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RESEARCH ARTICLE

Protection of the endangered fish lake minnow, *Eupallasella percnurus* (Pallas, 1814), within the Natura 2000 network in Poland: Present status and perspectives

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Abstract. The Natura 2000 network in Poland comprises over a thousand Special Protection Areas (SPAs) for birds and Special Areas of Conservation (SACs) for habitats and plant and animal species. One of these animals is the fish species lake minnow, *Eupallasella percnurus*, which is highly endangered with extinction and under strict protection. Presently it occurs in 27 SACs at 73 sites, i.e., considerably fewer than in the previous decade, when it occurred in 35 SACs at about 100 sites. Since it is very likely that the decline in the number of *E. percnurus* sites will continue in coming years, serious doubts are raised concerning the perspectives for its conservation within the Natura 2000 network and throughout Poland. The major threat to the existence of its habitats is climate change resulting in water bodies drying up at accelerated rates. Introductions of predatory fish species also contribute to the extinction of *E. percnurus* populations. Obviously, preserving the occurrence of *E. percnurus* in Polish inland waters will require the wide-ranging use of active conservation measures with a special emphasis on the revitalization of its most valuable habitats.

Keywords: fish occurrence, lake minnow, Natura 2000 network, nature conservation, threats

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Introduction

Lake minnow, *Eupallasella percnurus* (Pallas, 1814), is a member of the family Leuciscidae (order Cypriniformes) with a very wide range of the occurrence in the Northern Hemisphere (Kusznierz et al. 2017). This small (Fig. 1), freshwater fish has long been one of the rarest and most threatened fish species is Polish freshwaters (Witkowski 1992). It was protected by Polish law in 1975, when its catches were entirely forbidden (Rolik and Rembiszewski 1987). Today, lake minnow is subject to strict protection with the legal requirement that active conservation measures be implemented (Wolnicki and Sikorska 2019a). This species also has a very high status in the European Union, even though it occurs in just two countries – Poland and Lithuania (Wolnicki et al. 2020). It is one of only several vertebrate species of priority and requires establishing Special Areas of Conservation (SACs) within the Natura 2000 network. In contrast, lake minnow is

Figure 1. Adult lake minnow individuals caught at Wielki Klincz 1 in 2019 (Wielki Klincz PLH220083; Pomorskie Voivodeship).

not an endangered species on a global scale (Kottelat and Freyhof 2007).

The specificity of the lake minnow habitat is the primary factor in this species being seriously endangered with extinction in Poland. The vast majority of the habitats in which it occurs are small, shallow, artificial water bodies that were created as a consequence of peat exploitation for domestic use in the twentieth century, and currently water retention in them is highly limited. These water bodies are highly susceptible to total destruction from natural and anthropogenic factors, and even under the most favorable of conditions, they can exist over periods limited to just several decades (Wolnicki and Radtke 2009). The disappearance of most lake minnow habitats was first recorded in the 1960s in eastern Poland, where extensive programs of swamp drainage and land reclamation had been initiated (Danilkiewicz 1965). From then on, the total number of the existing sites has continued to decline significantly. At present, it is estimated that a maximum of 110-120 sites are extant (Wolnicki unpubl. data), whereas just two years ago there were about 140 sites (Wolnicki and Sikorska 2020), and as many as 160-170 in the 2008-2013 period (Wolnicki and Radtke 2009, Wolnicki and Sikorska 2020). Currently, the total range of lake minnow occurrence exceeds 15,000 km^2, which constitutes about 4.8% of Polish territory, and this is highly consistent with the species' historical range of occurrence (Wolnicki and Sikorska 2019a).

All lake minnow sites identified within SACs are subject to more or less regular monitoring usually every two to four years (not all SACs are monitored in the same year). This means that knowledge of the conservation status of the lake minnow within the Natura 2000 network is considerably more up-to-date than it is in all remaining sites that are rarely ever monitored. A particularly high number of the SACs with lake minnow sites was monitored as part of many local projects in the 2016-2021 period. The authors of the present work were personally involved in all but three of these projects. Thanks to these activities, the present knowledge of lake minnow occurrence and conservation within Natura 2000 in Poland is nearly complete and very up-to-date. However, only a few of the latest results of this monitoring have been published to date (Wolnicki et al. 2018, Wolnicki and Sikorska 2019b, Wolnicki and Radtke 2021). All the remaining data are included exclusively in unpublished reports prepared primarily by the authors of the present study. These reports are available by request only from Regional Directorates for Environmental Protection, which are responsible for all protection measures in their respective voivodeships in Poland. This means that information concerning the present status of lake minnow in SACs is not widely known and difficult to obtain.

