e-ISSN 1734-9168
http://www.isez.pan.krakow.pl/en/folia-biologica.html

Folia Biologica (Kraków), vol. 72 (2024), No 2
https://doi.org/10.3409/fb_72-2.08

Effect of selected environmental factors on the growth and survivability of the larvae of the Chinese sleeper *Perccottus glenii* Dybowski 1877

Maciej Błażejewski and Piotr Hliwa

Accepted June 18, 2024 *Published online June 27, 2024* *Issue online June 28, 2024*

Original article

Błażejewski M., Hliwa P. 2024. Effect of selected environmental factors on the growth and survivability of the larvae of the Chinese sleeper *Perccottus glenii* Dybowski 1877. Folia Biologica (Kraków) **72**: 74-86.

The aim of this study was to determine the influence of the temperature (range 15 to 25°C), pH (6 to 9) and salinity of water (between 0 to 10‰) on the growth, condition and survival of larvae of the Chinese sleeper. During the 28-day experimental rearing, the highest average body weight of 81.3 ± 16.3 mg was reached in fish from the group maintained at a water temperature 25°C, and was almost five times higher than the weight at the temperature of 15°C (15.6 ± 2.2 mg). A significantly higher body weight of Chinese sleeper larvae was also recorded in the group reared in alkaline water (pH 9), compared to those kept in acidic and neutral water. Statistically significant differences between the groups ($p \leq 0.05$) were recorded for the condition index (K) values and relative body weight (SGR) only in the experiment with different water temperatures of fish rearing. The highest number (16% of the initial stock) of abnormal larvae, associated with a lower jaw and vertebral structure deformities, was recorded in the group reared at 5‰ salinity (Z5). Simultaneously, 100% mortality of the stock was noted by the 10th day of rearing in the 10‰ salinity. The cumulative mortality of the Chinese sleeper larvae related to cannibalism Types I and II in all the experimental rearing was low, oscillating between 0.5% and 11.5% in the groups bred in water with a pH 9 and 0‰ salinity, respectively. The study results may help determine the critical values of water parameters that promote or limit development in the early stages of the Chinese sleeper and could be used in activities related to eradicating or significantly reducing the increasing abundance of this alien invasive fish species in freshwater ecosystems.

Key words: alien invasive species, fish larvae, temperature, salinity, pH

Maciej Błażejewski, Piotr Hliwa✉, Department of Ichthyology and Aquaculture, University of Warmia and Mazury in Olsztyn, Olsztyn, Poland.
E-mail: phliwa@uwm.edu.pl

The Chinese sleeper is a representative of the *Odontobutidae* family, whose natural range includes the Amur River basin, i.e. the territory of China, eastern Russia and Mongolia (Bogutskaya *et al.* 2008; Reshetnikov 2010). Currently, it is a permanent component of the fish stock of many habitat-diverse water bodies in Europe (Jurajda *et al.* 2006; Grabowska *et al.* 2011; Kvach *et al*. 2021).

According to the provisions of the Act of 11 August 2021 on alien species, the Chinese sleeper is classified as an invasive alien species (IAS) that poses a hazard to the entire European Union. This is because it competes for the habitat, breeding sites and food, and it preys on the eggs and fries of native fish species (Cambray 2003; Mills *et al*. 2004; Reshetnikov & Schliewen 2013; Szczerbik *et al.* 2023). The presence of the Chinese sleeper can be very detrimental, especially in small-sized, isolated water bodies populated, e.g. by the legally-protected and endangered native lake minnow *Eupallasella percnurus* (*Rhynchocypris percnurus*) (Wolnicki & Kolejko 2008), as well as the European mud minnow *Umbra* *krameri* (Grabowska *et al.* 2019) and amphibians such as the European fire-bellied toad *Bombina bombina* (L. 1761) or the smooth newt *Lissotriton vulgaris* (L. 1758) (Pupina *et al.* 2018; Fayzulin 2021). Another documented serious threat associated with the presence of the Chinese sleeper is that it is a vector for the transfer of exotic parasites, e.g. *Nippotaenia mogurndae* Yamaguti & Miyata, 1940 and *Gyrodactylus perccotti* Ergens & Yukhimenko, 1973 that were previously unknown in central European waters (Mierzejewska *et al.* 2010; Ondračková *et al.* 2012; Antal *et al.* 2015; Sokolov *et al.* 2015).

The spread of the Chinese sleeper is most often caused by ill-considered and unlawful human activities. It is considered by aquarists to be an attractive showcase species that is often released into open water once it has reached an excessive body size. In addition, it is used by anglers as live bait to catch predatory fish, e.g. the pike, which has repeatedly contributed to its transfer between water bodies (Cambray 2003; Kati *et al.* 2015). An additional factor supporting the spread of the Chinese sleeper in central Europe may also have been the transfer of its juvenile stages (larvae/fry) along with stocking material, e.g. of cyprinids (Bogutskaya & Naseka 2002).

The Chinese sleeper prefers heavily overgrown, stagnant areas of water bodies, usually with muddy bottoms, where periodic oxygen deficits are common (Jurajda *et al.* 2006). The females and males reach sexual maturity in the first year of life, with a body length of 3.7-3.8 cm (Kirczuk *et al.* 2024), and multi-spawn during the spring and summer, when the water temperatures reach 15-16°C. The Chinese sleeper is distinguished from most native fish species by its reproductive strategy, in which the male provides active care to the eggs and larvae (Kottelat & Freyhof 2007).

An important characteristic that promotes the occupation of new habitats by the Chinese sleeper is its high resistance to variable environmental conditions (short-term oxygen deficits and temperature fluctuations) (Lushchak & Bagnyukova 2007; Grabowska *et al.* 2010). Documented evidence of its occurrence in the mesohaline waters of the Black Sea, in the Dnieper River estuary, confirms the habitat opportunism of this freshwater species (Kvach *et al.* 2021). In addition, the Chinese sleeper thrives in waters with a low calcium, potassium and magnesium content, which occasionally results from the massive growth of the algae characteristic of small-sized, isolated water bodies. It is generally considered to be a taxon that adapts more easily to such conditions than, e.g. representatives of cyprinids (Martemyanov *et al.* 2021).

Information on the effects of abiotic factors on the growth or survivability of the juvenile stages of alien invasive ichthyofauna representatives, including the Chinese sleeper, is fragmentary. It has not yet been established whether its success in occupying new water bodies is determined by environmental changes or is instead linked to its physiological plasticity. Therefore, the aim of this study was to determine, under experimental conditions, the effects of a few selected environmental factors, i.e. temperature and pH and water salinity, on the growth, condition and survivability of the early developmental stages of the Chinese sleeper, and to identify their critical values that can facilitate or limit its spread in freshwater ecosystems.

Materials and methods

The larvae, used in all the experiments, were obtained from the semi-natural reproduction of sexually mature Chinese sleeper specimens caught by the electrofishing technique using an IUP-type pulse power generator in the Włocławek Reservoir, situated in the middle course of the Vistula River (Fig. 1).

