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RESEARCH ARTICLE

Physical and chemical water properties in water bodies inhabited by the endangered lake minnow, *Eupallasella percnurus* (Pall.), in central Poland

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Rafał Kamiński, Jacek Wolnicki, Justyna Sikorska

Abstract. The objective of the study was to characterize the physical and chemical water parameters of *Eupallasella percnurus* (Pall.) habitats, to identify the habitat preferences of this species, and, in particular, to determine which parameters would be useful in selecting water bodies for translocation to establish viable new populations as part of active protection programs for this species. Results obtained from seven water bodies in central Poland over a minimum of a four-year period are analyzed. Water temperature, oxygen saturation, conductivity, pH, and concentrations of mineral forms of nitrogen and phosphorus were determined. The key parameter for assessing habitat quality was identified as water pH ranging from 4.9 to 9.1. Low pH values appear to cause disturbances in natural fish recruitment. Populations from water bodies with water pH not lower than 5.0 did not exhibit any effects of unfavorable environmental conditions despite periodic water temperatures that significantly exceeded optimal values for this species (> 25°C) and dangerously low levels of water oxygen saturation (< 14%).

Keywords: conductivity, endangered fish, *Eupallasella percnurus*, lake minnow, oxygen, pH, temperature

R. Kamiński [✉], J. Wolnicki, J. Sikorska
Pond Fishery Department in Żabieniec
Inland Fisheries Institute in Olsztyn
Główna 48, Żabieniec, 05-500 Piaseczno, Poland
Tel./Fax: +48 22 756 20 44; e-mail: erka@infish.com.pl

Introduction

The lake minnow, *Eupallasella percnurus* (Pall.), is currently one of the most endangered vertebrate species in Europe. Its ecological status is evidenced by its inclusion in the group of only nine fish species of priority significance in the European Ecological Natura 2000 Network (Conservation status of habitat types and species; Article 17, Habitats Directive 92/43/EEC). In Poland it presently requires active protection measures. Thus far, such measures have been initiated only in Mazowieckie Voivodeship within the scope of a program entitled "Conservation of populations of lake minnow, *Eupallasella percnurus* (Pallas, 1814), in Mazowsze", which began implementation in 2002. The measures comprising this program include the introduction of this species into water bodies with no prior occurrence of it (Wolnicki et al. 2011). The main difficulty with such measures is the choice of appropriate water bodies.

Current knowledge of the habitat preferences of *E. percnurus* suggests that in Poland its habitats are mainly shallow, eutrophic or dystrophic water bodies with surface areas from 0.01 to 4.00 ha (Danilkiewicz 2001, Kolejko et al. 2006, Wolnicki et al. 2006, 2007, 2008a, Wolnicki and Radtke 2010). These water bodies are usually pits resulting from peat, or more seldom clay, exploitation (Wolnicki and Radtke 2010, Wolnicki et al. 2011). In northern Poland, the species also often inhabits small, natural water bodies usually densely overgrown by aquatic plants. The most frequent fish species cohabiting *E. percnurus* are crucian carp, *Carassius carassius* (L.), Prussian carp, *Carassius gibelio* (Bloch), and sunbleak, *Leucaspius delineatus* (Heckel). *E. percnurus* can, although rarely, be the only component of ichthyofauna in a water body.

Information on the physical and chemical water properties in water bodies inhabited by *E. percnurus* is sparse and fragmentary, and is usually limited to temperature data. Information on oxygen saturation, conductivity, pH, or concentrations of nutrients is very sparse (Zdun and Lesnik 1989, Kolejko et al. 2006, Wolnicki et al. 2006, 2007, 2008a, Kolejko and Sender 2008), although it can determine the success of fish introductions to initiate new populations within the scope of active species protection. The objective of the current study was to determine, based on long-term studies, the habitat preferences of *E. percnurus* with regard to basic physical and chemical water parameters, and to specify parameters that could be used to determine the suitability of water bodies for the introduction of this species.

