BioInvasions Records (2023) Volume 12, Issue 2: 625–636

Research Article

Alien prey in the diet of the indigenous Eurasian otter in Vistula River, Poland

Lidia Orłowska[1] and Jerzy Romanowski[2,*]

[1]*Institute of Biology, Pedagogical University of Cracow, Podchorążych Street 2, 30-084 Cracow, Poland*
[2]*Institute of Biological Sciences, Cardinal Stefan Wyszyński University, Wóycickiego 1/3, 01-938 Warsaw, Poland*
**Corresponding author*
E-mail: *j.romanowski@uksw.edu.pl*

Citation: Orłowska L, Romanowski J, (2023) Alien prey in the diet of the indigenous Eurasian otter in Vistula River, Poland. *BioInvasions Records* 12(2): 625–636, https://doi.org/10.3391/bir.2023.12.2.25

Received: 19 February 2022
Accepted: 30 October 2022
Published: 27 February 2023

Handling editor: Philippe Thibault
Thematic editor: April Blakeslee

Abstract

Several non-native fish species were recorded in the studies of Eurasian otter *Lutra lutra* diet in south European and English rivers. To document the role of alien species as a prey of this aquatic top predator in central Europe, the diet of the otter was studied by spraint analysis in the Vistula, a large European river. Fresh spraints were collected at the study site in central Poland from 2012 to 2016, and in south Poland in 2015. At both sites, fish were the staple food of otters, constituting over 90% of prey consumed. The food niche breadth of otters was relatively high. Among 20 fish species registered in the diet, there were four alien species: prussian carp *Carassius gibelio*, common carp *Cyprinus carpio*, topmouth gudgeon *Pseudorasbora parva,* and round goby *Neogobius melanostomus*. Besides alien fish species, the invasive spiny cheek crayfish *Orconectes limosus* was present in the diet of otters at both localities. Altogether, the five invasive species constituted a large proportion of the diet of otters at both sites (over 30%). According to the literature data and results of this study, at least 18 non-native fish species were preyed on by otters in Europe. It is suggested that alien prey will constitute an increasing fraction of the diet of the indigenous Eurasian otter.

Key words: predation, seminatural rivers, biological invasions, *Lutra lutra, Neogobius melanostomus, Orconectes limosus, Pseudorasbora parva*

Introduction

Biological invasions are considered a major threat to biological diversity (Simberloff 2011). Most studies focus on the negative effects of alien species on native species and communities. However, the interactions of non-native species in new ecosystems are more complex and involve long-term direct and indirect impacts (Pyšek et al. 2020). Invasive alien species can transmit parasites, affect the behavior of native animals and modify trophic networks, e.g., by becoming the prey of indigenous predators (Canning-Clode 2016).

There are currently around 14,000 alien species (including more than half originating from outside territories) in Europe and their number is constantly growing (Roy et al. 2019). Among these species, there are those whose presence in the aquatic habitats is particularly unfavorable for native fauna and flora (Vilà et al. 2010). Inland aquatic habitats are considered

one of the most vulnerable to biological invasions (Gherardi 2007). Out of over 160 alien fish species (Teletchea and Beisel 2018), 32 species have been identified as established in Europe (Sultana and Hashim 2016). Among 37 alien fish species in freshwater habitats of Poland most came from North and South America (14 species), and East Asia including Siberia (11 species). Among them, 26 species have acclimatized and formed established populations (Witkowski and Grabowska 2012).

In the last decades, several alien fish invaded the drainage area of the Vistula River, the largest river in Poland. Round goby *Neogobius melanostomus* (Pallas, 1814), was first documented in Zatoka Gdańska in 1990 (Skóra and Stolarski 1993; Skora and Rzeznik 2001; Corkum et al. 2004), and after ten years the species was reported 130 km upstream in the Vistula River (Głowaciński et al. 2011). Topmouth gudgeon (stone morocco) *Pseudorasbora parva* (Temminck & Schlegel, 1846) was first recorded in fishponds and rivers in western and southern Poland in the 1990s (Wisniowska 1996; Witkowski 2011). Amur sleeper *Perccottus glenii* Dybowski, 1877 was introduced to Poland around 1993 and inhabits lower and middle Vistula River including oxbows and various aquatic habitats in the river valley (Terlecki and Pałka 1999; Nowak et al. 2008). Prussian carp *Carassius gibelio* (Bloch, 1782) invaded many aquatic habitats in the whole of Poland since the 19th century (Holcik 1980). Freshwater systems in Poland were additionally invaded by the spiny cheek crayfish *Orconectes limosus* (Rafinesque, 1817) of American origin, that entirely displaced native crayfish in the Vistula River (Szaniawska et al. 2017).

Otters are top predators of aquatic ecosystems. The Eurasian otter is widespread in Poland and recent surveys documented the expansion of its population in the central part of the country. There, the species inhabits numerous aquatic habitats, e.g., Vistula River, large and small rivers, lakes, fishponds, and regulated channels (Brzeziński et al. 1996; Romanowski 2006; Romanowski et al. 2013). Eurasian otters prey on various fish species and other, mostly aquatic animals including amphibians, crustaceans, birds, and mammals (Erlinge 1967; Chanin 1981; Jędrzejewska et al. 2001; Krawczyk et al. 2016). They are opportunistic fish predators, and usually consume various species of fish proportionally to their occurrence. The variation in diet composition depends mainly on habitat. When availability of fish is low, otters shift their diet primarily to amphibians, and, secondarily, to birds and mammals (Jędrzejewska et al. 2001). Several non-native fish species play a role as prey of otters, with the common carp *Cyprinus carpio* Linnaeus, 1758 being the widely known example. This species forms about 20% of the otter diet at fish ponds in central Europe (Kloskowski 1999). Several other non-native fish species, including *Lepomis gibbosus* (Linnaeus, 1758), and *Carassius auratus* (Linnaeus, 1758) were recorded in the studies of otter diet in south European and English rivers (Blanco-Garrido et al. 2008; Miranda et al. 2008).