Considering the above, the primary aim of the present study was to summarize all the data on the present occurrence of lake minnow within the Natura 2000 network in Poland. Moreover, perspectives for its conservation in Poland were assessed based on the most important threats identified to the existence of its habitats and populations.

Sources of information, study area, material and methods

Information on the past and present status of lake minnow within the Natura 2000 network in Poland are included in approximately 50 unpublished reports containing the results of inventories or monitoring of this species, two published reports (Wolnicki 2013, 2016), and several publications (Wolnicki et al. 2008a,

2011a, 2011b, 2011c, 2018, Radtke et al. 2011, Sikorska and Wolnicki 2011, Wolnicki and Sikorska 2019b, Wolnicki and Radtke 2021). The authors of the present study conducted almost all of the field work and prepared all but three of the unpublished reports.

The study area comprised all Natura 2000 SACs in Poland where lake minnow sites of the occurrence were ever identified. The vast majority of the field work to identify lake minnow sites was conducted from 2007 to 2021. Most of the work performed earlier (2007-2011) were inventories rather than monitoring and preceded the establishment of the SACs.

Lake minnow sites of occurrence were identified with the obligatory methodology required for inventorying and monitoring its populations and habitats (Kusznierz 2010, Wolnicki 2021). The fish were caught in the water bodies investigated with specialized folding traps with two openings (25 x 25 x 40 cm; mesh 5 mm; opening diameter 60 mm) baited with bread (Wolnicki et al. 2008a, Sikorska and Wolnicki 2011). The time of trap exposition in the water was approximately 0.5 h; five to ten traps were usually deployed simultaneously in each water body. As a rule, catches were conducted in June during warm, calm weather when the fish were highly active.

In the present work the common names of the particular sites are used since these are used in unpublished or published information sources. However, some sites do not have an individual name at all, whereas some other sites have both a common (older) name and a newer official code name. The latter was required by the Regional Directorate for Environmental Protection in Gdańsk for all inventories and monitoring conducted in the 2019-2021 period in Pomorskie Voivodeship.

Results

Lake minnow occurrence within Natura 2000 in Poland

Polish lake minnow sites are known to exist in six voivodeships: Kujawsko-Pomorskie, Lubelskie, Mazowieckie, Pomorskie, Warmińsko-Mazurskie, and Wielkopolskie. The only site in Warmińsko-Mazurskie Voivodeship, which was found very recently, is not included within Natura 2000 (Wolnicki et al. 2019b). Before the end of 2015, approximately 101 lake minnow sites of occurrence were known to exist in 35 SACs that differed considerably in size from 2.2 ha to almost 13,600 ha (Table 1). Twenty of the SACs, in which 70 sites were identified, were located in Pomorskie Voivodeship, considerably fewer were in eight SACS, which included 19 sites, in Lubelskie Voivodeship. The number of lake minnow sites in the particular SACs ranged from one to 11. At present, 73 sites in which the species occurs were confirmed to occur in 27 SACs. Data on the past and present occurrence of lake minnow within the Natura 2000 network in particular voivodeships are presented below.

Kujawsko-Pomorskie Voivodeship

Kujawsko-Pomorskie Voivodeship has never been a place of extensive field inventories focused on identifying lake minnow sites of occurrence (Kusznierz 1995, 1996, Wolnicki et al. 2007a, 2007b, Wolnicki and Sikorska 2009). Consequently, only ten sites of this species were found to exist there in the first decade of the twenty-first century (Wolnicki et al. 2011b and unpubl. data), of which three were included within the Natura 2000 network as part of SAC Cyprianka PLH040013 (Table 1). Presently, it is highly likely that none of these sites still exists because of habitat loss or advanced degradation.