The experiments were conducted in accordance with the conditions set out in Decision No. WOPN.672.3.2017.MJ.2 of the Regional Director for Environmental Protection in Olsztyn of 7 August 2017 and Decision No. DZP-WG.672.208.2022.MK of the General Director for Environmental Protection in Warsaw of 6 September 2022.

After the capture, the Chinese sleeper spawners were transported in bags with oxygen to the laboratory of the Department of Ichthyology and Aquaculture, University of Warmia and Mazury in Olsztyn, Poland. After a quarantine period of a few days, once the phenotypic sex of the fish was determined, they were transferred to smaller spawning tanks with a volume of 40 dm^3 each, arranged in a recirculating system where, after a few more days, they began to be fed with frozen chironomid larvae and small portions of frozen fish (smelt and common bleak) (Katrinex, Poland). The sex ratio of the fish being stocked and used for spawning was 3:2 (male:female) each time, while their total body length and weight ranged from 7.5 to 12.0 cm and 34.5-50.0 g, respectively.

Once the fish were acclimatised, the process of photothermal stimulation was initiated in order to obtain the intended values of the abiotic parameters; namely, a photoperiod of 15L:9D (15 hours of light

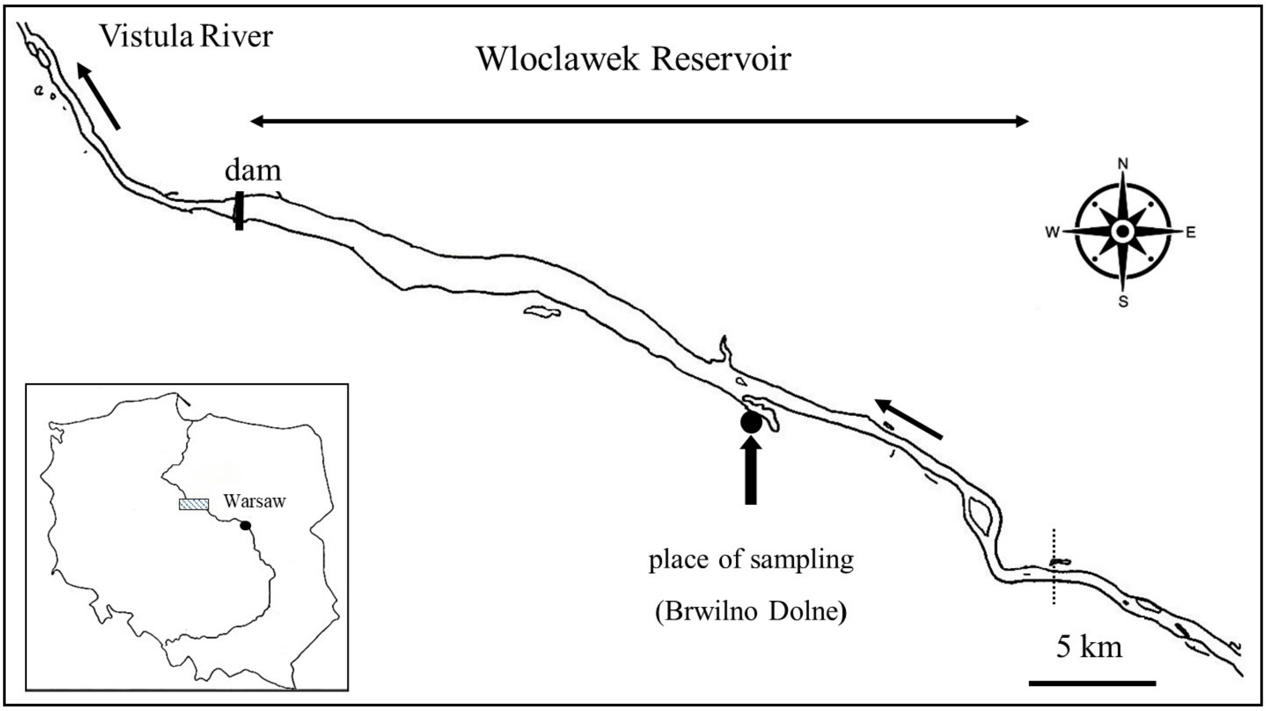

Fig. 1. Catching site of mature Chinese sleeper within the Włocławek Reservoir.

and 9 hours of darkness) and a water temperature of 19 ± 0.5ºC. Approximately 72 hours after the parameters had stabilised, successful spawning was recorded. It took place on an artificial substrate comprised of pieces of PCV tubing. The process of embryogenesis lasted seven days, followed by the larval hatching. After the yolk sac resorption and the initiation of active swimming and foraging, the specimens began to be fed *ad libitum* with *Artemia salina* nauplii (Ocean Nutrition Europe, Essen, Belgium). After five days post-hatching (5 DPH), when all the larvae were capable of taking food actively, they were placed in a specially designed experimental system to initiate the proper rearing experiment.

Each time, the research material was comprised of larvae whose initial total body length ranged from 4.9 to 5.3 mm, with their body weight ranging from 1.5 to 2.1 mg. The initial stocking density was 50 larvae per tank, in three replications, which means that 450 larvae were used in each experiment. The study applied the following water parameter variants:

(a) Temperature: 15ºC (Group T15); 20°C (Group T20); and 25°C (Group T25)

(b) Salinity: 0‰ (Group Z0); 5‰ (Group Z5) and 10‰ (Group Z10)

(c) pH 6.0 (Group pH6); 7.5 (Group pH7.5); and 9.0 (Group pH9).

The rearing was carried out in small-sized, recirculating systems equipped with an independent mechanical and biological water filtering system, comprised of the main tank with a volume of 0.4 m^3, in which nine aquaria with a volume of 1.5 dm^3 each were installed (3 for each experimental variant), with an average water flow rate of 0.1-0.2 dm^3 per minute. During all the rearing experiments, a constant light cycle of 12L:12D was maintained, with a light intensity of 300-400 lx. In the variants addressing the effects of salinity and pH, the water temperature was stabilised at a level of 20°C. In the experiment concerning the effects of water salinity and pH on the larval growth and survivability, non-iodised salt was used to determine the desirable salinity level and the pH value was stabilised using the following preparations: Tetra pH/KH Minus, Aqua-Vitro (Germany) and Natural Regulator by Seachem (USA). During each experiment, the values of the physicochemical parameters of the water (temperature, pH, oxygen concentration and salinity) were verified twice a day, with the measurements taken using a Hanna HI991300 multiparametric meter and a Hanna HI96822 refractometer (Hanna Instruments, USA).

During each of the 28-day rearing experiments, the larvae were randomly sampled every seven days to determine their body length and weight gains by measuring the body length *longitudo corporis* (*l.*c.)

and total length *longitudo totalis* (*l.t.*) with an accuracy of up to 0.1 mm using a LEICA Stereozoom S9D stereoscopic microscope equipped with LEICA LAS X software (LEICA Microsystems Ltd, Switzerland); and the body weight using an OHAUS Pioneer PA114CM analytical balance (OHAUS Corporation, USA) with an accuracy of up to 0.001 g. After the completion of the experiments, all the remaining fish were anaesthetised in an excessive concentration of the MS-222 preparation and were then preserved in a 2.5% glutaraldehyde solution for further analyses of selected parameters, including:

(a) Body weight variation coefficient – ZMC (%) = 100 × SD/Mk

(b) Body length variation coefficient – ZDC (%) = 100 × SD/Ltk

(c) Specific body weight growth – SGR (%/d) = 100 × (ln Mk – ln Mp)/t

(d) Condition factor – K = 100 × Mk/Ltk^3

where: Mk – final fish weight (g); Mp – initial fish weight (g); Ltk – total fish body length (cm); SD – standard deviation for Mk or Ltk; d – day; t – rearing time (days); and ln – natural logarithm.

