BioInvasions Records (2022) Volume 11, Issue 1: 267–277

Research Article

Abundance and size structure of invasive brown bullhead, *Ameiurus nebulosus* (Lesueur, 1819), in a mesotrophic lake (north-eastern Poland)

Dariusz Ulikowski, Piotr Traczuk and Krystyna Kalinowska*

Department of Lake Fisheries, S. Sakowicz Inland Fisheries Institute in Olsztyn, Rajska 2, 11-500 Giżycko, Poland

**Corresponding author*

E-mail: *k.kalinowska@infish.com.pl*

Citation: Ulikowski D, Traczuk P, Kalinowska K (2022) Abundance and size structure of invasive brown bullhead, *Ameiurus nebulosus* (Lesueur, 1819), in a mesotrophic lake (north-eastern Poland). *BioInvasions Records* 11(1): 267–277, https://doi.org/10.3391/bir.2022.11.1.27

Received: 26 July 2021

Accepted: 16 November 2021

Published: 24 January 2022

Handling editor: Michal Grabowski

Thematic editor: Stelios Katsanevakis

Abstract

Some alien invasive fish species, such as, for example, the brown bullhead *Ameiurus nebulosus* can be the dominant component of the native fish community. The aim of this study was to determine the abundance and size structure of *A. nebulosus* and its contribution to the ichthyofauna of mesotrophic Lake Jegocinek (Masurian Lake District, north-eastern Poland). In August 2020, a total of 723 individuals of *A. nebulosus* were caught by benthic and pelagic Nordic multi-mesh gillnets. This alien species probably originated from an illegal release into the lake. Total length and body weight of *A. nebulosus* ranged from 77 to 248 mm (mean of 146 ± 55 mm) and from 4.2 to 241.3 g (mean of 57.0 ± 54.9 g), respectively. The population of *A. nebulosus* was mainly represented by two size groups. The first group was composed of small-sized specimens (below 100 mm and < 10.0 g), while the second group consisted of large individuals (above 180 mm and 70.0 – 110.0 g). This indicates that the population in this lake has a multigenerational structure. Our study showed that *A. nebulosus* accounted for 19% of the total numbers and 21% of the total biomass of all caught fish. The total length and body weight did not differ significantly between the littoral and pelagic zones. Relative numbers (NPUE) were lower in the littoral than in the pelagic zone, while relative biomass (WPUE) was very similar in both zones. Although the values of the coefficient of condition were almost identical in the littoral and pelagic zones, it seems that the near-shore waters offer more favourable environmental conditions for the growth of *A. nebulosus* than deeper open waters of a lake.

Key words: invasion, alien fish, native ichthyofauna, community composition, Masurian Lake District

Introduction

The brown bullhead, *Ameiurus nebulosus* (Lesueur, 1819), is a native fish species to North America, from southern Canada to Florida and Mississippi drainage (Scott and Crossman 1973; Kottelat and Freyhof 2007). This species was introduced to water bodies of many countries in Europe, Asia, South America and also to island states of Hawaii and New Zealand for breeding and sports purposes (Rutkayová et al. 2012). It is very common invasive fish species in waters of Europe (Grabowska et al. 2010; Lusk et al. 2010; Semenchenko 2011; Rutkayová et al. 2012; Kutsokon et al. 2018; Popov and Kotova 2020), where it was first imported in the late 19th century. In Poland,

it was introduced in 1885 to breeding ponds (near the tributary of the Odra River, the Pomeranian Lake District), from which it penetrated into rivers and lakes (Horoszewicz 1971). After the World War II, a rapid expansion of this species was observed (Grabowska et al. 2010). Currently, it is spread in lakes and rivers situated in the southern areas of Poland (Kolejko 1998; Kornijów et al. 2003; Rechulicz et al. 2015; Rechulicz and Płaska 2018, 2019; Szlakowski et al. 2019). In the flowing waters, in 2011–2018, *A. nebulosus* was found on 44 sites among about 1470 surveyed ones, mainly located in Łęczna-Włodawa Lake District near complexes of ponds in the forks of rivers Wieprz and Tyśmienica, Vistula and San, as well as Odra and Stobrawa. The northern border of its range is marked by the Odra River in the estuary section of the Nysa Łużycka, Barycz, Grabia, lower Pilica, lower and middle Tyśmienica (Szlakowski et al. 2019). It is documented that in Masurian Lake District (north-eastern Poland), *A. nebulosus* was found in two eutrophic lakes of the Łyna River drainage basin in 2010 (Kapusta et al. 2010).