Lubelskie Voivodeship

In the twentieth century, today's Lubelskie Voivodeship was probably the largest lake minnow sanctuary in Poland with hundreds or maybe even thousands of small water bodies inhabited by populations of this species (Danilkiewicz 1965). It is believed that all of those water bodies were of anthropogenic origin with the vast majority in former peat excavations. In this part of Poland, which abounds in large swamps and peat bogs, peat excavation was

Table 1
Natura 2000 Special Areas of Conservation in Poland where lake minnow sites were present before the end of 2015

Voivodeship	Name and code of Natura 2000 Special Area of Conservation	Surface (ha)	Number of the identified sites
Kujawsko-pomorskie	Cyprianka PLH040013	109.3	3
Lubelskie	Dobromyśl PLH060033	636.8	4?
	Jelino PLH060095	8.4	1
	Jeziora Uściwierskie PLH060009	2065.6	5?
	Lasy Sobiborskie PLH060043	9709.3	3?
	Ostoja Poleska PLH060013	10159.1	2
	Pawłów PLH060065	871.0	2?
	Podpakule PLH060048	10.7	1
	Torfowiska Chełmskie PLH060023	2124.2	1
Mazowieckie	Białe Błota PLH140038	31.4	3?
	Krogulec PLH140008	113.1	2
	Ostoja Bagno Całowanie PLH140001	3447.5	1
	Poligon Rembertów PLH140034	241.9	1
	Strzebla Błotna w Zielonce PLH140040	2.2	1
Pomorskie	Dąbrówka PLH220088	504.6	4
	Guzy PLH220068	115.2	3
	Hopowo PLH220010	5.4	2
	Huta Dolna PLH220089	66.0	1
	Jeziora Wdzydzkie PLH220034	13583.8	2
	Lubieszynek PLH220074	671.4	6
	Mikołajki Pomorskie PLH220076	132.4	1
	Nowa Sikorska Huta PLH220090	174.7	2
	Piotrowo PLH220091	483.0	11
	Pomlewo PLH220092	177.4	3
	Prokowo PLH220080	885.6	3
	Przywidz PLH220025	953.1	3
	Stary Bukowiec PLH220082	308.4	5
	Sztumskie Pole PLH220087	571.9	2
	Szumleś PLH220086	976.5	8
	Uroczyska Pojezierza Kaszubskiego PLH220095	3922.3	2
	Waćmierz PLH220031	388.3	2
	Wielki Klincz PLH220083	288.2	6
	Wilcze Błota PLH220093	9.0	2
	Zielenina PLH220065	643.8	2
Wielkopolskie	Barłożnia Wolsztyńska PLH300028	22.0	1
Total		54,413.5	101?

? – uncertain number of sites

exceptionally intense because of the long, widespread local tradition of the domestic use of peat. Nearly all lake minnow sites became totally extinct decades ago when wetlands were drained for agriculture (Danilkiewicz 1968, 1985). To date, only 51 of the sites identified in the twentieth century are mentioned in the literature, and just seven have survived into the twenty-first century (Wolnicki and Sikorska 2009).

Intensive field inventories conducted in the early 2000s revealed quite a few discoveries of unknown lake minnow sites in the voivodeship (Wolnicki et al. 2006b, 2007b, Sikorska et al. 2007, Wolnicki and Kolejko 2008), and this work increased the total number of confirmed sites to 44 (Wolnicki and Radtke 2009, Wolnicki et al. 2011c). In 2015, approximately 20 of them were protected in eight SACs (Table 1).

Over the last decade almost all the lake minnow sites in the voivodeship vanished most often from habitat loss, but sometimes from the presence of the invasive alien fish species Amur sleeper, *Perccottus glenii* Dybowski or brown bullhead, *Ameiurus nebulosus* (Lesueur) (Wolnicki and Sikorska 2019a and unpubl. data). The lack of recent field inventories means the number of extant lake minnow sites in the Lubelskie Voivodeship cannot be confirmed, but it might not exceed five or six (Wolnicki and Sikorska unpubl. data). Three of these sites are protected in three SACs (Table 2), whereas no current information is available regarding the lake minnow presence in SAC Torfowiska Chełmskie PLH060023 (Table 1), where its vanishing single site might have already become extinct over the last 15 years. It should be mentioned that the Ostoja Poleska PLH060013 site in this SAC was created by a single successful translocation of wild lake minnow in 2016 (Wolnicki et al. 2018). Today it is the only existing site in Polesie National Park after the total disappearance of this fish species from the park at the beginning of the twenty-first century (Kolejko et al. 2007).