During the experimental rearing, dead specimens and food debris were removed daily from the tanks. During these operations, the possible causes of death was determined. The fish with signs of having been attacked from the caudal side or with damage to the trunk were classified as victims of Type I cannibalism, while those with no external signs of damage were classified as fish that had died of natural causes. The number of victims of Type II cannibalism (swallowed whole) was determined by calculating the difference between the initial stock and the number of fish remaining in the tank after the experimental rearing. The cumulative mortality (%) was determined based on the total number of specimens that had died.

In order to compare the average values of the body weight and length of the Chinese sleeper larvae, the experiments concerning the effects of selected abiotic factors used the single factor variance analysis (ANOVA). In cases where statistically significant intergroup differences ($p \leq 0.05$) were found, a further statistical analysis was carried out using the post-hoc Tukey test. The statistical differences in larval mortality in the experimental variant, expressed as a percentage, were converted using the *arcsin* function and analysed using the Brown-Forsythe test. The statistical analyses were conducted using STATISTICA software, version 13.1 (StatSoft).

Results

Effect of temperature on the growth and survivability of Chinese sleeper larvae

During the experiment, the basic physicochemical parameters of the water remained stable in the following ranges: pH of 7.6-8.3, with a water-dissolved oxygen concentration of 7.5-9.0 mg/dm^3. The average values of the temperature, being a parameter differentiating between the individual experimental variants, were close to the expected ones in individual groups (Table 1).

Differences in the values of the average body length of the larvae from Group T15, in relation to the two remaining groups, which were reared at a higher water temperatures (T20, T25), were already noted after the seven initial days of the experiment. Ultimately, the fish reached an average body length ranging from 9.4 ± 0.3 mm in Group T15 to 14.3 ± 0.8 mm in Group T25 (Fig. 2A). Similar differences were also noted for the body weight of the fish, which remained until the end of the experiment.

Table 1

Parameters of the water during the experimental rearing depending on the effects of varying temperatures on the growth and survival of the Chinese sleeper larvae

group	temperature (ºC)		pH		oxygen concentration (mg/dm^3)	
	range	average (±SD)	range	average (±SD)	range	average (±SD)
T15	14.1-15.6	14.9±0.38	7.6-8.2	7.9±0.21	7.8-8.9	8.1±0.46
T20	19.7-20.2	19.9±0.11	7.9-8.3	8.1±0.14	8.1-9.0	8.5±0.42
T25	24.1-25.2	24.9±0.43	7.8-8.3	8.0±0.14	7.5-8.5	7.8±0.41

The lowest average body weight after the completion of rearing was exhibited by the Chinese sleepers from Group T15, while the fish from Group T25 had the highest average body weight (Fig. 3A). The lowest value of the ZMC coefficient (11.5%) was calculated for the fish from Group T15, and it statistically significantly ($p \leq 0.05$) differed from that determined for the two other groups. The same trend was noted for the ZDC and SGR coefficients. The highest condition factor (K) value was obtained in Group T25, which was reared at the highest water temperature of the selected water temperatures (Table 4). The cumulative mortality recorded after the completion of the experiment in Group T15 was 34.7%, which was considerably higher than those recorded in the other two groups, where the values were at a similar level (Fig. 4A). At the same time, no intergroup differences were noted for the intensity of both Type I and Type II cannibalism (Fig. 5A).

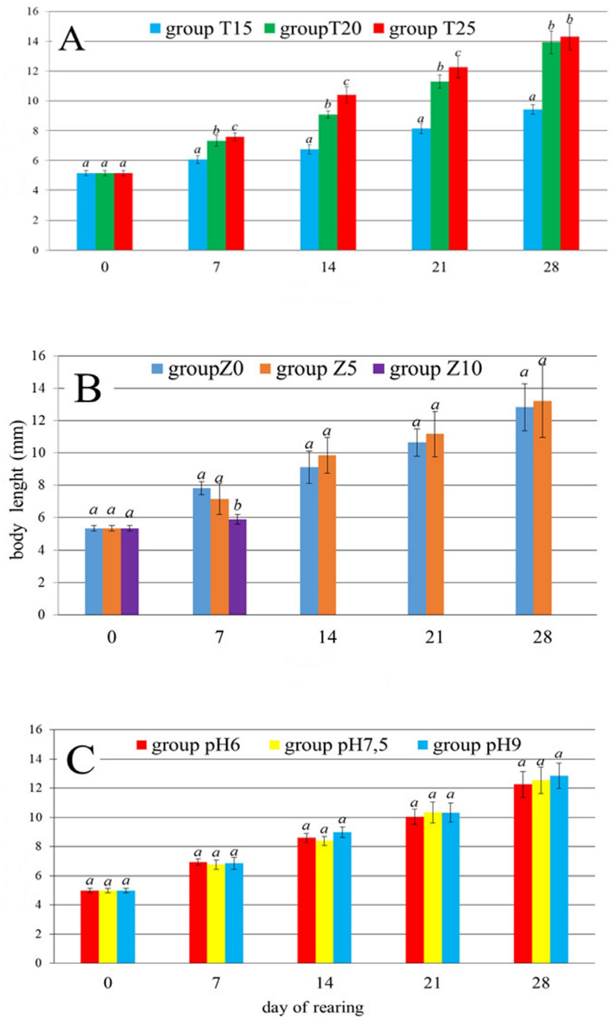

Fig. 2. Growth in body length of the Chinese sleeper larvae in the experimental rearing concerning the effects of: A – temperature, B – salinity, C – pH.

Effect of water salinity on the growth and survivability of the Chinese sleeper larvae

During the experiment, the value of the physicochemical parameters of the water oscillated, depending on the experimental variant, within the range of 7.6-8.5 for the pH and 6.9-8.9 mg/dm^3 O_2, while the average temperature was stable at 20.1 ± 0.38°C. On the other hand, the average values of salinity, as a key factor considered in this study, were as follows: 0‰ (Z0), 5.1 ± 0.46 ‰ (Z5) and 10.0 ± 0.37 ‰ (Z10), respectively (Table 2).