Ameiurus nebulosus is a benthic small fish reaching a total length of 25 cm and weight of about 300 g (e.g. Kapusta et al. 2010; Rechulicz et al. 2015; Rechulicz and Płaska 2018). However, in North America (native environment), it can reach a total length of up to 50 cm and weight of about 3 kg (Scott and Crossman 1973). *Ameiurus nebulosus* inhabits backwaters and pools of large lowland streams and rivers, ponds, nutrient-rich lakes, and reservoirs (Kottelat and Freyhof 2007). It can tolerate low concentration of dissolved oxygen (0.2 mg l^{-1}) and a wide range of temperature (Keast 1985a) that may be limiting for other fish species (Scott and Crossman 1973). This species is also tolerant of a wide pH range (3.4–9.1) (Kolejko 1998). It is an omnivorous species, feeding on detritus, plant material, filamentous algae, sewage-like material, annelids, larvae of insects, molluscs, crustaceans (cladocerans, copepods, isopods), leeches, amphipods, molluscs, oligochaetes, gastropods, and spawn and fry of other fish species (e.g. Kline and Wood 1996; Collier et al. 2018; Rechulicz and Płaska 2019). Adults, usually larger individuals (> 14 cm), can frequently graze on small-sized (up to 7 cm in total length) littoral fish, such as roach, bleak, rudd and ruffe, and their eggs (e.g. Keast 1985b; Barnes and Hicks 2003). In addition, adults are also specialized crayfish feeders (Keast 1985b). The diet of *A. nebulosus* depends on the age and size of fish (Kline and Wood 1996), habitat type (Barnes and Hicks 2003), and trophic status of lakes (Rechulicz and Płaska 2019). It was found that this alien species consumes usually the most abundant food resources in the ambient environment (Barnes and Hicks 2003; Rechulicz and Płaska 2019). Some non-native populations of *A. nebulosus* are considered "biointruders" that in a short period of time become an ecological and economic threat due to high reproductive potential and exceptional morphological and physiological plasticity (Hliwa and Błażejewski 2016).

The aim of the study was to determine the abundance and size structure of alien *A. nebulosus* and its contribution to the ichthyofauna of mesotrophic Lake Jegocinek (Masurian Lake District, north-eastern Poland).