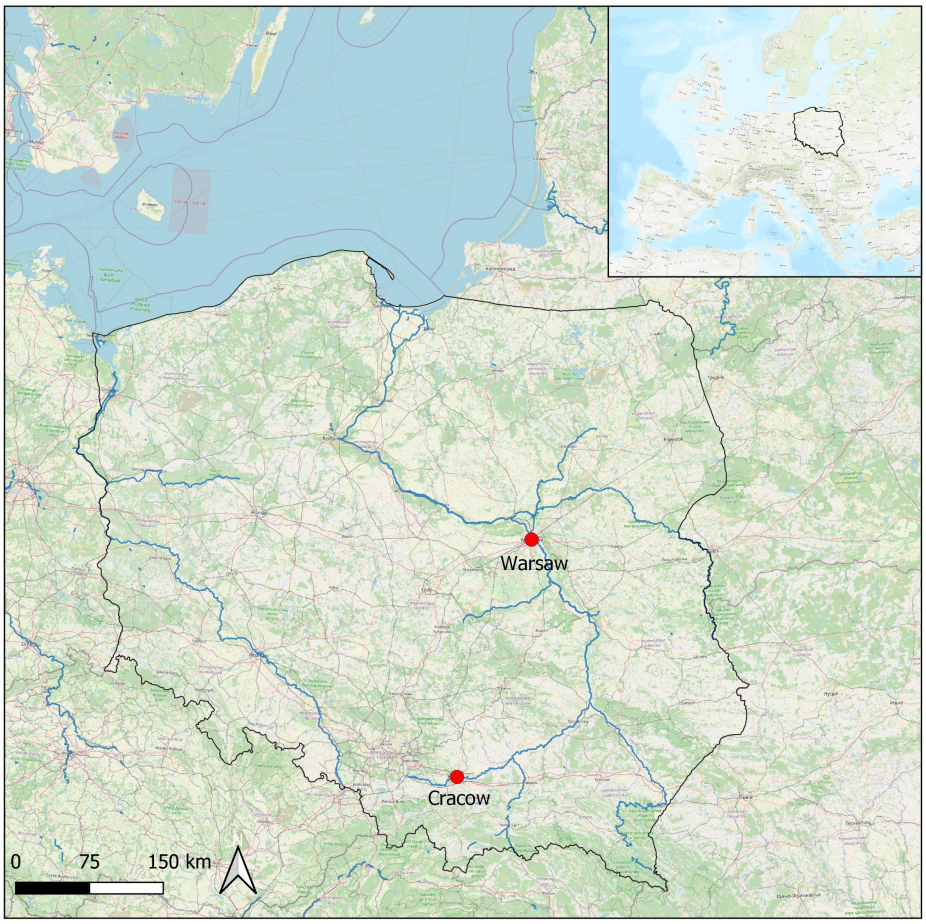

Figure 1. Location of study sites in the Vistula River in Poland.

Our study aimed to document the role of alien prey in the diet of otters inhabiting the Vistula River. Most of the earlier studies of otters analyzed the diet on medium and small watercourses (Brzeziński et al. 1993, 2006; Krawczyk et al. 2011) leaving large European rivers out of focus. To put these findings in a wider context, we also compare the available information on the presence of non-indigenous fish species in the diet of otters and freshwater habitats in Europe.

Study area

The Vistula is one of the largest semi-natural rivers in Central and Western Europe. Diverse riparian vegetation between the dykes and forests located inside the river valley provides an important refuge for fauna and flora and make up an ecological corridor, recognized in the European ecological network EECONET (Liro et al. 1995). Large sections of the Vistula are characterized by a dynamic process of formation and erosion of islands and sandy bars (Kajak 1993). Two study sites characteristic of the Vistula River and located app. 430 km apart were selected for this study: one in the middle course of the river (Warsaw study site, 52.3042; 20.9512), and the other in the upper course of the Vistula (Cracow study site, 50.0515; 19.9581) (Figure 1).

At the Warsaw study site, almost entire banks of the urban and suburban sections of the Vistula from its entry to Warsaw are protected with willow bundles and rocky windrows, except for 3.5 km long west bank in the city center, reinforced with stone and concrete walls. The width of the riverbed ranges from 400 m to 1400 m. The vegetation of river banks and accumulation terrace consists of herbaceous plants, shrubs, and trees, including fragments of riparian *Salici-Populetum* forests, except for the left bank in the city center, which is developed into boulevards.

At the Cracow study site, within the city limits of Cracow, the Vistula flows in a valley cut in Jurassic formations and chalk marls located mainly on its left bank. The bottom of the river is gravel and sand. The width of the riverbed ranges from 80 m to 110 m. On both sides, there are high banks overgrown with herbaceous plants and riparian vegetation dominated by willows *Salix* sp. (*Salicetum triandro - viminalis*, *Salicetum pentadro - cinereae* and *Salicetum albo - fragilis*) (Baścik and Degórska 2015). The exception is the city center where the river flows within the banks reinforced with stones and concrete (about 3.5 km on the west bank and 1.5 km on the east bank).

Materials and methods

A field study of the diet of the Eurasian otter was undertaken in the Warsaw study site from 2012 to 2016 and in the Cracow study site in 2015. At each study site, fresh otter spraints were collected along river banks, placed in separate labeled containers and stored frozen. Each spraint was soaked for 12 h before analysis, washed through a sieve with 0.5 mm mesh, and was oven-dried at 60 °C. All undigested remains were separated and identified under a stereoscopic microscope (Webb 1976). All prey remains were segregated into fractions and weighed with 0.1 g accuracy.