The analysis of the Chinese sleeper larval body length gains revealed variations within the groups under study as early as during the seven initial days of rearing, with the smallest sizes reached by the fish from Group Z10. However, at the end of the experiment, no differences were noted for the body length

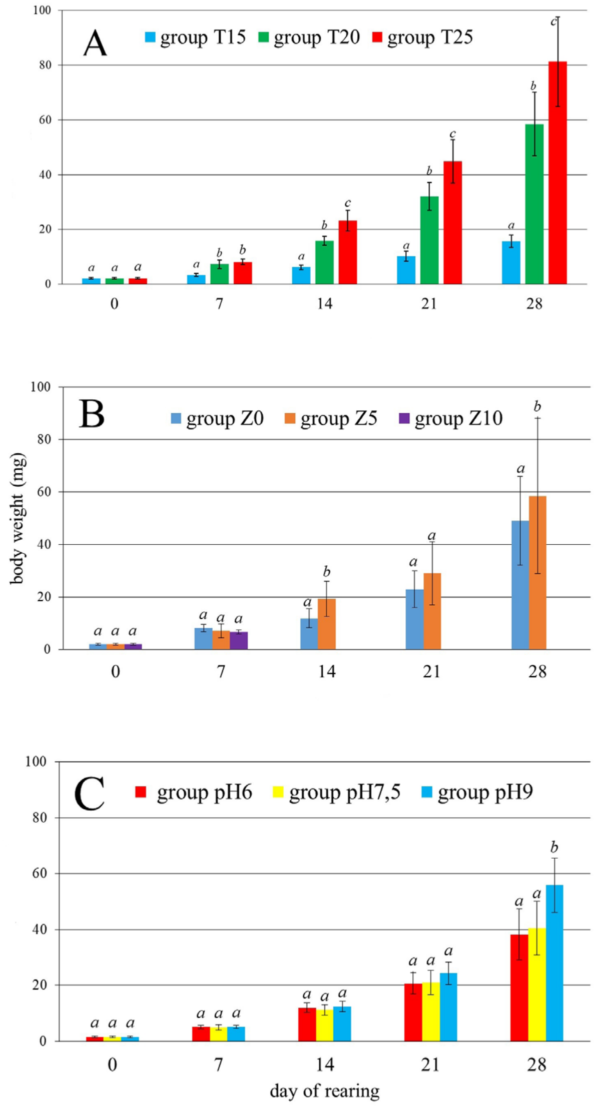

Fig. 3. Growth in body weight of the Chinese sleeper larvae in the experimental rearing concerning the effects of: A – temperature, B – salinity, C – pH.

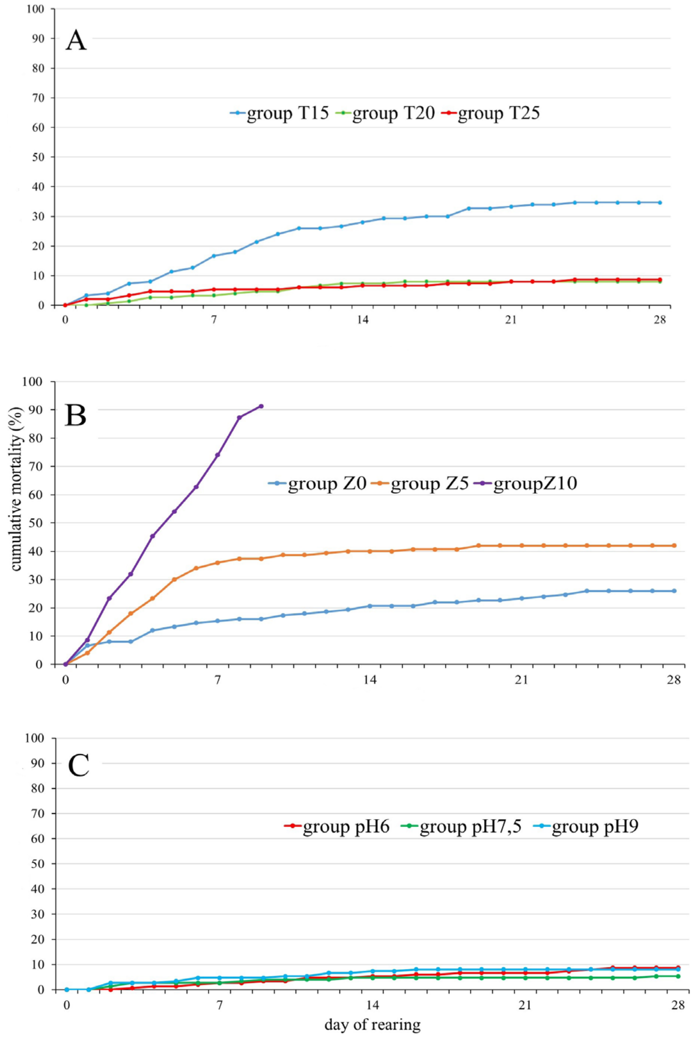

Fig. 4. Cumulative mortality of the Chinese sleeper larvae during the experimental rearing concerning: A – temperature, B – salinity, C – pH.

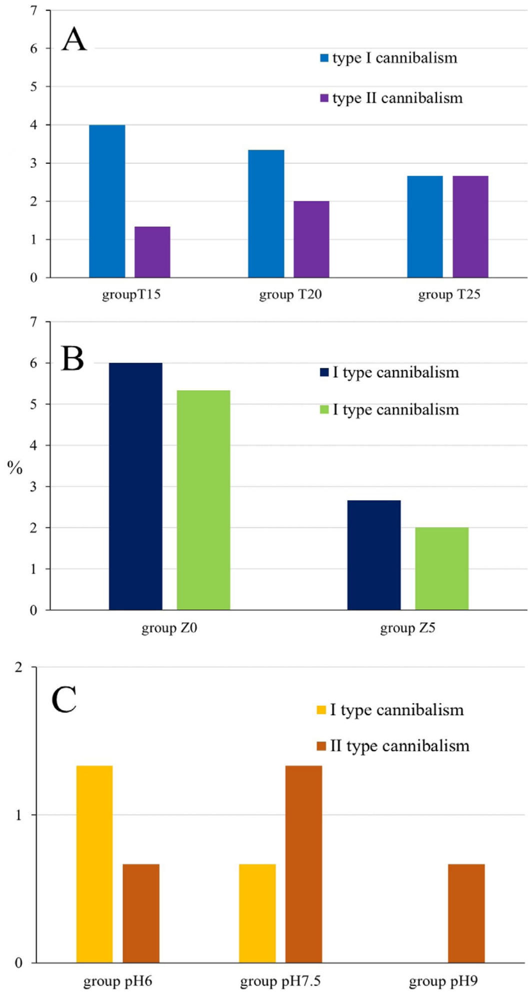

Fig. 5. Mortality of the Chinese sleeper larvae related to Types I and II cannibalism during the experimental rearing depending on: A – temperature, B – salinity, C – pH.