Table 2
Lake minnow sites within the Natura 2000 network in Lubelskie Voivodeship in Poland in 2021

Name and code of Natura 2000 Special Area of Conservation	Site common name	Geographical situation		Year of last verification
		latitude	longitude	
Ostoja Poleska PLH060013	-	51°25'51.6"	23°06'38.4"	2021
Pawłów PLH060065	-	51°09'16.0"	23°09'29.3"	2021
Podpakule PLH060048	Podpakule	51°21'13.6"	23°28'26.9"	2021

Mazowieckie Voivodeship

Today's Mazowieckie Voivodeship might have been an important sanctuary for lake minnow in the twentieth century because of the widespread practice of exploiting peat for domestic purposes. However, published data are scarce on its occurrence in this region of Poland. Dybowski (1916), Gąsowska and Rembiszewski (1967), Rolik and Rembiszewski (1987), and Kusznierz (1995) mentioned only about ten sites, none of which was confirmed to have survived to the early 2000s, when it was possible that lake minnow might not occur in this area at all (Wolnicki and Sikorska 2009, Wolnicki et al. 2011a). The first years of the twenty-first century brought new discoveries of previously unknown sites in the vicinity of Warsaw (Ligięza and Wolnicki 2003, Kusznierz et al. 2005); moreover, in 2004 this part of the voivodeship was the first place where new lake minnow populations were created by translocating juveniles originating from aquaculture (Wolnicki et al. 2008b, 2011a, 2019a, Wolnicki and Sikorska 2020). Consequently, seven sites were identified in the voivodeship as early as in in 2006 (Wolnicki et al. 2006a), whereas slightly later, 15 or 16 sites were noted by Wolnicki and Radtke (2009) and Wolnicki et al. (2011a). In 2015, there were probably eight sites of lake minnow occurrence in five SACs (Table 1).

At present, the total number of lake minnow sites in Mazowieckie Voivodeship probably does not exceed ten (Wolnicki unpubl. data), and six of those are protected in four SACs (Table 3). It is worth mentioning that the Warszówka site in the SAC Ostoja Bagno Całowanie PLH140001 was established in 2019 by repeated translocations of lake minnow juveniles originating from aquaculture (Wolnicki and Sikorska 2020).

Pomorskie Voivodeship

Since the first record of lake minnow occurrence near Gdańsk (Benecke 1881), 24 other sites in today's

Table 3
Lake minnow sites within the Natura 2000 network in Mazowieckie Voivodeship in Poland in 2021

Name and code of Natura 2000 Special Area of Conservation	Site common name	Geographical situation		Year of last verification
		latitude	longitude	
Białe Błota PLH140038	Białe Błota 1	52°21'30.6"	21°13'38.7"	2018
	Białe Błota 2	52°21'21.4"	21°13'47.5"	2021
Krogulec PLH140008	Glinianka	52°29'32.4"	21°15'25.2"	2018
Ostoja Bagno Całowanie PLH140001	Janów	52°03'40.4"	21°17'50.7"	2021
	Warszówka	51°59'07.7"	21°20'25.0"	2021
Strzebla Błotna w Zielonce PLH140040	Zielonka	52°17'45.0"	21°08'22.4"	2021

Pomorskie Voivodeship were recorded in publications before the end of the twentieth century (Wolnicki and Sikorska 2009). Probably only two of them have survived to the present (Radtke and Wolnicki unpubl. data). However, this region was undoubtedly one of two the largest Polish sanctuaries of lake minnow along with Lubelskie Voivodeship with its abundance of anthropogenic sites inhabited by this species (Wolnicki and Radtke 2009). In contrast to the latter, Pomerania was characterized by relatively high share of natural sites that arose in many depressions in the rolling topography of the region (Wolnicki and Radtke 2009, Radtke et al. 2011). The confirmed status of Pomorskie Voivodeship as a very important region of lake minnow occurrence was first revealed in the early twenty-first century. Pomorskie Voivodeship then became the target of the most extensive field inventories ever performed in Poland that included several hundred small water bodies (Radtke et al. 2003, 2004, 2006, Wolnicki et al. 2007b). New discoveries of lake minnow sites allowed estimating their total number in the voivodeship at approximately 100 (Radtke et al. 2011). At that time, approximately 70 sites were noted that were located in 20 SACs (Table 1).

Knowledge about the present state of lake minnow occurrence in Pomorskie Voivodeship is incomplete because of a considerable deficit of current information concerning sites outside of Natura 2000. However, extensive field investigations performed in 2019-2021 in particular revealed that 63 lake minnow sites are present in 18 Natura 2000 SACs (Table 4).