Mammals and birds were identified based on fur, teeth, vertebrae, and feathers, amphibians – based on *frontoparietale* and *illeum* (Webb 1976; Pucek 1981; Engelmann et al. 1985; Teerink 2003). Fish were identified based on scales, jaw apparatus, skull bones, and some other parts of the skeleton. Fish vertebrae were identified according to Webb (1976), *ossa pharyngea inferio*ra – according to Horoszewicz (1960), *praoperculum* and *interoperculum* – according to Libois et al. (1987). Round goby (*Neogobius melanostomus*) remains were identified based on comparative material. Invertebrates were identified based on fragments of chitin carapaces. Remains of *Carassius* sp. were classified as prussian carp *Carassius gibelio* based on the results of studies showing the absence of native crucian carp *C. carassius* in the study sections of Vistula (Backiel et al. 2000; Epler et al. 2003; Wiśniewolski and Ligięza 2011).

The composition of the otter diet was presented using two methods recommended in the analysis of food of this predator (Erlinge 1968; Carss and Parkinson 1996): 1) as a relative frequency of occurrence "RFO" of

Table 1. Main prey of otters in study sites on Vistula river, expressed by relative frequency of occurrence of prey items (RFO%) and percentage of biomass consumed (BC%).

	Warsaw		Cracow	
Number of spraints	102		152	
Number of items	128		159	
Prey type	RFO%	BC%	RFO%	BC%
Fish	77.34	91.75	94.34	99.75
Birds	1.56	1.55	0.63	0.03
Amphibians	10.16	5.30	3.14	0.13
Insects	2.34	0.05	0	0
Crayfish	8.59	1.35	1.89	0.08

each prey item, expressed as the percentage of occurrence of the particular item compared with the total number of occurrences of all items in the sample; 2) as a percentage of biomass consumed "BC". To calculate the contribution of the main types of prey in the diet, the following coefficients of digestibility were used: fish – 25, birds – 12, amphibians – 18, crayfish – 7, insects –5 (Jędrzejewska and Jędrzejewski 1998).

The food niche breadth was calculated according to Levins (1968): $B = \Sigma(p_i\ 2)\text{-}1$, where p_i is a fraction of a given prey group in the diet. For this calculation, the following groups of prey were used: mammals, birds, amphibians, crayfish, insects, and, due to the importance of fish in the otter diet, all recognized fish species.

Results

Fish made up the greatest part of the otter diet, both in terms of biomass consumed and relative occurrence, accounting for 99.8% of the food biomass (RFO = 94.3%) at the Cracow site and over 91.8% of the biomass (RFO = 77.3%) at the Warsaw site (Table 1). Amphibians accounted for 5.3% of biomass consumed at the Warsaw site, the remaining categories such as birds, crustaceans, and insects made up small parts of the biomass in both localities (Table 1). The food niche breadth of otters was higher in the Cracow site (B = 9.74) as compared to the Warsaw site (B = 7.36).

The analysis of 152 otter spraints collected in the Cracow site documented the presence of 18 species of fish representing the following families: Cobitidae, Cyprinidae, Percidae, Esocidae, and Salmonidae (Table 2). Prussian carp constituted the most numerous fish species preyed on by otters (RFO = 11.4%). Among Cyprinidae single occurrence of alien topmouth gudgeon was detected. The analysis of 102 spraints collected in the Warsaw site revealed the presence of 11 fish species representing the following families Cyprinidae, Percidae, and Esocidae. Round goby constituted the most numerous fish species preyed on by otters (RFO = 25.7%). The share of round goby in the diet of otters in the Warsaw site increased from 14% in 2012 to 28.7% in 2016 ($\chi^2 = 6.67$, p = 0.0098, df = 1) (Table 3). Besides four (including common carp *Cyprinus carpio*) alien fish species, the invasive spiny cheek crayfish *Orconectes limosus* was present in the diet of

Table 2. Variation in otter diet in study sites on Vistula river, expressed by relative frequency of occurrence of prey (RFO%). Non-native species marked in bold.

Prey		Warsaw	Cracow
Cobitis taenia	Spined loach	0	1.90
Cobitidae unidentified		0	1.42
Abramis brama	Bream	0	4.74
Alburnus alburnus	Bleak	2.34	2.37
Abramis bjoerkna	White bream	0	1.42
Carassius gibelio	**Prussian carp**	**1.40**	**11.37**
Chondrostoma nasus	Common nase	0.47	0
Cyprinus carpio	**Carp**	**0**	**1.90**
Gobio gobio	Gudgeon	5.61	1.42
Leuciscus (Squalius) cephalus	Chub	0	1.42
Leuciscus idus	Ide	0	1.90
Leuciscus leuciscus	Common dase	1.40	2.37
Leucaspius delineatus	Sunbleak	0.47	0.95
Pseudorasbora parva	**Topmounth gudgeon**	**0**	**0.47**
Rutilus rutilus	Roach	0.93	1.90
Scardinius erythrophthalmus	Rudd	1.87	4.27
Cyprinidae unidentified		29.44	37.44
Perca fluviatilis	Perch	0.93	2.84
Gymnocephalus cernuus	Ruff	0	0.95
Percidae unidentified		17.29	11.85
Esox lucius	Pike	3.74	0.95
Neogobius melanostomus	**Round goby**	**25.70**	**0**
Salmo t. trutta	Sea trout	0	0.47
Fish unidentified		8.41	5.69

Table 3. Variation in otter diet in Warsaw study site in two periods, expressed by relative frequency of occurrence of prey (RFO%). Non-native species marked in bold.

Prey	2012	2015–2016
Cyprinidae	58.14	40.35
Esocidae	6.98	2.92
Percidae	16.28	18.71
Neogobius melanostomus	**13.95**	**28.65**
Fish unidentified	4.65	9.36

otters at both localities with RFO = 8.6% in Warsaw and RFO = 1.9% in Cracow sites (Tables 1, 2). Altogether the five invasive species constituted a large proportion of the diet of otters at both sites (Warsaw RFO = 33.2%, Cracow RFO = 30.8%).