Table 2

Parameters of the water during the experimental rearing depending on the effects of varying salinity on the growth and survival of the Chinese sleeper larvae

group	salinity (‰)		pH		temperature (°C)		oxygen concentration (mg/dm^3)	
	range	average (±SD)	range	average (±SD)	range	average (±SD)	range	average (±SD)
Z0	0.0	0.0	7.6-8.2	7.9±0.18	19.7-21.5	20.1±0.38	7.8-8.9	8.1±0.43
Z5	4.0-6.0	5.1±0.46	8.0-8.2	8.1±0.07	19.7-21.5	20.1±0.38	7.5-8.8	8.3±0.49
Z10	9.0-11.0	10.0±0.37	8.0-8.5	8.2±0.12	19.7-21.5	20.1±0.38	6.9-8.5	7.8±0.58

of the Chinese sleepers originating from Groups Z0 and Z5 ($p>0.05$) (Fig. 2B), in contrast to the value of the average final weight ($p\leq0.05$) (Fig. 3B). After the completion of the experiment, the lowest values of the ZMC and ZDC coefficients, which amounted to 32.9 and 9.6%, respectively, were noted in Group Z0 ($p\leq0.05$). On the other hand, the values of the SGR coefficient and the K factor did not differ between Groups Z0 and Z5 ($p>0.05$) (Table 4).

The cumulative mortality in Group Z0 was 26.0%, while that in Group Z5 was 41.5%. As for Group Z10, a 100% mortality of the stock was noted between days 8 and 10 of the rearing (Fig. 4B). The analysis of Type I and II cannibalism showed the highest percentage of deaths resulting from such behaviour, for 6.0 and 5.3% of the stock, respectively, in the group reared in freshwater (Z0). As for Group Z5, it had an even lower value (Fig. 5B). On the other hand, in this group, developmental anomalies involving deformities in the head and lower jaw regions of the fish, which occurred in 16.0% of the reared specimens, were observed (Fig. 6).

Effect of water pH on the growth and survivability of the Chinese sleeper larvae

The dissolved oxygen content during the experimental rearing ranged from 6.8 to 9.0 mg/dm^3, with temperatures ranging from 19.5 to 20.8°C. The pH, as a factor differentiating between the experimental groups, had the following average values: 6.1 ± 0.3 (Group pH 6), 7.6 ± 0.17 (Group pH 7.5) and 8.9 ± 0.16 (Group pH 9) (Table 3).

The results of the experiment showed no significant effect of the pH in the range from 6.0 to 9.0 on an increase in the body length of the Chinese sleeper larvae ($p>0.05$) (Fig. 2C). By contrast, differences were noted for the average body weight of the studied fish from Groups pH 6 and pH 7.5, as compared to those reared in water with a pH value of 9 ($p\leq0.05$) (Fig. 3C). The final values of the analysed zootechnical indices were, in this case, at a similar level in all the groups (Table 4). The cumulative mortality did not exceed 10.0% of the initial stock of the tanks in any of the variants under study (Fig. 4C). The level of mortality due to Types I and II cannibalism proved to be minimal in each group, ranging from 0.5 to 1.5% (Fig. 5C).

Discussion

The turn of the 21st century was the period when most uncontrolled or unintentional transfers of alien fish species, posing a hazard to the biodiversity of freshwater ecosystems, were recorded in Europe (Grabowska *et al*. 2010; Witkowski & Grabowska 2012; Havel *et al*. 2015). The expansion of the range of the occurrence of such fish is promoted by human activities, as well as by global climate warming resulting in a gradual increase in the average tempera-

Fig. 6. Deformities in the Chinese sleeper larvae's head and lower jaw regions: normal (up) and deformed fish (down).

Table 3

Physicochemical parameters of the water during the experimental rearing depending on the effects of varying pH on the growth and survival of the Chinese sleeper larvae

group	pH		temperature(°C)		oxygen concentration (mg/dm^3)	
	range	average (±SD)	range	average (±SD)	range	average (±SD)
pH6	5.5-6.3	6.1±0.30	19.5-20.8	20.0±0.3	6.8-8.9	8.0±0.79
pH7.5	7.4-8.0	7.6±0.17	19.5-20.8	20.0±0.3	7.5-9.0	8.2±0.55
pH9	8.5-9.4	8.9±0.16	19.5-20.8	20.0±0.3	7.8-8.5	7.9±0.42

Table 4

Values (mean ±SD) of the zootechnical parameter of the Chinese sleeper larvae after the experimental rearing. Values denoted by different letter indices in the rows are statistically significantly different (p≤0.05)

parameter	factor/group							
	temperature (°C)			salinity (‰)		pH		
	T15	T20	T25	Z0	Z5	pH6	pH7.5	pH9
ZMC (%)	11.5±0.6^a	19.2±2.7^b	20.0±0.7^b	32.9±22^a	47.2±4.4^b	21.3±2.9	19.7±1.4	21.3±1.7
ZDC (%)	3.2±0.5^a	5.1±0.9^b	5.9±0.9^b	9.6±1.0^a	21.0±4.0^b	7.1±1.2	6.1±1.0	6.5±1.0
SGR (%)	3.12±0.15^a	5.10±0.07^b	5.61±0.02^b	4.90±0.29	5.27±0.27	5.02±0.15	5.09±0.21	5.28±003
K	1.24±0.27^{ab}	1.17±0.01^a	1.39±0.03^b	1.17±0.03	1.35±0.04	1.18±0.04	1.16±0.03	1.19±002

Descriptions: ZMC – body weight variation coefficient; ZDC – body length variation coefficient; SGR – specific body weight growth; K – condition factor. The results of the Z10 group are missing due to 100% mortality recorded up to the 10th day of experimental rearing.

ture of the Earth's waters and the homogenisation of the abiotic parameters of such habitats (Occhipinti-Ambrogi 2007; Petsch 2016). The reasons for the relatively rapid spread of alien species, such as the Chinese sleeper, topmouth gudgeon or Ponto-Caspian gobies, are increasingly becoming the subject of analyses addressing changes relating to, e.g. water parameter fluctuations or the direct or indirect role of humans in these processes.

The results of this study confirmed the high plasticity and easy adaptation of the Chinese sleeper larvae to the variable values of a few crucial abiotic factors, namely, temperature, pH and salinity. At the same time, it was demonstrated that a salinity level of approximately 8-10 ‰ could inhibit the development of its juvenile stages and thus limit the possibility of its potential further expansion.

The environmental requirements of the early developmental stages of the fish are different from those of adult specimens, as the eggs and larvae are more susceptible to fluctuations in the abiotic water parameters (Lopes *et al*. 2020). For the Chinese sleeper larvae, it was demonstrated that water temperature was potentially a crucial factor in the context of differentiating between their rate of body growth. This is because, as early as seven days after the experimental rearing, significant differences in body weight were observed in the groups of fish kept in varying thermal variants. The specimens reared in water at 25°C reached the highest final average body weight (81.3 ± 16.3 mg), which was five times higher than those kept in water at a temperature 10°C. In addition, varied mortality of the Chinese sleeper larvae was noted in the experimental variants. The largest differences in the values of this parameter were revealed for a four-week rearing, where the differentiating factor was the water temperature. The highest mortality rate was noted in the group of fish reared in water at an average temperature of 15°C, and it was associated with both cannibalism and a generally poorer fish condition. These results suggest that water temperatures at a level of 15°C or less can have an adverse effect on the early ontogeny of the Chinese sleeper, and thus significantly limit its survivability. This may be confirmed by the fact that the natural spawning of this species is usually initiated once water temperatures reach above 15°C (Kottelat & Freyhof 2007). The greatest average body length and weight were achieved by the Chinese sleeper larvae reared at 25°C, with this result confirming the observations made by Golovanov *et al.* (2013), who recognised temperatures in the order of 27°C as preferable and close to the optimum for juvenile forms of the Chinese sleeper. Given the accelerated rate of warming of the Earth's climate and the associated progressive increase in surface water temperatures, this may be an additional factor that is positively affecting the reproductive success of the Chinese sleeper. Consequently, this may translate into an intensification of the process of the expansion of this species into new territories in the decades to come (Pupins *et al*. 2023).