Materials and methods

The study was conducted from 2002 to 2011, and included newly-discovered sites of *E. percnurus* occurrence or water bodies into which it had been introduced. Water parameters from a total number of seven water bodies located in central Poland in the Mazowieckie Voivodeship were analyzed (Table 1). The study was conducted during periods when the water bodies were free of ice cover, usually five times annually. The exception was the water body in Gostynin, which was studied from one to four times annually. The following water parameters were analyzed: temperature, oxygen saturation, conductivity, pH, and concentrations of the dissolved nutrients of ammonium compounds, nitrates (III and V), and phosphates (V). The basic physical and chemical water parameters were determined electrometrically using a WTW Oxi 330 oxygen meter, a Slandi SC 300 conductometer, and a Knick Portamess 911 pH-meter. Nutrient substance concentrations were analyzed with spectrometric methods and a Slandi LF 205 photometer. The water for analyses was sampled from the surface of water bodies about 2-3 m from the shore, and always in the same location. Photographic documentation of the water bodies was made, and provided a basis for estimating changes in water level using a four-grade scale from very low ($\leq$ 1.0 m of maximum depth) to very high ($\geq$ 2.0 m of maximum depth).

The occurrence of *E. percnurus* was monitored two or three times annually in each of the water bodies analyzed using traps that are the standard fishing tool in studies of this type (Wolnicki et al. 2006, 2007, 2008a, 2008b). From three to 15 traps were deployed each time fishing was performed. The species composition of the fish caught, their number, and the occurrence of juvenile *E. percnurus* aged 0+ and 1+, identified by a total length below 50 mm and the lack of any visible primary or secondary sex characteristics (Wolnicki et al. 2008b), were all determined.

Results

The physical and chemical water parameters in the water bodies analyzed were diversified. Water temperature ranged from 0.0 to 30.0°C, oxygen saturation ranged from 3 to 225%, conductivity varied between 32 and 642 $\mu S\ cm^{-1}$, and pH between 4.9 and 9.1 (Table 2). In the majority of cases, the results of the analyzes of water nutrient concentrations indicated levels below detection limits. Sporadically, concentrations were significantly higher, reaching maximums of 1.3 mg dm^{-3} NH_4-N, 0.68 mg dm^{-3} NO_2^-, 1.7 mg dm^{-3} NO_3^-, and 1.4 mg dm^{-3} PO_4^{3-}.

Conductivity, pH, and water level values in the water bodies varied intensely with maximums of 302 $\mu S\ cm^{-1}$, 3.5, and 2 units during one calendar year, respectively (Table 3). The analysis of pooled data for all of the

Table 1
General characteristics of the investigated water bodies and *Eupallasella percnurus* populations

Parameter/ Water body	Białe Błota	Działy Czarnowskie	Glinianka	Gostynin	Kowalicha	Krogulec	Zielonka
Geographical co-ordinates*	N 52°21'31" E 21°13'45"	N 52°28'48" E 21°14'52"	N 52°29'33" E 21°15'25"	N 52°26'07" E 19°27'14"	N 52°30'29" E 21°15'26"	N 52°29'34" E 21°16'20"	N 52°17'46" E 21°08'29"
Type of water body	peat pit	natural lake	clay pit	peat pit	peat pit	natural lake	fire reservoir
Water surface (ha)	0.70-3.50	0.05-0.60	0.30-0.40	0.25-0.40	0.08-0.30	0.15-0.50	0.01-0.08
Maximum depth (m)	2.0	1.6	1.8	2.5	2.0	2.5	2.0
Year of discovery/initiation*	2005	2004	2002	2005	2004	2002	2006
Threat to existence*	high	high	medium	low	medium	high	high
Existing due to introduction*	no	yes	no	no	yes	no	no

*according to Wolnicki et. al. (2008a)