Discussion

Otters are opportunistic predators that prey on fish and various aquatic prey proportionally to their availability (Erlinge 1967; Jędrzejewska et al. 2001; Kruuk 2006; Krawczyk et al. 2016). The results of our study are in agreement with the above general rule of broad food niche of this predator. Fish were the staple food of otters in the Vistula. Their contributions to the diet, both in terms of biomass consumed (Table 1) and relative frequency of occurrence (Table 2) were high as compared to results of the analysis of the diet of otters inhabiting rivers of different sizes in eastern Poland (Brzeziński et al. 2006). Similarly the food niche of otters at both study sites

was relatively broad, which can be attributed primarily to a high number of fish species registered in the diet. The total number of 20 fish species preyed on by otters in the Vistula River is the highest number reported from the lowland rivers in central Europe studied so far. We relate it to the unique nature value of the Vistula River (van der Sluis et al. 2007). As a large and seminatural river, the Vistula River has high species richness of ichthyofauna, consisting of at least 33 species of fish (Wiśniewolski and Ligięza 2011). Most of the fish preyed on by otters in the Vistula River are common species in lowland rivers, except Common nase *Chondrostoma nasus* and dace *Leuciscus leuciscus*, recognized as least concern (LC) species IUCN Red List.

Worth noting is the high contribution of alien aquatic organisms in the diet of otters, exceeding 30%, at both study sites. This group consists of five species, including invasive round goby, topmouth gudgeon, common carp, prussian carp, and spiny cheek crayfish. Common carp was introduced widely at least as early as the Roman Empire (Balon 2006). It is regularly reported as prey of otters in many studies, with the highest contributions in aquaculture habitats that offer concentrated food resources for the predators (Kloskowski 1999; Adámek et al. 2003; Lanszki et al. 2007). Similarly, records of topmouth gudgeon in otter diets come from studies of fish ponds (Kortan et al. 2007; Lanszki et al. 2007; Orlowska 2019). The high frequency of round goby in the diet (25.7%) is somewhat unexpected as the species is recorded for the first time as a prey of otters. This benthic fish occupies shallow rocky littoral waters, which makes it an easy prey for otters (Kruuk 2006). Most probably high frequency of round goby in the diet of otters indicates the high contribution of this species in fish communities of the Vistula River. The other indication of a high abundance of round goby is its high share in sport fisherman's catches in Warsaw (Romanowski *unpublished*).

The analysis of results of diet studies from seminatural freshwater habitats revealed at least 18 non-native fish species that were preyed upon by otters in Europe (Table 4). Common carp was the most often reported species (10 studies from 8 countries, for reports see Table 4), followed by *Lepomis gibbosus* (Linnaeus, 1758) (6 countries), *Carassius auratus* (Linnaeus, 1758), and *Pseudorasbora parva* (4 countries each). Generally otters in southern Europe tend to prey on more non-native fish species (15 species) as compared to west and central Europe (11 species) (Table 4). This tendency can be explained by higher number of non-native fish species that invaded freshwater habitats in southern European countries (Supplementary material Appendix 1). However, non-native fishes have been reported to be preyed upon by otters less frequently as compared to native fishes in freshwaters in Iberia (Blanco-Garrido et al. 2008), Italy (Prigioni et al. 2006), and England (Miranda et al. 2008; Almeida et al. 2012). Our study failed to record *Perccottus glenii* Dybowski, 1877, which inhabits oxbows in Vistula River valley (Terlecki and Pałka 1999). Interestingly,

Table 4. Non-native fish registered in otter diet and in freshwater (excluding aquaculture) habitats in 26 European countries. For detailed list of the non-native fish country reports and references see Appendix 1.

Species	Countries where species was recorded in otter diet	Number of countries where species was recorded in freshwater habitats
Alburnus alburnus	Spain [1]	3
Ameiurus nebulosus	Hungary [2], Poland [3]	18
Carassius auratus	Bulgaria [4], Czech Republic [5], Portugal [6], Spain [7, 14]	15
Carassius carassius	France [8], Italy [9]	5
Carassius gibelio	Bulgaria [4], Poland [**this paper**]	13
Ctenopharyngodon idella	Bulgaria [4], Hungary [2]	13
Cyprinus carpio	Czech Republic [10], France [8], Hungary [2], Italy [9], Poland [3; **this paper**], Portugal [11], Spain [1; 7], U.K. [12]	16
Gambusia holbrooki	Portugal [11], Spain [13; 14]	8
Hypophthalmichthys molitrix	Bulgaria [4]	10
Hypophthalmichthys nobilis	Bulgaria [4]	11
Lepomis gibbosus	Bulgaria [4], France [8], Hungary [2], Italy [15], Portugal [11], Spain [7],	19
Leucaspius delineatus	France [8], U.K. [12]	5
Micropterus salmonides	Italy [9], Portugal [11], Spain [14]	14
Neogobius melanostomus	Poland [**this paper**]	13
Oncorhynchus mykiss	Czech Republic [10], Spain [14]	23
Perca fluviatilis	Italy [15]	4
Pseudorasbora parva	Bulgaria [4], Czech Republic [10], Hungary [2], Poland [**this paper**]	17
Silurus glanis	Italy [16]	7

1 Ruiz-Olmo and Jiménez (2009); 2 Lanszki et al. (2009); 3 Kloskowski et al. (2013); 4 Georgiev (2006); 5 Jurajda et al. (1996); 6 Simoes (2017); 7 Blanco-Garrido et al. (2008); 8 Libois (1997); 9 Smiroldo et al. (2009); 10 Lyach and Cech (2017); 11 Pedroso and Santos-Reis (2006); 12 Miranda et al. (2008); 13 Barrientos et al. (2014); 14 Martínez-Abraín et al. (2020); 15 Remonti et al. (2008); 16 Smiroldo et al. (2019).

this invasive species has not been reported in the dietary study of otters within its secondary range in Europe. In addition to alien fish, various non-native crayfish species may also constitute prey of otters: in Doñana (Spain) non-native crayfish became the main prey of this predator even in aquatic habitats inhabited by fish (Delibes and Adrian 1987).