Fish, being poikilothermic organisms, are capable of regulating their physiological processes in response to persistent changes in ambient temperatures (Gunderson & Stillman 2015). In adult fish, the acclimatisation to changing temperatures is carried out by compensatory systems, with the involvement of the thyroid hormone (Little *et al*. 2013). As for juveniles, this response, which is induced during the early stages of development, has primarily a genetic basis, as the functioning of the endocrine system is poorly advanced (Le Roy *et al*. 2017). The ability of individual species to compensate for thermal changes is important for the conservation of ichthyofaunal biodiversity, as it will determine the vulnerability of different taxa to both present and future climate change (Little *et al*. 2020). On the other hand, higher water temperatures can modify the social behaviour of fish due to changes in their physiological mechanisms, thus significantly affecting intra- and inter-species interactions that can disturb the functioning of ecosystems in a warmer environment (Alfonso *et al*. 2021). This is manifested, for example, by an increase in their locomotor activity or more frequent aggressive behaviour (Angiulli *et al*. 2020).

The Chinese sleeper is a species that gradually colonises new water bodies. However, even though its presence in brackish water has been noted (Popov 2014; Kvach *et al*. 2021), there is no available data on its behaviour and reproductive capacity under such conditions. The results of the experiment involving the rearing of the Chinese sleeper larvae in water of varying salinity (from 0 to 10‰) showed a higher larval mortality at a level of 42.5% in the group with a salinity of 5‰, and death of all the specimens in the variant where the highest salinity was applied. The 100% mortality of the stock, noted over the initial eight days of the experiment, clearly shows that a salinity value in the order of 10‰ is close to lethal for the Chinese sleeper in its juvenile stages. On the other hand, a salinity in the order of 5‰ has been observed to have a positive effect on the larval growth rate. It needs to be noted, however, that this simultaneously resulted in the emergence of a small percentage of specimens (approximately 12% of the stock) with body deformities, such as deformities in the head region. Nonetheless. these anomalies did not affect the larval capacity to feed or move freely, which confirms the high plasticity of the species in response to environmental changes. It can therefore be concluded that the Chinese sleeper is not only able to survive in brackish waters, but also to develop properly in them, indicating that it may colonise and consequently generate a serious threat to native ichthyofauna inhabiting, for example, euryhaline areas in the estuarine zones of large rivers.

The tolerance to varying salinity and its effect on the growth and development of invasive species are often dependent on the original range limit of the fish. As for the round goby *Neogobius melanostomus* (Pallas, 1814), which, in Poland, primarily inhabits the Baltic Sea coast, a salinity at a level of 7.5‰ has a positive effect on its growth and condition (Hempel & Thiel 2015). This characteristic probably stems from its original origin, with a natural habitation in the brackish waters (estuaries and river mouths) feeding the Black Sea, Sea of Azov and the Caspian Sea; namely, the Dnieper, Dniester, Don, Kuban and the rivers of the Caucasus.

The responses in the early life stages of primarily marine fish to changes in water pH are relatively well recognised, especially in recent decades, where increasing CO_2 concentrations in the oceans have resulted in the increased acidity of this environment, thus contributing to an increased mortality of their larvae (Kikkawa *et al*. 2003). In freshwater environments, acidification has become more common due to increased acid leaching from the soil, pollutants, acid rain, agricultural and mining runoff, or the increased CO_2 levels caused by climate change (Hogsden & Harding 2012). The experiment, which was aimed at determining the effect of a varying water pH ranging from 6.0 to 9.0 on early post-embryonic stages of the Chinese sleeper, showed no significant intergroup changes with regard to the zootechnical parameters under analysis. The observed low level of stock mortality in the individual variants did not exceed 10%, and the uniform growth and good condition of the fish clearly indicate the high tolerance of the juvenile forms of this species to changes in the pH values.

A similar study on the effect of a varying water pH on the early stages of ontogenetic development was conducted on other species classified as invasive alien species found in Poland, i.e. the racer goby and topmouth gudgeon (Hliwa 2010). In four weeks of experimental rearing, the analyses revealed differences in the average weight and length values for the racer goby larvae, primarily between the specimens from Groups pH 6.0 and pH 7.5. A high statistically significant value of the intergroup cumulative mortality was also noted, resulting mainly from inter-individual cannibalism. Until Day 14 of the study it did not exceed 20%, but gradually increased to a level of 48.9% in Group pH 6.0, and reached as much as 75.6% of the stock in the group of the racer goby larvae kept in water with the highest pH value of 9.0 (Hliwa 2010). The final value of this parameter proved, in general, to be considerably higher compared to the results of a study conducted under experimental conditions analogous to those used for the Chinese sleeper. In general, the adaptability of the Chinese sleeper to varying water pH values has been confirmed, e.g. by reports of its habitation in highly-acidic water bodies. This is because its presence has been recorded in places such as former peat excavation sites where, in addition, there were periodic mass deaths of fish in the summer and winter periods (Baranov & Vasil'ev 2022).

The laboratory test results prove that the Chinese sleeper exhibits high plasticity in many dimensions with respect to changes in the environmental parameters. The experiments conducted on the larvae of other fish species, including those of economic significance, such as carp *Cyprinus carpio* L., pike *Esox lucius* L. and perch *Perca fluviatilis* L., have also confirmed that temperature, salinity and the water pH usually have a crucial effect on the growth and survivability of fish (Korwin-Kossakowski 1988; Saat & Veersalu 1996; Jacobsen *et al*. 2007).

As for the Chinese sleeper, there is still little documented data available on its effect on the native ichthyofauna. In general, however, alien fish species may prove to be more efficient in competing for food than native ones, or they may be unfamiliar and, therefore, much more dangerous predators (Havel *et al*. 2015). The Chinese sleeper is perceived as a potential food competitor with native fish species, and such interactions are likely to intensify, particularly in small biotopes with poor food resources (Grabowska *et al*. 2019). Homogenisation or abrupt changes in abiotic factors, leading to the disruption of previously stabilised interspecies relationships in ecosystems, usually promote a range expansion by the alien species. What is more, the invasive taxa can sometimes strongly alter the hydrology, biogeochemical cycle or the biotic composition of the invaded ecosystems themselves and thus modulate the effects of other stressors (Strayer 2010). In this context, it is particularly important to extend the knowledge of the biology (particularly with regard to reproduction) of the Chinese sleeper, as this may indirectly contribute to the development of optimal and universal methods aimed at the protection of ichthyofaunal biodiversity. This is because the pressure exerted by the Chinese sleeper on the native taxa is increasingly resulting in the displacement of the latter, and thus, in the impoverishment of the qualitative and quantitative structure of water-based organisms inhabiting aquatic ecosystems.