Table 2
Extreme water properties recorded in the investigated water bodies

Parameter/ Water body	Białe Błota		Działy Czarnowskie		Glinianka		Gostynin		Kowalicha		Krogulec		Zielonka	
	Extreme													
	low	high	low	high	low	high	low	high	low	high	low	high	low	high
Temperature (°C)	5.3	25.4	0.0	28.7	0.0	29.3	11.0	27.5	0.0	27.3	0.0	30.0	0.5	22.5
Oxygen saturation (%)	3	225	41	160	20	133	12	102	22	113	44	132	15	89
Conductivity (µS cm^{-1})	60	136	43	227	43	120	399	642	41	107	32	108	236	600
pH	5.0	7.4	5.1	7.6	6.0	8.9	7.2	9.1	5.1	8.8	4.9	8.4	5.9	7.3
NH_4-N (mg dm^{-3})	*	*	*	1.1	*	1.0	*	*	*	1.3	*	1.1	*	0.3
NO_2^- (mg dm^{-3})	*	*	*	0.59	*	0.53	*	*	*	0.44	*	0.68	*	*
NO_3^- (mg dm^{-3})	*	*	*	0.6	*	*	*	0.6	*	0.8	*	*	*	1.7
PO_4^{3-} (mg dm^{-3})	*	0.5	*	0.2	*	0.4	*	0.2	*	1.4	*	0.3	*	0.4
Water level	1	4	1	3	1	3	1	3	1	4	1	4	1	4

Asterisk indicates values below detection range: NH_4-N 0.1 mg dm^{-3}; NO_2^- 0.02 mg dm^{-3}; NO_3^- 0.5 mg dm^{-3}; PO_4^{3-} 0.1 mg dm^{-3}. Water level is presented on a four-step scale where 1 is the lowest level and 4 is the highest level

Table 3
Maximum annual changes in values of conductivity and pH, and water level in the investigated water bodies

Parameter/ Water body	Białe Błota	Działy Czarnowskie	Glinianka	Gostynin	Kowalicha	Krogulec	Zielonka
Conductivity (μS cm^{-1})	44 (2006)	131 (2005)	74 (2007)	131 (2005)	59 (2005)	40 (2007)	302 (2007)
pH	1.2 (2005)	2.3 (2006)	2.7 (2006)	0.9 (2007)	3.0 (2005)	3.5 (2005)	0.8 (2010)
Water level	1*	2 (2005)	2*	1*	2 (2007)	2 (2003)	1*

Brackets present the year of maximum annual changes. Values marked with an * were observed for two years or more. Water level is presented on a four-step scale where 1 is the lowest level and 4 is the highest level

water bodies revealed significant correlations between the date of the analysis and pH value (Spearman's rank correlation, n = 236, r_s= -0.20, P < 0.002), and between the date of the analysis and water level in a given water body (n = 253, r_s= 0.33, P < 0.001). A significant negative correlation between water level and water pH was also determined (n = 236, r_s= -0.22, P < 0.001).

E. percnurus occurrence throughout the observation period in the six water bodies investigated was based on control catches. Only in Działy Czarnowskie was the total disappearance of this species and *C. gibelio* noted in winter 2005/2006, and was probably because of the extremely low water level and extreme cold. In 2006, *E. percnurus* was reintroduced into the water body, following which its occurrence was confirmed every year, and for the last time in fall 2010. At the Krogulec site, *E. percnurus* was caught annually, but beginning in 2006 only large, sexually mature individuals were caught. At the remaining sites, the occurrence of both mature and juvenile fish was observed annually.

Discussion

The results collected suggest that *E. percnurus* is well adjusted to life in the diverse, changeable, and unstable environmental conditions that develop in small limnic water bodies. In the majority of cases, however, the water parameters analyzed suggested its preference for uncontaminated waters. During the observation period, conductivity and the concentration of ammonia, nitrates, and nitrites corresponded to the parameters of the third quality class for surface waters in Poland (five-grade scale, with the highest water quality classified as first quality class; Journal of Laws of 2004, No. 32, item 284). Among the nutrient substances analyzed, only very high concentrations of phosphates that exceeded 1.0 mg dm^{-3}, which occurred sporadically and were difficult to explain, suggested low water quality. Periodically, very high water temperatures, low oxygen saturation and/or low pH values suggested a decrease in water quality to the lowest class in all of the water bodies analyzed.

