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OBSERVATIONS OF THE SIGNAL CRAYFISH *PACIFASTACUS LENIUSCULUS* (DANA) IN A LAKE IN THE EASTERN SUWAŁKI LAKE DISTRICT

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ABSTRACT. The aim of the study was to identify the characteristics of a population of signal crayfish *Pacifastacus leniusculus* (Dana) which were introduced into the lake eleven years ago. In 1992, 1,100 one-year-old signal crayfish specimens were released into the lake. The lake has a surface area of 57.6 ha, an average depth of 5.9 m and a maximum depth of 15.4 m and is currently in a moderately advanced trophic state. The lake was inhabited by numerous populations of the noble crayfish *Astacus astacus* (L.) until 1988 when they were poisoned. The catch rate statistics of crayfish fishermen have indicated that the growth in the signal crayfish populations has been progressive since 1996. In 1998, the sixth year they inhabited the lake, the size of the catch population, which occurred in that and in following years, was formed. Specimens measuring from 11 to 14 cm dominated in this population, while only a very few crayfish specimens reached a length of approximately 16 cm. As the crayfish specimens increased in body length, the male body weight predominance over female body weight also increased. While for specimens 10 cm long this figure was as high as 17.5%, for 16 cm long specimens it peaked at 33.6%. Noble and narrow-clawed crayfish have also been observed in control catches since 1999. The signal crayfish had similar weights at the same body lengths to those of the noble and narrow-clawed crayfish *Astacus leptodactylus* Esch. and were heavier than the spiny-cheek crayfish *Orconectes limosus* (Raf.). The signal crayfish reproduce in late September and early October, which is at least two weeks earlier than indigenous crayfish.

Key words: SIGNAL CRAYFISH *(PACIFASTACUS LENIUSCULUS)*, INTRODUCTION, GROWTH, AGE, SEXUAL DIMORPHISM

INTRODUCTION

The first attempts to introduce signal crayfish *Pacifastacus leniusculus* (Dana) to Polish waters were undertaken in the 1970s (Kossakowski et al. 1978, 1983). Contrary to the original expectations of the project's instigators, the introduction was at least partially successful. This crayfish species reproduced in and inhabited a water-filled gravel pit near Stare Juchy and Ełk in northern Poland until at least 1991 (Krzywosz et al. 1995a). Additionally, a signal crayfish population which originates from this period currently inhabits one of the Masurian Province rivers (Krzywosz and Krzywosz 2001).

In the early 1990s another attempt to cultivate the signal crayfish in Poland was undertaken. Young specimens were imported from Sweden and cultivated at two locations in the Masurian Province of northern Poland. The specimens reared at the Dgał Experimental Hatchery in Pieczarki near Giżycko were moved to the Aquamar closed cultivation facility in Miastko (Krzywosz 1999). The signal crayfish produced at the Stocking Center of the Polish Anglers' Association in Gawrych Ruda on Lake Wigry, were introduced into two lakes. They still inhabit one of these lakes, and it is this population that is the subject of this study. In the 1990s, a successful attempt to introduce these crayfish into the Pomeranian Lake District was made (Śmietana – personal communication). The fact that the signal crayfish inhabits open Polish waters is unquestionable.

Information regarding the ability of the signal crayfish to adapt to Polish conditions and how they cope with inhabiting these environments is not abundant (Kossakowski et al. 1978, 1983, Krzywosz 1994, Krzywosz et al. 1995a, Krzywosz and Krzywosz 2001). The same is true of interactions between the signal crayfish and Polish crayfish, including the noble crayfish *Astacus astacus* (L.) and the narrow-clawed crayfish *Astacus leptodactylus* Esch. There is also very little information regarding interactions between signal crayfish and spiny-cheek crayfish *Orconectes limosus* (Raf.) (Krzywosz and Krzywosz 2001). Although the species *Aphanomyces astaci* is the more likely culprit, the signal crayfish is associated with transferring the "plague", which is deadly for indigenous Polish crayfish. The disease has yet to manifest itself in the studied lake, but it should still be carefully observed.

The aim of this work was to determine to what degree the introduced signal crayfish has adapted to the conditions prevailing in the studied lake, and to describe the features of the population which has formed over the 11 years since introduction.

MATERIAL AND METHODS

STUDY AREA

The studies were carried out in one of the lakes in the Eastern Suwałki Lake District located in the drainage area of the Pregoła River (Fig. 1). In an effort to prevent uncontrolled catches and illegal signal crayfish transfers, neither the name of the lake nor its location are given. The area of the lake is 57.6 ha, the maximum depth is 15.4 m and the average depth is 5.9 m. The lake has several intermittent tributaries and one intermittent outlet.

The ichthyofauna is dominated by Cyprinidae and perch *Perca fluviatilis* L. and pikeperch *Esox lucius* L, but there are no eel *Anguilla anguilla* L.