Wielkopolskie Voivodeship

Information on the past occurrence of lake minnow in this part of Poland is exceptionally meagre (Gąsowska and Rembiszewski 1967, Kusznierz 1995, Wolnicki and Sikorska 2009, Sikorska and Wolnicki 2011). These sources indicate that about a century ago not more than three to four sites of this species were recorded there. It should be stressed that Wielkopolska has long suffered from progressive declines in ground water and steppe formation that has resulted primarily from human activities such as land drainage and deforestation (Kasprzak 1984, Zuber 1988). All this led to the disappearance of many smaller and larger water bodies and even lakes. Today, it is most likely that only one lake minnow site survives in the whole voivodeship. It is named Barłożnia Wolsztyńska, and it was created in the twentieth century from peat excavation (Sikorska and Wolnicki 2011). This site is protected within the Natura 2000 network (Table 5). It is noteworthy that the revitalization of fish habitat at this site in 2015 saved it from drying up completely (Wolnicki and Sikorska 2019b).

Discussion

Disappearance of lake minnow within Natura 2000

One particular feature of the Polish lake minnow is that the basins of the Oder and Vistula rivers in Poland

Table 4
Lake minnow sites within the Natura 2000 Network in Pomorskie Voivodeship in Poland in 2021

Name and code of Natura 2000 Special Area of Conservation	Site common name	Site code	Geographical situation		Year of last verification
			latitude	longitude	
Dąbrówka PLH220088	Dąbrówka 1	-	54°09'41.2"	18°04'59.0"	2016
	Dąbrówka 2	-	54°09'38.2"	18°05'41.1"	2016
	-	-	54°09'38.2"	18°05'42.2"	2016
	Kłobuczyno	-	54°10'25.2"	18°05'12.4"	2016
	Śledziowa Huta	-	54°09'19.2"	18°05'48.5"	2016
Huta Dolna PLH220089	Huta Dolna	PLH220089_strzebla_1	54°13'48.0"	18°20'21.0"	2020
Jeziora Wdzydzkie PLH220034	Stawiska 1	PLH220034_strzebla_1	54°03'30.8"	18°00'49.2"	2016
	Stawiska 2	PLH220034_strzebla_2	54°03'33.9"	18°01'14.9"	2021
Lubieszynek PLH220074	Lubieszynek 1	PLH220074_strzebla_1	54°06'30.7"	18°12'35.7"	2020
	Lubieszynek 2	PLH220074_strzebla_2	54°06'33.8"	18°12'35.1"	2020
	Lubieszynek 3	PLH220074_strzebla_3	54°06'39.2"	18°12'44.8"	2020
	Zielona Wieś 1	PLH220074_strzebla_4	54°07'17.4"	18°12'33.3"	2020
	Zielona Wieś 2	PLH220074_strzebla_5	54°07'02.0"	18°12'15.3"	2020
	-	PLH220074_strzebla_6	54°07'06.2"	18°12'28.1"	2020
	-	PLH220074_strzebla_7	54°07'04.5"	18°12'52.7"	2020
	-	PLH220074_strzebla_8	54°07'00.9"	18°12'56.2"	2020
	-	PLH220074_strzebla_9	54°07'07.6"	18°13'07.1"	2020
	-	PLH220074_strzebla_10	54°06'05.4"	18°13'12.9"	2020
Mikołajki Pomorskie PLH220076	Mikołajki Pomorskie	PLH220076_strzebla_1	53°50'18.8"	19°10'44.3"	2021
Nowa Sikorska Huta PLH220090	-	PLH220090_strzebla_1	54°11'34.7"	18°06'07.1"	2020
	-	PLH220090_strzebla_2	54°11'29.1"	18°05'53.1"	2020
	Nowa Sikorska Huta 2	PLH220090_strzebla_3	54°11'40.1"	18°05'39.2"	2020
	-	PLH220090_strzebla_4	54°11'42.4"	18°05'37.0"	2020
	-	PLH220090_strzebla_5	54°11'39.5"	18°05'16.7"	2020
	Nowa Sikorska Huta 1	PLH220090_strzebla_6	54°11'40.7"	18°05'26.7"	2020
Piotrowo PLH220091	Piotrowo 1A	PLH220091_strzebla_2	54°11'34.9"	18°09'31.0"	2019
	Piotrowo 3	PLH220091_strzebla_3	54°11'49.0"	18°09'05.0"	2019
	Chylowa Huta 1	PLH220091_strzebla_4	54°12'03.1"	18°10'13.4"	2019
	Grabowska Huta 2	PLH220091_strzebla_6	54°11'18.8"	18°10'01.7"	2019
	Piotrowo 5	PLH220091_strzebla_7	54°11'14.6"	18°08'41.0"	2019
Pomlewo PLH220092	Pomlewo	PLH220092_strzebla_1	54°13'38.5"	18°23'41.2"	2020
	-	PLH220092_strzebla_2	54°13'38.0	18°23'34.0"	2020
	Kozia Góra	PLH220092_strzebla_3	54°13'01.8"	18°23'48.9"	2020
Prokowo PLH220080	Sośniak	PLH220080_strzebla_1	54°21'33.0"	18°13'31.0"	2021
Przywidz PLH220025	-	PLH220025_strzebla_1	54°10'38.6"	18°20'13.4"	2019
	-	PLH220025_strzebla_2	54°10'38.5"	18°19'53.5"	2019
	-	PLH220025_strzebla_3	54°10'29.0"	18°19'39.0"	2019
Stary Bukowiec PLH220082	Stary Bukowiec 1	PLH220082_strzebla_1	54°01'13.0"	18°03'39.1"	2020
	-	PLH220082_strzebla_3	54°01'07.3"	18°03'48.9"	2020
	-	PLH220082_strzebla_4	54°01'00.4"	18°03'55.8"	2020
	-	PLH220082_strzebla_5	54°01'23.5"	18°03'45.5"	2020