E. percnurus mainly inhabits shallow water bodies. If they are not shaded from direct sunlight, summer temperatures can reach considerable values. The maximum temperature recorded in a water body inhabited by this species in central Poland was 30.0°C. Above this value the mortality of adult *E. percnurus* was noted under laboratory conditions (Malyshev 1982). Other laboratory analyses indicated that the temperature at which development and growth ceased (biological zero) was approximately 7.5-10.5°C, while optimum for embryonic development was within the range of 22 to 25°C (Kamiński et al. 2006). The temperature optimum for growth is 25 and 22°C for larvae and juveniles, respectively. At 28°C, slower growth and increased mortality occur (Wolnicki et al. 2004). With the exception of the Zielonka site located in a forest and distinguished by the decidedly lowest observed maximum temperature (22.5°C), the present results indicate that *E. percnurus* populations were exposed periodically to temperatures above 25°C in all of the water bodies investigated. These values exceed the optimum for early developmental stages of the species, which can affect the stability of individual populations.

Another unfavorable phenomenon, observed only in summer, was low water oxygen saturation, which periodically decreased to below 10%. Oxygen deficits also occur during long periods of ice cover on water bodies in winter. This issue, however, has yet to be studied. *E. percnurus* is a species adapted to life under conditions of periodic oxygen deficits. Under laboratory conditions, however, it was shown to be less resistant to oxygen deficit than its frequent cohabitant *C. gibelio*. *E. percnurus* deaths were observed as soon as after two hours of exposure to waters at a temperature of 19.5°C and with oxygen saturation of approximately 14% (1.3 mg dm^{-3}) (Malyshev 1982). Under natural conditions, however, the analyzed populations could survive short periods of decreases in oxygen saturation, including values that are lower than those which cause fish deaths in laboratory studies. The survival strategy of *E. percnurus* under such conditions is not understood, however extreme low oxygen saturation must affect fish activity and the size of their food base.

Low surface water quality in certain water bodies inhabited by *E. percnurus* was also evidenced by the results of pH measurements. Both the upper (9.1) and the lower (4.9) water pH limits recorded within the scope of this study are typical of the lowest quality class of surface waters. Changes in pH values are among the most significant abiotic factors that can modify fish species composition in lakes (Hutorowicz et al. 2005), and it also appears that it can also constitute a restricting factor in *E. percnurus* occurrence. Gradual decreases of water pH in lakes is recognized as a natural process. Long-term data collected from *E. percnurus* sites in central Poland present a distinct, gradual decreasing trend in water pH. The negative correlation between pH and water level in the water bodies suggests that the increased water levels resulting from heavy precipitation in 2007-2010 could accelerate the process.

The lowest pH value recorded to date in a water body inhabited by *E. percnurus* was 4.9 in Krogulec in 2005. For this water body the maximum pH value of 8.4 was recorded in the same year. This is equivalent to a change in pH of 3.5 units. Whereas this high water pH was within the range of values recorded in other water bodies and could not have been dangerous to the fish, strong water acidification could restrict natural recruitment or even render it impossible. This process probably also occurred in consecutive years and resulted in the total lack of juveniles in catches conducted in 2006-2010. The negative influence of water with low pH on embryonic fish development has also been observed in studies of other species. In roach, *Rutilus rutilus* (L.), and bream, *Abramis brama* (L.), disturbances in embryonic development occur at pH 6.0, and in European perch, *Perca fluviatilis* L., and northern pike, *Esox lucius* L., at pH 5.0 (Rask 1992, Vuorinen and Vuorinen 1992).