The significant contribution of alien fish and crayfish in the diet of otters in the Vistula probably reflects their high availability and may be promoted by human alteration of habitat in urban and suburban sections of the river, as indicated by Crooks et al. (2011). This study confirms the predictions of Balestrieri et al. (2013) that the progressive spread of non-native fish in European freshwaters is expected to drive changes in the foraging behavior of top predators. This suggests that alien prey will constitute an increasing fraction of the diet of the indigenous Eurasian otter. The high share of alien fish and crayfish in the diet of otters, revealed in this study, represents a rare documented case of predation on invasive species. There are a few examples of native predators preying on alien species. In the well-studied guild of 27 species of vertebrate predators in Białowieża Primeval Forest, only six mammalian and avian predators consumed alien prey with low frequency (from 0.3%–2.7% of prey) (Jędrzejewska and Jędrzejewski 1998). The successful invasions of alien species are often attributed to decreased control of their populations by natural predators and parasitism, predicted

by the enemy release hypothesis (Elton 1958). The enemy release was considered as a possible mechanism contributing to the rapid spread and increase of the harlequin ladybird *Harmonia axyridis*, one of the most successful insect invaders in recent decades (Ceryngier et al. 2018) . In this short review of otter feeding habits we demonstrated the opposite case of one native predator preying upon at least 18 non-native fish species in Europe. The interesting question of whether otters could have a potential limiting effect on the distribution and numbers of invasive fish remains open for future studies. It is worth noting that our results support the need to call for more conservation of native predators in Europe. The potential to control invasive aquatic species adds a new perspective to efforts to reconcile conflicts between otter conservation and perceived economic damage caused by the otters to aquaculture and fisheries.

Acknowledgements

The authors thank students of WBNS UKSW for assistance in the field work, Kamila and Mathias Franz for remarks on the manuscript, and Kamila Franz for preparing the map. The authors acknowledge anonymous reviewers for their valuable comments.

Authors' contribution

LO research conceptualization, investigation and data collection, data analysis and interpretation, writing – original draft and review; JR research conceptualization, investigation and data collection, data interpretation, writing – original draft, review and editing

References

Adámek Z, Kortan D, Lepič P, Andreji J (2003) Impacts of otter (*Lutra lutra* L.) predation on fishponds: A study of fish remains at ponds in the Czech Republic. *Aquaculture International* 11: 389–396, https://doi.org/10.1023/A:1025787330366

Almeida D, Copp GH, Masson L, Miranda R, Murai M, Sayer CD (2012) Changes in the diet of a recovering Eurasian otter population between the 1970s and 2010. *Aquatic Conservation: Marine and Freshwater Ecosystems* 22: 26–35, https://doi.org/10.1002/aqc.1241

Backiel T, Wisniewolski W, Borzecka I, Buras P (2000) Fish assemblages in semi-natural and regulated large river stretches. *Polskie Archiwum Hydrobiologii* 47(1): 29–44

Balestrieri A, Remonti L, Vezza P, Prigioni C, Copp GH (2013) Do non-native fish as prey favour the conservation of the threatened indigenous Eurasian otter? *Freshwater Biology* 58: 995–1007, https://doi.org/10.1111/fwb.12102

Balon EK (2006) The oldest domesticated fishes and the consequences of an epigenetic dichotomy in fish cultureo. *Aqua: Journal of Ichthyology & Aquatic Biology* 11(2): 47–86

Barrientos R, Merino-Aguirre R, Fletcher DH, Almeida D (2014) Eurasian otters modify their trophic niche after the introduction of non-native prey in Mediterranean fresh waters. *Biological Invasions* 16: 1573–1579, https://doi.org/10.1007/s10530-013-0622-9

Baścik M, Degórska B (eds) (2015) Środowisko przyrodnicze Krakowa. Zasoby-Ochrona-Kształtowanie [Natural environment of Krakow. Resources-Protection-Management], II ed. Instytut Geografii i Gospodarki Przestrzennej, Uniwersytet Jagielloński, Kraków, 435 pp

Blanco-Garrido F, Prenda J, Narvaez M (2008) Eurasian otter (*Lutra lutra*) diet and prey selection in Mediterranean streams invaded by centrarchid fishes. *Biological Invasions* 10: 641–648, https://doi.org/10.1007/s10530-007-9158-1

Brzeziński M, Jędrzejewski W, Jędrzejewska B (1993) Diet of otters (*Lutra lutra*) inhabiting small rivers in the Białowieża National Park, eastern Poland. *Journal of Zoology* 230: 495–501, https://doi.org/10.1111/j.1469-7998.1993.tb02701.x

Brzeziński M, Romanowski J, Cygan JP, Pabin B (1996) Otter *Lutra lutra* distribution in Poland. *Acta Theriologica* 41: 113–126, https://doi.org/10.4098/AT.arch.96-11

Brzeziński M, Romanowski J, Kopczyński Ł, Kurowicka E (2006) Habitat and seasonal variations in diet of otters, *Lutra lutra* in eastern Poland. *Folia Zoologica* 55(4): 337–348

Canning-Clode J (ed) (2016) Biological invasions in changing ecosystems: Vectors, ecological impacts, management and predictions. De Gruyter Open Poland, Warsaw, Poland, https://doi.org/10.1515/9783110438666

Carss DN, Parkinson SG (1996) Errors associated with otter *Lutra lutra* faecal analysis. I. Assessing general diet from spraints. *Journal of Zoology* 238: 301–317, https://doi.org/10.1111/j.1469-7998.1996.tb05396.x

Ceryngier P, Nedvěd O, Grez AA, Riddick EW, Roy HE, San Martin G, Steenberg T, Veselý P, Zaviezo T, Zúñiga-Reinoso Á, Haelewaters D (2018) Predators and parasitoids of the harlequin ladybird, *Harmonia axyridis*, in its native range and invaded areas. *Biological Invasions* 20: 1009–1031, https://doi.org/10.1007/s10530-017-1608-9