cont. Table 4

Name and code of Natura 2000 Special Area of Conservation	Site common name	Site code	Geographical situation		Year of last verification
			latitude	longitude	
Sztumskie Pole PLH220087	Sztumskie Pole	PLH220087_strzebla_1	53°56'32.7"	18°59'02.7"	2020
	-	PLH220087_strzebla_2	53°56'37.3"	18°58'52.8"	2020
Szumleś PLH220086	Szumleś Królewski 1	-	54°09'13.3"	18°14'00.5"	2016
	Szumleś Królewski 2	-	54°08'48.3"	18°14'34.9"	2016
	Szumleś Szlachecki	-	54°08'49.3"	18°15'48.0"	2016
	Szumleś Szlachecki	-	54°08'56.5"	18°15'41.2"	2016
	Wielki Kamień	-	54°09'04.7"	18°13'10.8"	2016
	Szatarpy	-	54°08'37.2"	18°16'18.6"	2021
Uroczyska Pojezierza Kaszubskiego PLH220095	Drozdowo	PLH220095_strzebla_1	54°12'51.5"	18°08'21.7"	2021
	Wieżyca	PLH220095_strzebla_2	54°13'06.5"	18°08'12.3"	2021
	-	PLH220095_strzebla_3	54°12'06.9"	18°07'16.1"	2021
Waćmierz PLH220031	-	PLH220031_strzebla_2	53°59'51.2"	18°41'56.0"	2020
	-	PLH220031_strzebla_3	53°59'58.4"	18°42'00.1"	2020
Wilcze Błota PLH220093	Wilcze Błota	PLH220093_strzebla_1	54°00'45.4"	18°09'14.1"	2020
	Wilcze Błota	PLH220093_strzebla_2	54°00'45.0"	18°09'16.0"	2020
Wielki Klincz PLH220083	-	-	54°05'28.5"	18°04'56.1"	2019
	Wielki Klincz 1	-	54°05'26.1"	18°04'54.2"	2019
	-	-	54°05'21.7"	18°05'08.8"	2019
	-	-	54°05'20.7"	18°04'36.1"	2019
	-	-	54°05'22.4"	18°04'28.9"	2019
	Wielki Klincz 2	-	54°05'23.5"	18°04'29.9"	2019
Zielenina PLH220065	Celmerostwo	PLH220065_strzebla_1	54°07'30.4"	18°23'01.1"	2020

constitute the western edge of the species' worldwide range (Kottelat and Freyhof 2007, Kusznierz et al. 2017). There is no evidence, however, that the progressive vanishing of lake minnow sites in Poland either over decades or very recently might be attributed to this fact. In the twenty-first century, especially severe losses of sites, including those within Natura 2000, occurred in the short period of 2015-2021, when 27% of the sites in eight SACs were found to be extinct. In Kujawsko-Pomorskie Voivodeship all the lake minnow sites occurring in one SAC (Cyprianka PLH040013) probably became extinct, which was, to some extent, predicted in the past (Wolnicki and Radtke 2010). Particularly high losses were recorded in Lubelskie Voivodeship, where only three of 19 lake minnow sites survived in only three SACs, which previously numbered eight. The relatively low decline recorded in the number of lake minnow sites protected within Natura 2000 in Pomorskie Voivodeship does not provide a true picture of the situation of this species in this part of Poland. In fact, in the last several years no less than 15 sites became extinct there within or outside of Natura 2000 (Wolnicki and

Table 5
Lake minnow sites within the Natura 2000 Network in Wielkopolskie Voivodeship in Poland in 2021

Name and code of Natura 2000 Special Area of Conservation	Site common name	Geographical situation		Year of last verification
		latitude	longitude	
Barłożnia Wolsztyńska PLH300028	Barłożnia Wolsztyńska	52°10'27.2"	16°07'51.7"	2021

Radtke unpubl. data). However, these considerable losses were compensated in large part by the discovery of previously unknown sites in some SACs, especially in Lubieszynek PLH220074 (Wolnicki and Radtke 2021) and Nowa Sikorska Huta PLH220090 (Wolnicki and Radtke unpubl. data), while their complex inventories performed in 2020.