Author Contributions

Research concept and design: P.W.H., M.B.; Collection and/or assembly of data: M.B.; Data analysis and interpretation: M.B.; Writing the article: P.W.H., M.B.; Critical revision of the article: P.W.H., M.B.; Final approval of article: P.W.H., M.B.

Funding

This study was financed by state funds appropriated to University of Warmia and Mazury under Code No. 11.610.015-110 and funded by the Minister of Science under the "Regional Initiative of Excellence Programme 2024-2027".

Conflict of Interest

The authors declare no conflict of interest.

References

Alfonso S., Gesto M., Sadoul B. 2021. Temperature increase and its effects on fish stress physiology in the context of global warming. J. Fish Biol. **98**: 1496-1508. https://doi.org/10.1111/jfb.14599

Angiulli E., Pagliara V., Cioni C., Frabetti F., Pizzetti F., Alleva E., Toni M. 2020. Increase in environmental temperature affects exploratory behaviour, anxiety and social preference in *Danio rerio*. Sci. Rep. **10**: 1-12. https://doi.org/10.1038/s41598-020-62331-1

Antal L., Székely C., Molnár K. 2015. Parasitic infections of two invasive fish species, the Caucasian dwarf goby and the Amur sleeper, in Hungary. Acta Vet. Hung. **63**: 472-484. https://doi.org/10.1556/004.2015.044

Baranov V.Y., Vasil'ev A.G. 2022. Phenotypic plasticity of the Amur sleeper (*Perccottus glenii*) invasive populations during the colonization of water bodies. Russ. J. Biol. Invasions **13**: 412-427. https://doi.org/10.1134/S2075111722040038

Bogutskaya N.G., Naseka A.M. 2002. *Perccottus glenii* Dybowski, 1877. Freshwater Fishes of Russia. Zoological Institute RAS. Available on internet at http://www.zin.ru/Animalia/Pisces/eng/taxbase_e/species_e/perccottuss_el.htm (last accessed on: 10 January 2024).

Bogutskaya N.G., Naseka A.M., Shedko S.V., Vasiléva E.D., Chereshnev I.A. 2008. The fishes of the Amur River: updated check-list and zoogeography. Ichthyol. Explor. Fres. **19**: 301-366.

Cambray J.A. 2003. Impact on indigenous species biodiversity caused by the globalization of alien recreational freshwater fisheries. Hydrobiologia **500**: 217-230. https://doi.org/10.1023/A:1024648719995

Fayzulin A.I. 2021. Impact assessment of the Amur sleeper *Perccottus glenii* Dybowski, 1877 on amphibians in Samara Oblast. IOP Conf. Ser.: Earth Environ. Sci. **818**: 012009. https://doi.org/10.1088/1755-1315/818/1/012009

Golovanov V.K., Kapshai D.S., Gerasimov Y.V., Golovanova I.L., Karabanov D.P., Smirnov A.K., Shlyapkin I.V. 2013. Thermopreference and thermostability of the Amur sleeper juveniles *Perccottus glenii* in autumn. J. Ichthyol. **53**: 240-244. https://doi.org/10.1134/S0032945213020033

Grabowska J., Kotusz J., Witkowski A. 2010. Alien invasive fish species in Polish waters: an overview. Folia Zool. **59**: 73-85. https://doi.org/10.25225/fozo.v59.i1.a1.2010

Grabowska J., Pietraszewski D., Przybylski M., Tarkan A., Marszał L., Lampart-Kałużniacka M. 2011. Life-history traits of Amur sleeper, *Perccottus glenii*, in the invaded Vistula River: Early investment in reproduction but reduced growth rate. Hydrobiologia **661**: 197-210. https://doi.org/10.25225/fozo.v59.i1.a1.2010

Grabowska J., Błońska D., Kati S., Nagy S., Kakareko T., Kobak J., Antal L. 2019. Competitive interactions for food resources between the invasive Amur sleeper (*Perccottus glenii*) and threatened European mudminnow (*Umbra krameri*). Aquat. Conserv. **29**: 2231-2239. https://doi.org/10.1002/aqc.3219

Gunderson A.R., Stillman J.H. 2015. Plasticity in thermal tolerance has limited potential to buffer ectotherms from global warming. Proc. Roy. Soc. B. **282**: 20150401. https://doi.org/10.1098/rspb.2015.0401

Havel J.E., Kovalenko K.E., Thoma S.M., Amalfitano S., Kats L.B. 2015. Aquatic invasive species: challenges for the future. Hydrobiologia **750**: 147-170. https://doi.org/10.1007/s10750-014-2166-0

Hempel M., Thiel R. 2015. Effects of salinity on survival, daily food intake and growth of juvenile round goby *Neogobius melanostomus* (Pallas, 1814) from a brackish water system. J. Appl. Ichthyol. **31**: 370-374. https://doi.org/10.1111/jai.12696

Hliwa P. 2010. Elementy biologii rozrodu przedstawicieli obcej inwazyjnej ichtiofauny – babki łysej *Neogobius gymnotrachelus* (Kessler, 1857) i czebaczka amurskiego *Pseudorasbora parva* (Temminck and Schlegel, 1846) [Elements of the reproductive biology of alien invasive fish species, racer goby *Neogobius gymnotrachelus* (Kessler, 1857) and topmouth gudgeon *Pseudorasbora parva* (Temminck et Schlegel, 1846)]. Rozprawy i Monografie. Uniwersytet Warmińsko-Mazurski w Olsztynie, **156**: 1-97. (In Polish with English summary).

Hogsden K.L., Harding J.S. 2012. Anthropogenic and natural sources of acidity and metals and their influence on the structure of stream food webs. Environ. Pollut. **162**: 466-474. https://doi.org/10.1016/j.envpol.2011.10.024

Jacobsen L., Skov C., Koed A., Berg S. 2007. Short-term salinity tolerance of northern pike, *Esox lucius*, fry, related to temperature and size. Fisheries Manag. Ecol. **14**: 303-308. https://doi.org/10.1111/j.1365-2400.2007.00551.x

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

Kati S., Mozsár A., Árvad D., Cozma N.J., Czeglédi I., Antal L., Nagy S.A., Erõs T. 2015 Feeding ecology of the invasive Amur sleeper (*Perccottus glenii* Dybowski, 1877) in Central Europe. Int. Rev. Hydrobiol. **100**: 116-128. https://doi.org/10.1002/iroh.201401784

Kikkawa T., Ishimatsu A., Kita J. 2003. Acute CO_2 tolerance during the early developmental stages of four marine teleosts. Environ. Toxicol. **18**: 375-382. https://doi.org/10.1002/tox.10139

Kirczuk L., Dziewulska K., Czerniejewski P., Brysiewicz A., Rechulicz J., Ligięza J. 2024. Annual reproductive cycle of Chinese sleeper *Perccottus glenii*, Dybowski, 1877 (Teleostei: Gobiiformes: Odontobutidae) an invasive fish inhabiting Central Europe. The European Zool. J. **91**: 105-121. https://doi.org/10.1080/24750263.2023.2301438

Korwin-Kossakowski M. 1988. Larval development of carp, *Cyprinus carpio* L., in acidic water. J. Fish Biol. **32**: 17-26. https://doi.org/10.1111/j.1095-8649.1988.tb05332.x

Kottelat M., Freyhof J. 2007. Handbook of European freshwater fishes. Cornol, Switzerland and Berlin, Germany, Pp. 549-550.

