1877) in Central Europe. *Int Rev Hydrobiol* 100: 116–128.

Koščo J, Manko P, Miklisová D, Košuthová L. 2008. Feeding ecology of invasive *Perccottus glenii* (Perciformes, Odontobutidae) in Slovakia. *Czech J Anim Sci* 53: 479–486.

Kvach Y, Drobiniak O, Kutsokon Y, Hoch I. 2013. The parasites of the invasive Chinese sleeper *Perccottus glenii* (Fam. Odontobutidae), with the first report of *Nippotaenia mogurndae* in Ukraine. *Knowl Manag Aquat Ecosyst* 409: 05.

Kvach Y, Kutsokon Y, Stepien CA, Markovych M. 2016. Role of the invasive Chinese sleeper *Perccottus glenii* Dybowski 1877 (Actinopterygii: Odontobutidae) in the distribution of fish parasites in Europe: New data and a review. *Biologia* 71: 941–951.

Lemmens P, Mergay J, Vanhove T, De Meester L, Declerck SAJ. 2015. Suppression of invasive topmouth gudgeon *Pseudorasbora parva* by native pike *Esox lucius* in ponds. *Aquat Conserv* 25: 41–48.

Litvinov AG, O'Gorman R. 1996. Biology of amur sleeper (*Perccottus glenii*) in the delta of the Selenga River, Buryatia, Russia. *J Gt Lakes Res* 22: 370–378.

Louette G. 2012. Use of a native predator for the control of an invasive amphibian. *Wildl Res* 39: 271–278.

Martinez-Ibarra JA, Grant-Guillen JI, Arredondo-Jimenez JI, Rodriguez-Lopez MH. 2002. Indigenous fish species for the control of *Aedes aegypti* in water storage tank in Southern Mexico. *Biocontrol* 47: 481–486.

Mérö TO. 2016. The first record in central Europe of the alien invasive rotan, Perccottus glenii, in the diet of the European perch Perca fluviatilis. *Nat Croat* 25: 155–157.

Musseau C, Boulenger C, Crivelli AJ, Lebel I, Pascal M, Bouletreau S, Santoul F. 2015. Native European eels as a potential biological control for invasive crayfish. *Freshw Biol* 60: 636–645.

Nehring S, Steinhof J. 2015. First records of the invasive Amur sleeper, *Perccottus glenii* Dybowski, 1877 in German freshwaters: A need for realization of effective management measures to stop the invasion. *BioInvasions Rec* 4: 223–232.

Pedreschi D, Mariani S, Coughlan J, Voigt CC, O'Grady M, Caffrey J, Kelly-Quinn M. 2015. Trophic flexibility and opportunism in pike *Esox lucius*. *J Fish Biol* 87: 876–894.

Pyke GH. 2008. Plague minnow or mosquito fish? A review of the biology and impacts of introduced Gambusia species. *Annu Rev Ecol Evol S* 39: 171–191.

Rakauskas V, Smilgevičienė S, Arbačiauskas K. 2010. The impact of introduced Ponto-Caspian amphipods and mysids on perch (*Perca fluviatilis)* diet in Lithuanian lakes. *Acta Zool Lit* 20: 189–197.

Reshetnikov AN. 2003. The introduced fish, rotan (*Perccottus glenii*), depresses populations of aquatic animals (macroinvertebrates, amphibians, and fish). *Hydrobiologia* 510: 83–90.

Reshetnikov AN. 2004. The fish *Perccottus glenii*: History of introduction to western regions of Eurasia. *Hydrobiologia* 522: 349–350.

Reshetnikov AN. 2013. Spatio-temporal dynamics of the expansion of rotan *Perccottus glenii* from West Ukrainian centre of distribution and consequences for European freshwater ecosystems. *Aquat Invasions* 8: 193–206.

Reshetnikov AN, Chibilev EA. 2009. Distribution of the fish rotan (*Perccottus glenii* Dybowski, 1877) in the Irtysh River basin and analysis of possible consequences for environment and people. *Contemp Probl Ecol* 2: 224–228.

Reshetnikov AN, Ficetola GF. 2011. Potential range of the invasive fish rotan (*Perccottus glenii*) in the Holarctic. *Biol Invasions* 13: 2967–2980.

Skov C, Nilsson PA. 2007. Evaluating stocking of YOY pike *Esox lucius* as a tool in the restoration of shallow lakes. *Freshw Biol* 52: 1834–1845.

Sokolov SG, Reshetnikov AN, Protasova EN. 2014. A checklist of parasites in non-native populations of rotan *Perccottus glenii* Dybowski, 1877 (Odontobutidae). *J Appl Ichthyol* 30: 574–596.

Telcean I, Cicort-Lucaciu A. 2016. Messages of invasive *Perccottus glenii* individuals eaten by an *Esox lucius* from the Danube Delta. *J Fish* 4: 435–438.

Thoresson G. 1993. Guidelines for Coastal Monitoring. Kustrapport 1. Öregrund, Sweden: National Board of Fisheries, Institute of Coastal Research.

Turesson H, Brönmark C. 2004. Foraging behaviour and capture success in perch, pikeperch and pike and the effects of prey density. *J Fish Biol* 65: 363–375.

Virbickas J. 2000. Lietuvos žuvys (Fishes of Lithuania). Vilnius, Lithuania: Ekologijos institutas.

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