Chanin P (1981) The diet of the otter and its relations with the feral mink in two areas of Southwest England. *Acta Theriologica* 26: 83–95, https://doi.org/10.4098/AT.arch.81-5

Corkum LD, Sapota MR, Skóra K (2004) The Round Goby, *Neogobius melanostomus*, a Fish Invader on Both Sides of the Atlantic Ocean. *Biological Invasions* 6: 173–181, https://doi.org/10.1023/B:BINV.0000022136.43502.db

Crooks KR, Burdett CL, Theobald DM, Rondinini C, Boitani L (2011) Global patterns of fragmentation and connectivity of mammalian carnivore habitat. *Philosophical Transactions of the Royal Society B: Biological Sciences* 366: 2642–2651, https://doi.org/10.1098/rstb.2011.0120

Delibes M, Adrian M (1987) Effects of crayfish introduction on otter *Lutra lutra* food in the Donana National Park, SW Spain. *Biological Conservation* 42: 153–159, https://doi.org/10.1016/0006-3207(87)90021-8

Elton CS (1958) The ecology of invasions by animals and plants. Methuen, London, England, 181 pp, https://doi.org/10.1007/978-1-4899-7214-9

Engelmann W, Fritzsche J, Unther R, Obst F (1985) Lurche und Kriechtiere Europas [Amphibians and reptiles of Europe]. Neumann Verlag, Leipzig, 420 pp

Epler P, Socha M, Chyb J, Mikołajczyk T, Popek W, Łopuch G, Ludzik A (2003) Ichtiofauna Wisły w okolicach Krakowa [The ichthyofauna of Vistula river in the Cracow area]. *Roczniki Naukowe Zootechniki. Suplement* 17(2): 623–626

Erlinge S (1967) Food habits of the fish-otter *Lutra lutra* L. in south Swedish habitats. *Viltrevy* 4: 371–443

Erlinge S (1968) Food Studies on Captive Otters *Lutra lutra* L. *Oikos* 19: 259–270, https://doi.org/10.2307/3565013

Georgiev DG (2006) Diet of the Otter *Lutra lutra* in Different Habitats of South-Eastern Bulgaria. *Otter Specialist Group Bulletin* 23(1): 5–11

Gherardi F (2007) Biological invasions in inland waters: an overview. In: Gherardi F (ed), Biological Invaders in Inland Waters: Profiles, Distribution, and Threats. Invading Nature - Springer Series in invasion Ecology, Volume 2. Springer, Dordrecht, The Netherlands, pp 3–25, https://doi.org/10.1007/978-1-4020-6029-8

Głowaciński Z, Okarma H, Pawłowski J, Solarz W (2011) Gatunki obce w faunie Polski [Alien species in the fauna of Poland]. Instytut Ochrony Przyrody PAN, Kraków, 698 pp

Holcik J (1980) *Carassius auratus* (Pisces) in the Danube River. *Acta Scientarium Naturalium, Academiae Scientarium Bohomoslovacae, Brno* 14: 1–43

Horoszewicz L (1960) Wartość kości gardłowych dolnych (ossa pharyngea inferiora) jako kryteriów gatunkowego oznaczania ryb karpiowatych (Cyprinidae) [The value of lower pharyngeal arches as species criteria for defining fish of the Cyprinidae family]. *Roczniki Nauk Rolniczych* 75-B-2: 238–256

Jędrzejewska B, Jędrzejewski W (1998) Predation in Vertebrate Communities. The Białowieża Primeval Forest as a Case Study. Ecological Studies. Springer-Verlag, Berlin, Heidelberg, https://doi.org/10.1007/978-3-662-35364-6

Jędrzejewska B, Sidorovich VE, Pikulik MM, Jędrzejewski W (2001) Feeding habits of the otter and the American mink in Białowieża Primeval Forest (Poland) compared to other Eurasian populations. *Ecography* 24: 165–180, https://doi.org/10.1034/j.1600-0587.2001.240207.x

Jurajda P, Prášek V, Roche K (1996) The autumnal diet of otter (*Lutra lutra*) inhabiting four streams in the Czech Republic. *Folia Zoologica* 45(1): 9–16

Kajak Z (1993) The Vistula river and its riparian zones. *Hydrobiologia* 251: 149–157, https://doi.org/10.1007/BF00007175

Kloskowski J (1999) Otter *Lutra lutra* predation in cyprinid-dominated habitats. *Zeitschrift fur Saugetierkunde* 64: 201–209, https://doi.org/10.1515/mamm.2000.64.3.287

Kloskowski J, Rechulicz J, Jarzynowa B (2013) Resource availability and use by Eurasian otters *Lutra lutra* in a heavily modified river-canal system. *Wildlife Biology* 19: 439–451, https://doi.org/10.2981/12-104

Kortan D, Adámek Z, Poláková S (2007) Winter predation by otter, *Lutra lutra* on carp pond systems in South Bohemia (Czech Republic). *Folia Zoologica* 56(4): 416–428

Krawczyk AJ, Skierczyński M, Tryjanowski P (2011) Diet of the Eurasian otter *Lutra lutra* on small watercourses in Western Poland. *Mammalia* 75: 207–210, https://doi.org/10.1515/mamm.2011.005

Krawczyk AJ, Bogdziewicz M, Majkowska K, Glazaczow A (2016) Diet composition of the Eurasian otter *Lutra lutra* in different freshwater habitats of temperate Europe: A review and meta-analysis. *Mammal Review* 46: 106–113, https://doi.org/10.1111/mam.12054