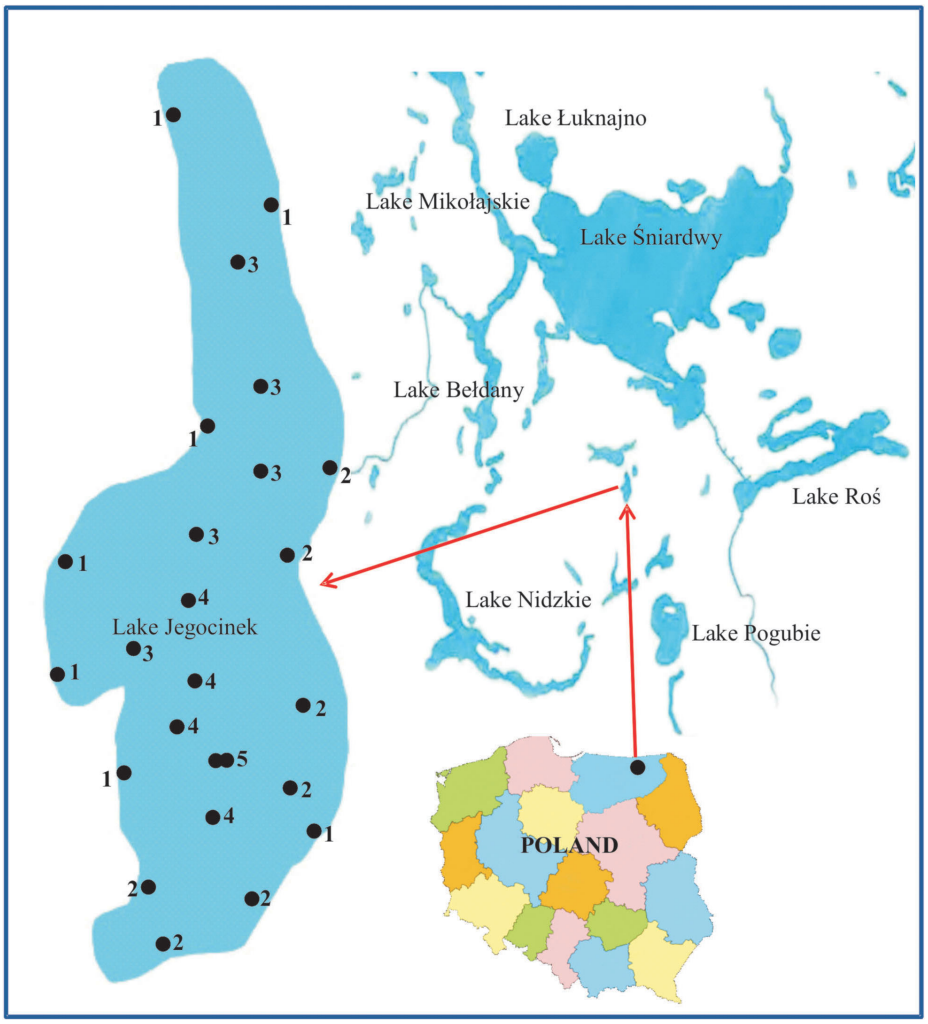

Figure 1. Map of mesotrophic Lake Jegocinek with the sampling sites (Masurian Lake District, north-eastern Poland). Benthic gillnets: 1 – sites at 0–3 m depth, 2 – sites at 3–6 m depth represent littoral zone, 3 – sites at 6–12 m depth, 4 – sites at 12–20 m depth, represent profundal zone. Pelagic gillnets: 5 – sites at the deepest point of a lake, represent pelagic zone.

Materials and methods

The study was conducted in mesotrophic, dimictic Lake Jegocinek (Masurian Lake District, north-eastern Poland; Figure 1) on one sampling occasion, 11 August 2020. The basic morphological, physical, chemical and trophic characteristics of the lake are presented in Table 1.

Water temperature, oxygen concentration, pH, and conductivity were measured *in situ* at 1.0 m depth intervals with an YSI multiparameter probe (Yellow Spring Instruments, USA). Water transparency was measured with a Secchi disc. Trophic state index (TSI) of lakes was calculated from Secchi disc depth according to Carlson (1977).

Fishing was carried out using Nordic multi-mesh gillnets according to European standard protocol (EN 14757). Benthic gillnets were 1.5 m deep and 30 m long and composed of 12 mesh sizes from 5 mm to 55 mm (knot-to-knot). Pelagic gillnets were 6 m deep and 27.5 m long and composed of 11 mesh sizes from 6.25 mm to 55 mm (knot to knot). A total of 23 benthic and 2 pelagic gillnets were used. Nets time exposition was

Table 1. The morphological, physical and chemical characteristics of Lake Jegocinek. TSI – trophic state index.

Morphological parameters		
	Latitude	53.6517°
	Longitude	21.7050°
	Area (ha)	52.3
	Mean depth (m)	7.1
	Maximum depth (m)	17.9
	Length max. (km)	1.6
	Width max. (km)	0.5
Physical and chemical parameters		
	Secchi disc depth (m)	4.9
	pH	8.65
	Conductivity (µS cm^{-1})	228.3
	TSI	37.07
	Trophic status	mesotrophy

12 hours (between 18:00 and 6:00). The benthic nets were located at the depths of 0–3 m (7 gillnets), 3–6 m (7 gillnets), 6–12 m (5 gillnets) and 12–20 m (4 gillnets), while pelagic gillnets were suspended at the depth of 0–6 m from the water surface and at the depth of 6–12 m. All of the caught species were identified and counted. Individual measurements of total length (TL) and body weight (W) were made with an accuracy of 1.0 mm and up to 0.1 g, respectively. In the case of *A. nebulosus*, 110 (25 from pelagic gillnets and 85 from benthic gillnets) randomly selected specimens (15% of all caught individuals) were measured and weighted. All other specimens were sorted into different size classes and weighted.