Threats to lake minnow habitats and populations

To sum up all the data that referred primarily to the last decade, lake minnow sites became extinct in eight SACs located in four voivodeships (Table 6). The disappearance of the sites was caused by habitat loss or population extinction or both. The reason for the disappearance of some habitats was caused by extremely shallowed water bodies not retaining water over longer periods without precipitation. This threat manifested itself especially strongly in the exceptionally dry years of 2015 and 2016, when a relatively large number (15-20) of Polish lake minnow sites, including those outside Natura 2000, dried up (Wolnicki and Sikorska 2020). Progressive shallowing of lake minnow habitats in combination with intense aquatic vegetation overgrowth were often identified as the most common threats to the existence of its habitats (e.g., Wolnicki and Radtke 2010, Radtke et al. 2011, Sikorska and Wolnicki 2011, Wolnicki et al. 2011a, 2011b). In the 2015-2021 period, unexpectedly strong increases in water acidification were recorded at several lake minnow sites in Poland including those in three Natura 2000 SACs (Table 6). This resulted in decreases in water pH below 5.0, which is accepted as the lower limit of pH range of lake minnow tolerance (Wolnicki 2021). The reasons for the drastic changes in water pH remain unclear the more so because they might have differed among habitats.

Lake minnow populations occur very rarely as the only representative of ichthyofauna in water

Table 6
Natura 2000 Special Areas of Conservation in Poland where all lake minnow sites became extinct

Voivodeship	Name and code of Natura 2000 Special Area of Conservation	Years of extinction	Reason for extinction
Kujawsko-pomorskie	Cyprianka PLH040013	2008-2015	Habitat loss from drying up
Lubelskie	Dobromyśl PLH060033	2015-2020	Habitat loss from drying up or population extinction caused by invasive alien fish species *Perccottus glenii* or *Ameiurus nebulosus*
	Jelino PLH060095	2017-2020	Population extinction caused by invasive alien fish species *Ameiurus nebulosus* and ažstrong increase in water acidification
	Jeziora Uściwierskie PLH060009	2015	Habitat loss from drying up or population extinction caused by invasive alien fish species *Ameiurus nebulosus*
	Lasy Sobiborskie PLH060043	2015	Habitat loss from drying up, or ažstrong increase in water acidification, or population extinction caused by invasive alien fish species *Perccottus glenii* or *Ameiurus nebulosus*
Mazowieckie	Poligon Rembertów PLH140034	2010	Population extinction from ažstrong increase in water acidification
Pomorskie	Guzy PLH220068	2017-2019	Population extinction caused by introduction of native predatory fish species *Esox lucius*
	Hopowo PLH220010	2017-2019	Population extinction caused by introduction of native predatory fish species *Esox lucius*