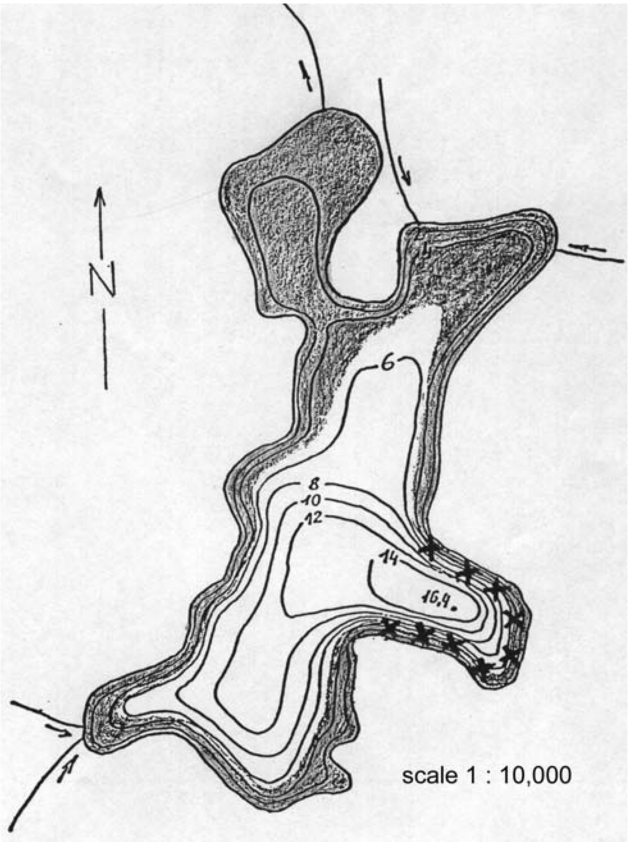

Fig. 1. Bathymetric plan, vegetation range of occurrence in the lake (dark area) and areas where crayfish were caught (X).

The emerged flora is mainly represented by reed *Phragmites australis* (Cav.), cattail *Typha latifolia* L., lake bulrush *Schoenoplectus lacustris* (L.) Palla, manna-grass *Glyceria aquatica* (L.) Wahlb. and horsetail *Equisetum limosum* L. These plant species cover approximately 10% of the area of the lake and grow along most of the shoreline forming denser aggregations in the bays. The submerged flora occurs at depths of up to 5 m, and there are large meadows comprised mainly of water-thyme *Elodea canadensis* Rich. and stoneworts *Chara* sp. There are also several species of pond-weeds *Potamogeton* sp., water nimfoils *Myriophyllum spicatum* L. and *Myriophyllum verticillatum* L., horn-wort *Ceratophyllum demersum* L. and water-lily *Nuphar luteum* (L.) Sm. Isoetes *Isoëtes lacustris* L., a plant which is characteristic in lakes with low eutrophication, inhabits the hard, or even stony, bottoms of the eastern part of the lake. The total area of the lake covered by submerged flora is 21%.

MATERIALS

The appropriate habitats for crayfish are present along almost the entire shoreline of the lake; the silty, northeastern bay is the one exception (Fig. 1). The area suitable for noble crayfish inhabitation was estimated at 13.5 ha (Białokoz and Krzywosz, unpublished data). In the 1968 – 1987 period the average, annual noble crayfish catch in this lake was 731 kg and its average efficiency was relatively high at 54 kg per ha.

In 1988, the entire noble crayfish population in the lake was killed by improperly conducted fertilization and crop dusting in the drainage area of the lake (Białokoz, unpublished data).

In May 1992, 1,100 one-year-old signal crayfish specimens from the Stocking Center in Gawrych Ruda were introduced into the lake. Their sizes varied greatly from 1.6 to 6.8 cm with an average length of 3.4 cm.

Crayfish control catches have been conducted since 1996 with Swedish Evo-type crayfish traps with fish as bait. A total of 1,314 specimens were caught. Measurements of body length (± 0.1 cm – from the rostrum to the end of the telson) and weight (± 1g) were taken and each specimen was sexed. The dependence of body weight on body length in specimens of both sexes which had not lost their pincers was determined using the simple regression method and STATGRAPHICS Plus 4. This dependence is expressed by the power equation $W = al^n$ where: W – body weight (g); l – body length (cm); a, n – coefficients.

ENVIRONMENT

Studies of the physical and chemical water parameters were conducted in order to determine their quality and to describe the conditions in which the crayfish live. Standard Methods were applied (Standard Methods 1975, Hermanowicz et al. 2000). The quality and quantity composition of phytoplankton were also determined.

Temperature and oxygen profiles of the lake were conducted in August 2001 during the peak of summer stagnation and at its end in September (Fig. 2).