The coefficient of condition (K) of *A. nebulosus* was calculated using the Fulton's formula (Williams 2000; Mozsár et al. 2014). CPUE (catch per unit effort) was determined using the number of individuals (NPUE) and total weight (WPUE) per 100 m^2 of gillnet for littoral zone (14 benthic gillnets at 0–3 and 3–6 m depths) and pelagic zone (2 pelagic gillnets at 0–6 and 6–12 m depths).

Data were statistically analysed using the STATISTICA software (StatSoft, Inc.). The nonparametric Mann-Whitney *U*-test was used to analyse the differences in total length and body weight of *A. nebulosus* between the littoral and pelagic zones, because the data were not normally distributed.

Results

Environmental parameters

Water temperature was 24.3 °C at the surface and decreased with a depth to 6.2 °C (Figure 2). Thermocline developed at a depth of 5–8 m. During the study period, dissolved oxygen concentrations decreased from about 9 mg l^{-1} (108% oxygen saturation) in the surface water layers to 0.7 mg l^{-1} (6% oxygen saturation) at a depth of 9 m (Figure 2). Hypoxic conditions (< 2 mg l^{-1}) were observed at the depths of 7–9 m, while anoxic conditions (< 0.5 mg l^{-1}) were found at a depth of below 10 m. The lake was characterised

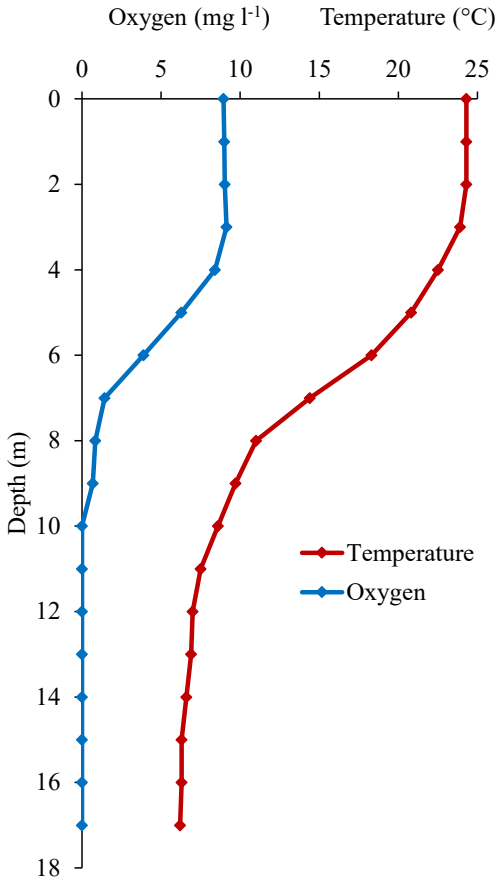

Figure 2. Vertical gradients of temperature and oxygen in mesotrophic Lake Jegocinek (Masurian Lake District, north-eastern Poland).

by alkaline pH, medium electrolytic conductivity, high Secchi disc visibility and mesotrophic conditions (Table 1).

Fish community

A total of 13 species of fish belonging to 5 families (Cyprinidae, Percidae, Esocidae, Coregonidae, and Ictaluridae) were found in the mesotrophic lake in 2020 (Table 2). The fish community was dominated by perch (57% of the total numbers and 26% of the total biomass) and roach (21% of the total numbers and 38% of the total biomass). *Ameiurus nebulosus* was the third dominant species both in the total numbers (19%) and biomass (21%). Three other species, such as rudd, ruffe and bream constituted about 0.5% of the total numbers and 1.1, 0.3 and 4.1% of the total biomass, respectively. The contribution of the obligatory predators (pike and pike-perch) to the total numbers and biomass did not exceed 1.9% (Table 2).

Ameiurus nebulosus population characteristics

A total of 723 individuals of *A. nebulosus* were caught from 16 gillnets, while 9 benthic gillnets at the depths below 6 m were without this species. At the depths of 6–12 m, only 4 specimens of roach with a total biomass of 99.0 g were recorded, while at the depths of 12–20 m no fish were found.

Table 2. List of fish species, number and weight of individuals, and relative abundance (%) of fish in the mesotrophic Lake Jegocinek.