Kvach Y., Karavanskyi Y., Tkachenko P., Zamorov V. 2021. First record of the invasive Chinese sleeper, *Perccottus glenii* Dybowski, 1877 (Gobiiformes: Odontobutidae) in the Black Sea. BioInv. Records **10**: 411-418. https://doi.org/10.3391/bir.2021.10.2.19

Le Roy A., Loughland I., Seebacher F. 2017. Differential effects of developmental thermal plasticity across three generations of guppies (*Poecilia reticulata*): canalization and anticipatory matching. Sci. Rep. **7**: 4313. https://doi.org/10.1038/s41598-017-03300-z

Little A.G., Kunisue T., Kannan K., Seebacher F. 2013. Thyroid hormone actions are temperature-specific and regulate thermal acclimation in zebrafish (*Danio rerio*). BMC Biol. **11**: 26. https://doi.org/10.1186/1741-7007-11-26

Little A.G., Loughland I., Seebacher F. 2020. What do warming waters mean for fish physiology and fisheries? J. Fish Biol. **97**: 328-340. https://doi.org/10.1111/jfb.14402

Lopes A.F., Faria A.M., Dupont S. 2020. Elevated temperature, but not decreased pH, impairs reproduction in a temperate fish. Sci. Rep. **10**: 20805. https://doi.org/10.1038/s41598-020-77906-1

Lushchak V.I., Bagnyukova T.V. 2007. Hypoxia induces oxidative stress in tissues of a goby, the rotan *Perccottus glenii*. Comp. Biochem. Phys. B. **148**: 390-397. https://doi.org/10.1016/j.cbpb.2007.07.007

Martemyanov V., Mavrin A., Shuman L. 2021. Minimum cations concentrations in water required for maintenance of ion balance between the Amur sleeper *Perccottus glenii* (Pisces) and the external environment. Inland Water Biol. **14**: 797-802. https://doi.org/10.1134/S1995082921060079

Mierzejewska K., Martyniak A., Kakareko T., Hliwa P. 2010. First record of *Nippotaenia mogurndae* Yamaguti and Miyata, 1940 (Cestoda, Nippotaeniidae), a parasite introduced with Chinese sleeper to Poland. Parasitol. Res. **106**: 451-456. https://doi.org/10.1007/s00436-009-1685-5

Mills M.D., Rader R.B., Belk M.C. 2004. Complex interactions between native and invasive fish: the simultaneous effects of multiple negative interactions. Oecologia **141**: 713-721. https://doi.org/10.1007/s00442-004-1695-z

Occhipinti-Ambrogi A. 2007. Global change and marine communities: Alien species and climate change. Mar. Pollut. Bull. **55**: 342-352. https://doi.org/10.1016/j.marpolbul.2006.11.014

Ondračková M., Matějusová I., Grabowska J. 2012. Introduction of *Gyrodactylus perccotti* (Monogenea) into Europe on its invasive fish host, Amur sleeper (*Perccottus glenii*, Dybowski 1877). Helminthologia **49**: 21-26. https://doi.org/10.2478/s11687-012-0004-3

Petsch D.K. 2016. Causes and consequences of biotic homogenization in freshwater ecosystems. Int. Rev. Hydrobiol. **101**: 113-122. https://doi.org/10.1002/iroh.201601850

Popov I.Y. 2014. New fish species in the Russian part of the Gulf of Finland and inland water bodies of St. Petersburg and Leningrad Oblast. Russ. J. Biol. Inv. **5**: 90-98. https://doi.org/10.1134/S207511171402009X

Pupina A., Pupins M., Nekrasova O., Tytar V., Kozynenko I., Marushchak O. 2018. Species distribution modelling: *Bombina bombina* (Linnaeus, 1761) and its important invasive threat *Perccottus glenii* (Dybowski, 1877) in Latvia under global climate change. J. Env. Res. Eng. Manag. **74**: 79-86. https://doi.org/10.5755/j01.erem.74.4.21093

Pupins M., Nekrasova O., Marushchak O., Tytar V., Theissinger K., Čeirāns A., Skute A., Georges J.Y. 2023. Potential threat of an invasive fish species for two native newts inhabiting wetlands of Europe vulnerable to climate change. Diversity **15**: 201. https://doi.org/10.3390/d15020201

Reshetnikov A.N. 2010. The current range of amur sleeper *Perccottus glenii* Dybowski, 1877 (Odontobutidae, Pisces) in Eurasia. Russ. J. Biol Inv. **1**: 119-126. https://doi.org/10.1134/S2075111710020116

Reshetnikov A.N, Schliewen U.K. 2013. First record of the invasive alien fish rotan *Perccottus glenii* Dybowski, 1877 (Odontobutidae) in the Upper Danube drainage (Bavaria, Germany). J. Appl. Ichthyol. **29**: 1367-1369. https://doi.org/10.1111/jai.12256

Saat T., Veersalu A. 1996. The rate of early development in perch *Perca fluviatilis* L. and ruffe *Gymnocephalus cernuus* (L.) at different temperatures. Ann. Zool. Fenn. **33**: 693-698.

Sokolov S.G., Protasova E.N., Reshetnikov A.N. 2015. First data on parasites of the rotan, *Perccottus glenii* Dybowski, 1877 (Perciformes: Odontobutidae), from Germany, with a detection of the previously unknown merocercoid of the gryporhynchid cestode *Mashonalepis macrosphincter* (Fuhrmann, 1909). Acta Zool. Bulg. **67**: 557-560.

Strayer D.L. 2010. Alien species in fresh waters: ecological effects, interactions with other stressors, and prospects for the future. Fresh. Biol. **55**: 152-174. https://doi.org/10.1111/j.1365-2427.2009.02380.x

Szczerbik P., Nowak M., Nocoń J., Łuszczek-Trojnar E., Drąg-Kozak E., Chyb J., Popek W. 2023. Study of the diets of two coexisting species – invasive Chinese sleeper (*Perccottus glenii* Dybowski, 1877) and native European perch (*Perca fluviatilis* Linnaeus, 1758). Folia Biol. Kraków **71**: 19-27. https://doi.org/10.3409/fb_71-1.03

Witkowski A., Grabowska J. 2012. The non-indigenous freshwater fishes of Poland: threats for native ichthyofauna and consequence for fishery: a review. Acta Ichthyol. Piscat. **42**: 77-87. https://doi.org/10.3750/AIP2011.42.2.01

Wolnicki J., Kolejko M. 2008. The state of the lake minnow population in the water ecosystems of Polesie Lubelskie and the basis of the species protection program in this region of the country. Nature monograph. Liber-Duo s.c., Lublin, Pp. 1-89. https://doi.org/10.2478/v10086-011-0025-4