Kruuk H (2006) Otters, ecology behaviour and conservation. Oxford University Press, Oxford, 265 pp, https://doi.org/10.1093/acprof:oso/9780198565871.001.0001
Lanszki J, Pallos ZS, Nagy D, Yoxon G (2007) Diet and fish choice of Eurasian otters (*Lutra lutra* L.) in fish wintering ponds in Hungary. *Aquaculture International* 15: 393–402, https://doi.org/10.1007/s10499-007-9103-4
Lanszki J, Széles LG, Yoxon G (2009) Diet composition of otters (*Lutra lutra* L.) living on small watercourses in southwestern Hungary. *Acta Zoologica Academiae Scientiarum Hungaricae* 55(3): 293–306
Levins R (1968) Evolution in changing environments:some theoretical exploration. Princeton Univ. Press, Princeton, New Jersey, 120 pp, https://doi.org/10.1515/9780691209418
Libois R (1997) Regime et tactique alimentaires de la Loutre (*Lutra lutra*) dans le massif Central [Seasonal diet and feeding tactics of the European otter (*Lutra lutra*) in Central France]. *Vie Milieu* 47(1): 33–45
Libois R, Hallet-Libois C, Lafontaine L (1987) Le regime de la loutre *Lutra lutra* en Bretagne interieure. *Revue d Ecologie* 42: 135–144, https://doi.org/10.3406/revec.1987.5399
Liro A, Głowacka I, Jakubowski W, Kaftan J, Matuszkiewicz A, Szacki J (1995) National Ecological Network EECONET-Poland. IUCN Poland, Warsaw, 66 pp
Lyach R, Cech M (2017) Do otters target the same fish species and sizes as anglers? A case study from a lowland trout stream (Czech Republic). *Aquatic Living Resources* 30: 11, https://doi.org/10.1051/alr/2017011
Martínez-Abraín A, Marí-Mena N, Vizcaíno A, Vierna J, Veloy C, Amboage M, Guitián-Caamaño A, Key C, Vila M (2020) Determinants of Eurasian otter (*Lutra lutra*) diet in a seasonally changing reservoir. *Hydrobiologia* 847: 1803–1816, https://doi.org/10.1007/s10750-020-04208-y
Miranda R, Copp GH, Williams J, Beyer K, Gozlan RE (2008) Do Eurasian otters *Lutra lutra* (L.) in the Somerset Levels prey preferentially on non-native fish species? *Fundamental and Applied Limnology* 172: 339–347, https://doi.org/10.1127/1863-9135/2008/0172-0339
Nowak M, Popek W, Epler P (2008) Range expansion of an invasive alien species, Chinese sleeper, *Perccottus glenii* Dybowski, 1877 (Teleostei: Odontobutidae) in the Vistula River drainage. *Acta Ichthyologica et Piscatoria* 38: 37–40, https://doi.org/10.3750/AIP2008.38.1.05
Orlowska L (2019) Distribution of the alien fish in the diet of the Eurasian otter (*Lutra lutra*) in the south-western Poland. In: Book of Abstracts - 33rd European Mustelid Colloquium. Faculdade de Ciencias da Universidade de Lisboa, Lisboa, Portugal, 59 pp
Pedroso NM, Santos-Reis M (2006) Summer diet of Eurasian otters in large dams of South Portugal. *Hystrix, the Italian Journal of Mammalogy* 17: 117–128, https://doi.org/10.4404/hystrix-17.2-4369
Prigioni C, Balestrieri A, Remonti L, Gargaro A, Priore G (2006) Diet of the Eurasian otter (*Lutra lutra*) in relation to freshwater habitats and alien fish species in southern Italy. *Ethology, Ecology and Evolution* 18: 307–320, https://doi.org/10.1080/08927014.2006.9522698
Pucek Z (ed) (1981) Keys to vertebrates of Poland: Mammals. Mammal Research Institute Polish Academy of Sciences, Warsow, 367 pp
Pyšek P, Hulme PE, Simberloff D, Bacher S, Blackburn TM, Carlton JT, Dawson W, Essl F, Foxcroft LC, Genovesi P, Jeschke JM, Kühn I, Liebhold AM, Mandrak NE, Meyerson LA, Pauchard A, Pergl J, Roy HE, Seebens H, Kleunen M van, Vilà M, Wingfield MJ, Richardson DM (2020) Scientists' warning on invasive alien species. *Biological Reviews* 95: 1511–1534, https://doi.org/10.1111/brv.12627
Remonti L, Prigioni C, Balestrieri A, Sgrosso S, Priore G (2008) Trophic flexibility of the otter (*Lutra lutra*) in southern Italy. *Mammalian Biology* 73: 293–302, https://doi.org/10.1016/j.mambio.2007.04.004
Romanowski J (2006) Monitoring the otter recolonisation of Poland. *Hystrix - The Italian Journal of Mammalogy* 17: 37–46, https://doi.org/10.4404/hystrix-17.1-4363
Romanowski J, Brzeziński M, Żmihorski M (2013) Habitat correlates of the Eurasian otter *Lutra lutra* recolonizing Central Poland. *Acta Theriologica* 58: 149–155, https://doi.org/10.1007/s13364-012-0107-8
Roy HE, Bacher S, Essl F, Adriaens T, Aldridge DC, Bishop JDD, Blackburn TM, Branquart E, Brodie J, Carboneras C, Cottier-Cook EJ, Copp GH, Dean HJ, Eilenberg J, Gallardo B, Garcia M, García-Berthou E, Genovesi P, Hulme PE, Kenis M, Kerckhof F, Kettunen M, Minchin D, Nentwig W, Nieto A, Pergl J, Pescott OL, M. Peyton J, Preda C, Roques A, Rorke SL, Scalera R, Schindler S, Schönrogge K, Sewell J, Solarz W, Stewart AJA, Tricarico E, Vanderhoeven S, Velde G van der, Vilà M, Wood CA, Zenetos A, Rabitsch W (2019) Developing a list of invasive alien species likely to threaten biodiversity and ecosystems in the European Union. *Global Change Biology* 25: 1032–1048, https://doi.org/10.1111/gcb.14527
Ruiz-Olmo J, Jiménez J (2009) Diet diversity and breeding of top predators are determined by habitat stability and structure: A case study with the Eurasian otter (*Lutra lutra* L.). *European Journal of Wildlife Research* 55: 133–144, https://doi.org/10.1007/s10344-008-0226-3
Simberloff D (2011) How common are invasion-induced ecosystem impacts? *Biological Invasions* 13: 1255–1268, https://doi.org/10.1007/s10530-011-9956-3