Species	Number		Weight	
	inds.	%	(g)	%
European perch, *Perca fluviatilis* Linnaeus, 1758	2148	57.20	17785.1	26.40
Roach, *Rutilus rutilus* (Linnaeus, 1758)	800	21.30	25640.0	38.07
Brown bullhead, *Ameiurus nebulosus* (Lesueur, 1819)	723	19.25	13927.7	20.68
Rudd, *Scardinius erythrophthalmus* (Linnaeus, 1758)	20	0.53	736.6	1.09
Ruffe, *Gymnocephalus cernua* (Linnaeus, 1758)	20	0.53	182.2	0.27
Bream, *Abramis brama* (Linnaues, 1758)	19	0.51	2789.9	4.14
Pike, *Esox lucius* (Linnaeus, 1758)	7	0.20	1271.9	1.89
European whitefish, *Coregonus lavaretus* (Linnaeus, 1758)	6	0.16	4256.0	6.32
Bleak, *Alburnus alburnus* (Linnaeus, 1758)	5	0.13	73.9	0.11
Tench, *Tinca tinca* (Linnaeus, 1758)	3	0.08	576.4	0.86
Pike-perch, *Sander lucioperca* (Linnaeus, 1758)	2	0.05	27.6	0.04
Crucian carp, *Carassius carassius* (Linnaeus, 1758)	1	0.03	20.1	0.03
White bream, *Blicca bjoerkna* (Linnaeus, 1758)	1	0.03	66.7	0.10

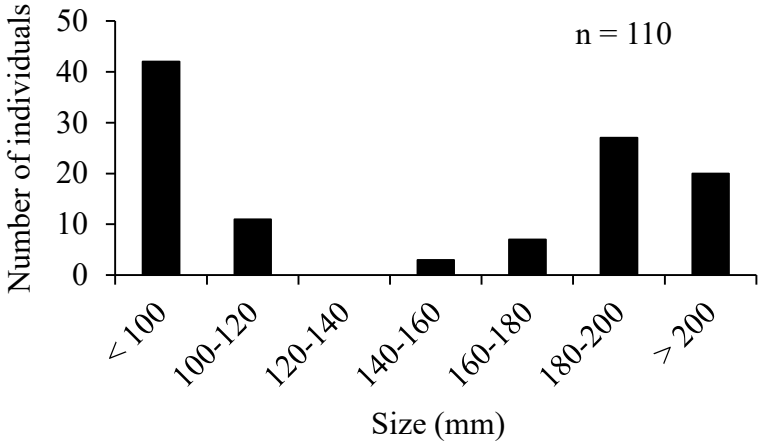

Figure 3. Distribution of total lenght (TL) of *A. nebulosus* from mesotrophic Lake Jegocinek (Masurian Lake District, north-eastern Poland).

Total length (TL) of *A. nebulosus* ranged from 77 to 248 mm (mean of 146.5 ± 55.3 mm), while body weight (W) varied between 4.2 and 241.3 g (mean of 57.0 ± 54.9 g). Among a total of 110 measured individuals, most specimens (42) were less than 100 mm (Figure 3), accounting for 38% of the total number of caught individuals. In addition, specimens with a total length of 180–200 mm were also quite numerous (27 individuals). In the case of body weight, *A. nebulosus* population was mainly represented by small individuals (< 10 g) that constituted 32% of weighted specimens (Figure 4). However, a large percentage share (19%) of medium-sized specimens with a body weight of 70–90 g was observed. The total length and weight of *A. nebulosus* did not differ significantly between the littoral and pelagic zones (U = 939.0, p = 0.378 and U = 925.5, p = 0. 328, respectively). The value of NPUE (relative mean numbers) was distinctly lower in the littoral zone than in the pelagic zone, while the values of WPUE (relative mean biomass) were almost the same in both zones. The coefficient of conditions (K) was very similar in both zones and did not differ significantly (U = 851.0, p = 0.131) (Table 3).