bodies (Kamiński et al. 2011). Instances of this were only recorded in several strongly dystrophic waters. Its populations are most often accompanied and often dominated by common species of small, non-predatory Cypriniformes as particularly invasive alien gibel carp, *Carassius gibelio* (Bloch), or its hybrids with native crucian carp, *Carassius carassius* (L.), or rather sparsely – the latter only, which are all the most typical inhabitants of different small water bodies in Poland (Danilkiewicz 1965, Steć 1966, Wolnicki and Kolejko 2008). Sunbleak, *Leuciscus delineates* (Heckel), bitterling, *Rhodeus amarus* (Bloch), and tench, *Tinca tinca* (L.) were notably less frequent co-occurring fish species. Many observations indicated that all the fish species mentioned can coexist with lake minnow for decades. In contrast to non-predatory species, predatory fishes are able to entirely eliminate lake minnow populations in a matter of several years. Alien and native predatory fish species were the primary reason for the extinction of lake minnow populations in six SACs, including four in Lubelskie Voivodeship (Table 6). This part of Poland was found to be especially threatened by invasive fish species (*P. glenii*, *A. nebulosus*) more than a decade ago (Wolnicki and Kolejko 2008, Wolnicki and Radtke 2010). In addition to accidental or intentional stocking, other factors contributing to this situation were the generally widespread presence of these predators in this region and the occurrence of well-developed irrigation and drainage systems. The latter can facilitate local fish migrations considerably. Relatively new threat, but of the growing importance, was the introduction of native predatory fishes into lake minnow habitats. The Northern pike, *Esox lucius* L., was identified as the cause of lake minnow extinction in two SACs (Guzy PLH220068 and Hopowo PLH220010) in Pomorskie Voivodeship. Moreover, this species and native perch, *Perca fluviatilis* L., were found to have caused the extinction of several other lake minnow populations in the voivodeship (e.g., in Piotrowo PLH220091 and Zielenina PLH220065) and in other regions, including areas outside of Natura 2000. Introductions of predatory fish increased considerably in the 2016-2020 period. The introduced species were noted primarily in water bodies that had formerly been popular with local anglers. Thus, they were responsible for most of the introductions, although in some very rare cases, it is possible that waterfowl might have been the vector of developing eggs of predatory fish (Steć 1966, Lovas-Kiss et al. 2020, Radtke and Wolnicki unpubl. data).

The aforementioned threats to the existence of lake minnow habitats and populations proved to be of the increasing importance, but they are not the only ones recorded in the twenty-first century. Wolnicki and Radtke (2010) also identified, for example, intense agriculture in the vicinity of lake minnow habitats that resulted in excessive eutrophication with its further consequences, intentional draining, intentional filling in with different materials, or the transformation of water bodies into recreational reservoirs. All of these factors were responsible for some lake minnow habitat loss both within and outside of Natura 2000.

In view of the above, it is very likely that the negative trends being observed currently in lake minnow conservation sites within Natura 2000 will continue in the coming years. Consequently, further declines in the number of lake minnow sites and, obviously, in the number and importance of the SACs protecting this species should be expected. It must be highlighted here that as many as 16 of the 27 SACs providing lake minnow protection in Poland at present possess just one or two lake minnow sites. Climate change resulting in long periods of droughts and high temperatures in summer are especially threatening to lake minnow habitats (Wolnicki and Sikorska 2020). The confirmed rate of disappearance of many lake minnow habitats has recently become considerably higher than was predicted only several years ago. This conclusion can be drawn when the current state of the sites in Lubelskie Voivodeship are compared with considerations of the extinction risk to lake minnow populations from habitat loss (Sowińska-Świerkosz and Kolejko 2019). In fact, most of these sites have already ceased to exist or have become fishless from temporal drying. Obviously, therefore, the conservation of lake minnow occurrence in Polish inland waters requires the

wide-ranging application of active protection measures with a special emphasis on revitalizing habitats. It is noteworthy that only sites protected within the Natura 2000 network can potentially be revitalized. In fact, it is their only advantage over sites outside of the network, because there are no substantial differences between the former and the latter in terms of threats to their existence.

Active protection of lake minnow in Poland

In Poland several attempts have been made to date to revitalize existing lake minnow habitats and water bodies planned for lake minnow translocations within Natura 2000 (Wolnicki et al. 2019a, Wolnicki and Sikorska 2019b, 2020). All of these measures consisted of enhancing water retention in extremely shallow water bodies by deepening them partially in combination with removing reeds and their rhizomes. Most of these measures considerably improved the living conditions of the fish, which also made it possible to establish new lake minnow populations by translocating wild or cultivated individuals (Wolnicki et al., 2018, 2019a, Wolnicki and Sikorska 2020). All measures of this kind should be based on knowledge of the natural genetic diversity of the lake minnow populations used as a sources of fish for direct or indirect translocations (Kaczmarczyk and Wolnicki 2016). This is to ensure that these measures are implemented using fish from local populations of the highest possible genetic variability; however, these occur seldom in Poland (Kaczmarczyk et al. 2019 and unpubl. data).

Besides habitat revitalization, there are no effective means to counteract introductions of predatory fish to lake minnow sites or to substantially mitigate the negative effects of these introductions. Consequently, it seems that active habitat protection should be restricted to carefully selected lake minnow sites within Natura 2000. The sites should be of the highest possible natural value and not threatened by any form of illegal human activity, including introductions of predatory fish, so that they have the best prospects for long-lasting success. To this end, a well-conceived, comprehensive program of lake minnow protection in Poland, including a list of sites and measures of the highest priority, is indispensable. However, such a program has yet to be developed.

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