Simoes S (2017) Ecology and feeding behaviour of common otter in the lower Mondego River Valley. PhD Thesis, Universidado de Coimbra, Coimbra, Portugal, 34 pp
Skora KE, Rzeznik J (2001) Observations on Diet Composition of *Neogobius melanostomus* Pallas 1811 (Gobiidae, Pisces) in the Gulf of Gdansk (Baltic Sea). *Journal of Great Lakes Research* 27: 290–299, https://doi.org/10.1016/S0380-1330(01)70644-2
Skóra K, Stolarski J (1993) New fish species in the Gulf of Gdansk, *Neogobius* sp. [cf. *Neogobius melanostomus* (Pallas 1811). *Bulletin of the Sea Fisheries Institute* 1(128): 83–84
Sluis T van der, Romanowski J, Matuszkiewicz J, Bouwma I (2007) Comparison of scenarios for the Vistula River, Poland. In: Hong SK, Nakagoshi N, Fu BJ, Morimoto Y (eds), Landscape Ecological Applications in Man-Influenced Areas: Linking Man and Nature Systems. Springer International Publishing, pp 417–433, https://doi.org/10.1007/1-4020-5488-2
Smiroldo G, Balestrieri A, Remonti L, Prigioni C (2009) Seasonal and habitat-related variation of otter *Lutra lutra* diet in a Mediterranean river catchment (Italy). *Folia Zoologica* 58(1): 87–97
Smiroldo G, Balestrieri A, Pini E, Tremolada P (2019) Anthropogenically altered trophic webs: alien catfish and microplastics in the diet of Eurasian otters. *Mammal Research* 64: 165–174, https://doi.org/10.1007/s13364-018-00412-3
Sultana M, Hashim Z (2016) Invasive Alien Fish Species in Freshwater of the Continents. *Journal of Environmental Science and Natural Resources* 8: 63–74, https://doi.org/10.3329/jesnr.v8i2.26868
Szaniawska A, Dobrzycka-Krahel A, Jaszczołt J (2017) Spiny-cheek crayfish *Orconectes limosus* (Rafinesque, 1817) on its way to the open coastal waters of the Baltic Sea. *Oceanological and Hydrobiological Studies* 46: 451–463, https://doi.org/10.1515/ohs-2017-0044
Teerink B (2003) Hair of West European Mammals: Atlas and Identification Key. Cambridge University Press, Cambridge, 224 pp
Teletchea F, Beisel JN (2018) Alien fish species in France with emphasis on the recent invasion of Gobies. In: Ray S (ed), Biological Resources of Water. IntechOpen, pp 75–92, https://doi.org/10.5772/intechopen.73408
Terlecki J, Pałka R (1999) Occurrence of *Perccottus glenii* Dybowski 1877 (Perciformes, Odontobutidae) in the middle stretch of the Vistula River, Poland. *Archives of Polish Fisheries* 7(1997): 141–150
Vilà M, Basnou C, Pyšek P, Josefsson M, Genovesi P, Gollasch S, Nentwig W, Olenin S, Roques A, Roy D, Hulme PE, Andriopoulos P, Arianoutsou M, Bazos I, Kokkoris I, Yannitsaros A, Zikos A, Augustin S, Cochard PO, Lopez-Vaamonde C, Sauvard D, Yart A, Bacher S, Bretagnolle F, Gasquez J, Chiron F, Kark S, Shirley S, Clergeau P, Cocquempot C, Coeur d'Acier A, Dorkeld F, Migeon A, Navajas M, David M, Delipetrou P, Georghiou K, Desprez-Loustau ML, Didziulis V, Essl F, Galil BS, Hejda M, Jarosik V, Pergl J, Perglová I, Kühn I, Winter M, Kühn PW, Marcer A, Pino J, McLoughlin M, Minchin D, Panov VE, Pascal M, Poboljsaj K, Scalera R, Sedlácek O, Zagatti P (2010) How well do we understand the impacts of alien species on ecosystem services? A pan-European, cross-taxa assessment. *Frontiers in Ecology and the Environment* 8: 135–144, https://doi.org/10.1890/080083
Webb JB (1976) Otter spraint analysis. An Occasional Publication, London, UK, 1976, 12 pp
Wiśniewolski W, Ligięza J (2011) Ichthyofauna of selected water bodies and the Vistula River in Warsaw. *Fragmenta Faunistica* 54: 59–76, https://doi.org/10.3161/00159301FF2011.54.1.059
Wisniowska L (1996) Diet of the otter (*Lutra lutra*) in fish ponds in southern Poland. *Journal of Wildlife Research* 1(3): 272–277
Witkowski A (2011) Czebaczek amurski - *Pseudorasbora parva*. In: Głowaciński Z, Okarma H, Pawłowski J, Solarz W (eds), Gatunki obce w faunie Polski [Alien Species in the Fauna of Poland]. Institute of Nature Conservation, Polish Academy of Sciences in Cracow, Krakow, pp 391–397
Witkowski A, Grabowska J (2012) The non-indigenous freshwater fishes of Poland: Threats to the native Ichthyofauna and consequences for the fishery: A review. *Acta Ichthyologica et Piscatoria* 42: 77–87, https://doi.org/10.3750/AIP2011.42.2.01

Web sites and online databases

IUCN (2022) The IUCN Red List of Threatened Species. Version 2021-3. https://www.iucnredlist.org (accessed 12 December 2021)

Supplementary material

The following supplementary material is available for this article:

Appendix 1. List of countries in Europe where the presence of non-native fishes has been found.

This material is available as part of online article from:
http://www.reabic.net/journals/bir/2023/Supplements/BIR_2023_Orłowska_Romanowski_SupplementaryMaterial.pdf