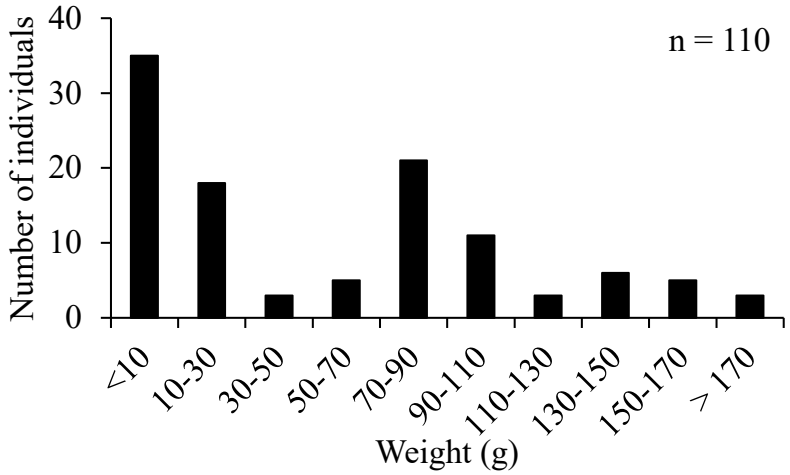

Figure 4. Distribution of body weight (W) of *A. nebulosus* from mesotrophic Lake Jegocinek (Masurian Lake District, north-eastern Poland).

Table 3. Number of measured fish (N), total length (TL), body weight (W), coefficient of condition (K), catch per unit effort for the number (NPUE), and catch per unit effort for the biomass (WPUE) of *Ameiurus nebulosus* in the littoral (14 benthic gillnets) and pelagic (2 pelagic gillnets) zones of mesotrophic Lake Jegocinek. Mean values and standard deviations with ranges in parentheses of TL, W, K, NPUE, and WPUE.

Parameter	Littoral	Pelagial
N	85	25
TL (mm)	149 ± 58 (77–248)	138 ± 45 (78–199)
W (g)	61.6 ± 59.1 (4.2–241.3)	41.3 ± 33.9 (5.7–91.2)
K	1.20 ± 0.15 (0.82–1.58)	1.15 ± 0.11 (0.97–1.38)
NPUE (inds./100m^2)	64.76 ± 99.61	95.45 ± 94.71
WPUE (g/100m^2)	1464.06 ± 1255.32	1425.48 ± 507.02

Discussion

In the present study, we investigated the abundance and distribution of the invasive alien brown bullhead *A. nebulosus* in a mesotrophic lake situated in the Masurian Lake District. It is unclear how this species reached the lake. Because the studied lake is not connected with other lakes, it is very likely that *A. nebulosus* has been introduced by accidental transfer and originated from an illegal release into the lake. The presence of *A. nebulosus* in commercial fishing in Lake Nidzkie (K. Lisowski *unpubl. data*), belonging to the Great Masurian Lake system, may indicate a rapid spread of this invasive species to this system. However, this assumption needs further studies.

In our study, specimens of *A. nebulosus* did not exceed 25 cm in total length and body weight of 242 g. In Polish inland waters, total length (TL) range from 6.5 to 25.3 cm and body weight varied between 3.9 and 270 g (Kolejko 1998; Kapusta et al. 2010; Rechulicz et al. 2015; Rechulicz and Płaska 2019). The most common are usually these with a total length from 12 to 20 cm (Rechulicz and Płaska 2018). In our study, *A. nebulosus* population was represented by both small (< 100 mm and < 10 g) and medium/large sized (> 180 mm, 70–90 g) individuals indicating that this alien invasive species is in the fast-growing state. In contrast, Rechulicz et al. (2015) found that in the polymictic and eutrophic Lake Domaszne, the population

was stable due to the large share of specimens with a body length of 16–18 cm (59% of the population) and the normality of the distribution of the length.