E. percnurus appears to be highly tolerant of water acidification, but this has yet to be studied. Data collected within the scope of the current study suggest that water with a pH below 5.0 can negatively influence the effectiveness of natural recruitment of this fish species. This means that special attention must be paid to water reaction when selecting water bodies for translocations of *E. percnurus* and that no translocation should be conducted in water bodies with recorded water pH values lower than 5.0. Other water properties should also be taken into consideration when selecting water bodies for the introduction of *E. percnurus*, and also when assessing existing habitats of this species. According to current findings, the following water parameter ranges are well tolerated by *E. percnurus* under natural conditions: temperature 0.0-30.0°C, oxygen saturation 3-225%, conductivity 32-642 µS cm^{-1}, pH 5.0-9.1, NH_4-N ≤ 1.3 mg dm^{-3}, NO_2^- ≤ 0.68 mg dm^{-3}, NO_3^- ≤ 1.7 mg dm^{-3}, and PO_4^{3-} ≤ 1.4 mg dm^{-3}. It is important to note, however, that these ranges have not yet been determined in detail, and this species' tolerance of individual water qualities might prove to be wider.

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Streszczenie

Właściwości fizyczne i chemiczne wody w zbiornikach zasiedlonych przez zagrożoną strzeblę błotną *Eupallasella percnurus* (Pall.) w centralnej Polsce

W latach 2002-2011 prowadzono badania, których celem było scharakteryzowanie na podstawie fizykochemicznych cech wody zbiorników zasiedlonych przez strzeblę błotną *Eupallasella percnurus* w środkowej Polsce, szczególnie zaś określenie cech pomocnych w typowaniu zbiorników do zarybień prowadzonych w ramach aktywnej ochrony gatunku. W analizie uwzględniono wyniki zebrane dla siedmiu zbiorników, w których przez co najmniej 4 lata badano następujące parametry wody: temperaturę, nasycenie tlenem, przewodnictwo elektrolityczne, pH oraz zawartość mineralnych związków azotu i fosforu. Stwierdzono, że kluczowym parametrem do oceny jakości siedliska strzebli błotnej jest

pH wody. W przeprowadzonych analizach pH wody wynosiło od 4,9 do 9,1. Niskie pH wody, w okolicach wartości minimalnej odnotowanej w analizach, wydaje się wpływać negatywnie na proces naturalnej rekrutacji ryb tego gatunku, czego objawem był brak w połowach osobników młodocianych. Populacje zasiedlające zbiorniki wodne o pH wody utrzymującym się powyżej 5,0, dotychczas nie wykazywały objawów oddziaływania niekorzystnych cech środowiska, mimo okresowego bytowania ryb w temperaturze znacznie przekraczającej wartości optymalne dla gatunku (> 25°C) oraz niebezpiecznie niskiej zawartości tlenu w wodzie (< 14%). Wieloletnia analiza zmian pH wody wykazała systematyczny spadek jego wartości w większości badanych stanowisk. Zjawisko to jest niepokojące, gdyż niskie pH wody może prowadzić do zakłócenia przebiegu rozwoju embrionalnego strzebli błotnej i w efekcie do zagrożenia istnieniu niektórych populacji. Silnie kwaśny odczyn wody (pH < 5,0) należy też uznać za czynnik wykluczający zbiorniki wodne z grona akwenów przeznaczonych do zarybienia strzeblą błotną w ramach aktywnej ochrony gatunku. Analiza wyników wieloletnich badań wskazuje, że strzebla błotna tworzy stabilne populacje, wykazujące niezakłócone następstwo pokoleń, w zbiornikach wodnych, w których fizyczne i chemiczne parametry jakości wody powierzchniowej wynoszą: temperatura 0,0-30,0°C, nasycenie wody tlenem 3-225%, przewodnictwo elektrolityczne 32-642 μS cm^{-1}, pH 5,0-9,1, NH_4-N $\leq$ 1,3 mg dm^{-3}, NO_2^- $\leq$ 0,68 mg dm^{-3}, NO_3^- $\leq$ 1,7 mg dm^{-3} i PO_4^{3-} $\leq$ 1,4 mg dm^{-3}.