Ameiurus nebulosus affects the structure of the native fish community through predation on eggs and fry, competition for food and habitat, hybridisation with native species, habitat degradation and alteration, and the transmission of pathogens and parasites (Grabowska et al. 2010). In some lakes in eastern Poland, *A. nebulosus* may become the dominant species both in the abundance and biomass of the fish community (Kolejko 1998; Kornijów et al. 2003). For example, in the shallow lakes, this species accounted for 71% of the total numbers and 43% of the total biomass of fish and its contribution decreased with the increasing trophic status of lakes (Kornijów et al. 2003). However, in other lakes, the percentage contribution of the brown bullhead to the total numbers and biomass was below 10% (Kolejko 2010; Rechulicz et al. 2015). Our study showed that *A. nebulosus* was one of the three dominant fish species and constituted 19% of the total numbers and 21% of the total biomass. We identified 13 species of fish belonging to 5 families (Cyprinidae, Percidae, Esocidae, Coregonidae, and Ictaluridae). Similar results (14 species of fish belonging to 4 families: Cyprinidae, Percidae, Esocidae and Ictaluridae) were obtained by Rechulicz et al. (2015) in a shallow eutrophic lake situated in the Łęczna-Włodawa Lake District. It is likely that in the near future the population of *A. nebulosus* may alter the structure of the fish fauna and become a dominant species in the community. However, further studies are required to assess the changes in this population over the next few years in the studied lake. It should be emphasised that *A. nebulosus* is only occasionally eaten by predatory fish, e.g. European catfish *Silurus glanis* L. (Danilkiewicz 1997) and European eel *Anguilla anguilla* L. (Kolejko 1998). In addition, avian predation by cormorants and seagulls may be a significant threat to this invasive fish (Dedual 2002). The increase in mean annual temperature of air (Napiórkowska-Krzebietke 2017) and water (Ulikowski et al. 2019), and frequently observed the intense blooms of filamentous phytoplankton, mainly cyanobacteria, being the result of climate change, may be an additional factor contributing to the fast growth of this species compared to other native species of ichthyofauna. Literature data shows that the two crucial factors governing growth of *A. nebulosus* are temperature and food availability (Brett 1979; Brett and Groves 1979; Crowder and Magnuson 1983). The best growth is observed at 20–30 °C, and the amounts of food consumed by *A. nebulosus* generally increase with temperature (Keast 1985a). In turn, filamentous algae, such as *Spirogyra* and *Anabaena flos-aqua* are regarded as a significant food source for this species (Gunn et al. 1977), but not for other species of the temperate climatic zone (Kaczkowski et al. 2017).

It is documented that *A. nebulosus* usually swim within the top 10 m of water, but sometimes it is observed in water to a depth of 17 m (Dedual 2002). At night, they extensively use shallow water, while during the day,

when light intensity is high, they avoid shallow depths (0–2 m) as a defense strategy against bird predation (Dedual 2002). It was found that *A. nebulosus* mainly concentrate in shallow, sheltered, macrophyte-dominated littoral zone up to a depth of 1.5 m (Kolejko 1998; Barnes and Hicks 2003). In our study, *A. nebulosus* was found both in the littoral zone to a depth of 6 m and in the pelagic zone probably to a depth of 9 m, where oxygen concentrations were 0.68 mg l^{-1} (6% oxygen saturation). No specimens were found in the deeper water due to permanent oxygen deficiency. Although *A. nebulosus* can tolerate low dissolved oxygen concentration (0.2 mg l^{-1}) (Scott and Crossman 1973), it may avoid depths with the complete absence of dissolved oxygen. Much higher relative numbers (NPUE) in the pelagic than in the littoral zone may suggest that the population of *A. nebulosus* migrates to the pelagic zone to the search for food resources or to avoid the competition for space (Keen 1982). In turn, the relatively similar values of the coefficient of condition in the littoral and pelagic zones indicates that *A. nebulosus* may occur in both zones, but it seems that the near-shore waters offer more favourable environmental conditions for the growth of *A. nebulosus* than open waters of the lake.

Acknowledgements

We are grateful to Waldemar Kozłowski, Stefan Marciniak, Jan Rola, and Kacper Ulikowski for help in field work organization and sampling. We thank Karol Lisowski for information about fish in Lake Nidzkie. We would like to thank the anonymous reviewers for their valuable comments, which greatly helped us to improve the manuscript.

Funding declaration

This research was financed through the S. Sakowicz Inland Fisheries Institute in Olsztyn within its statutory research activity (topic no. S-011).

Authors' contribution

DU: research conceptualization, sample design and methodology, investigation and data collection, data analysis and interpretation, writing – original draft. PT: conceptualization, sample design and methodology, investigation and data collection, data analysis and interpretation, writing – review. KK: conceptualization; sample design and methodology, investigation and data collection, data analysis and interpretation, writing – review and editing.

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