RESULTS

THE LAKE ENVIRONMENT

At the peak of summer stagnation the layer of well-mixed and oxygenated epilimnion water extended to a depth of 5 m. The temperature gradient was observed

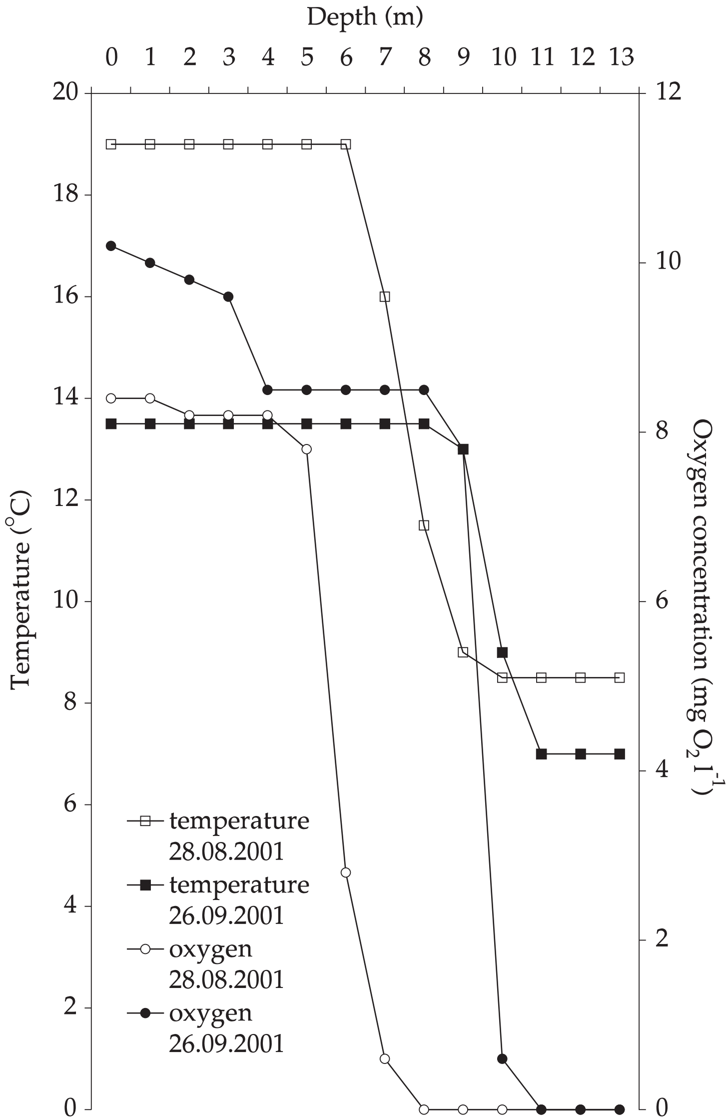

Fig. 2. Oxygen content and water temperature distribution.

in the water layer from 6 to 9 meters, and this layer was almost devoid of oxygen. Autumn mixing deepened the well-oxygenated epilimnion layer to 9 m.

The contents of ammonia nitrogen ($N\text{-}NH_4$), nitrate nitrogen ($N\text{-}NO_3$) and nitrite nitrogen ($N\text{-}NO_2$) were relatively low in the tested sample, while the content of phosphorus, especially of mineral phosphorus ($P\text{-}PO_4$), was high (Table 1).

TABLE 1

Physical and chemical parameters of the lake water on 28 August 2001

Parameter	Surface	Bottom	Purity class*
Visibility (m)	2.7		II
pH	8.15	7.26	
mg CO_2 l^{-1}	0.20	0.40	
mg CO_3^{-2} l^{-1}	0.000	0.000	
mg HCO_3^- l^{-1}	171.0	195.0	
mg N-NH_4 l^{-1}	0.155	0.678	I
mg N-$N0_2$ l^{-1}	0.000	0.014	I
mg N-NO_3 l^{-1}	0.026	0,065	I
mg P-PO_4 l^{-1}	0.068	0.212	III
mg P-Tot l^{-1}	0.021	0.072	II
mg Ca^{+2} l^{-1}	37.0	43.0	
mg Mg^{+2} l^{-1}	9.7	9.7	
Permanganate value	19.2	19.2	II
mg Cl^{-1} l^{-1}	7.0	7.0	

** - Lake purity class according to Kudelska et al. (1983)*

TABLE 2

Taxonomic composition and amount of lake plankton on 28 August 2001

Species	Specimen l^{-1}
Cyanoprokaryota	
Anabaena spiroides Klebahn	42
Anabaena flos-aquae Bébisson, ex Bornet et Flahault	146
Aphanizomenon flos-aquae [L.] Ralfs ex Bornet et Flahaut	146
Lyngbya sp.	1,562
Merismopedia sp.	21
Microcystis viridis (A. Braun in Rabenhorst) Lemmermann	42
Microcystis aeruginosa (Kützing)	42
Oscillatoria sp.	21
Cryptophyceae	
Cryptomonas erosa Ehrenberg	167
Dinophyceae	
Ceratium hirundinella O. F. Müller	229
Peridinium sp.	42
Bacillariophyceae	
Asterionella formosa Hassal	21
Aulacoseira italica (Ehrenberg) Simonsen	42
Cocconeis plancetula Ehrenberg	42
Cosmarium sp.	21
Fragilaria ulna var. *acus* (Kützing) Lange-Bertalot	21
Fragilaria ulna (Nitzch) Lange-Bertalot var. ulna	21
Stephanodiscus rotula (Kützing) Hendey	21
Euglenophyceae	
Trachelomonas volvocina Ehrenberg	250
Chlorophyta	
Actinastrum hantzschii Lagerheim	42
Total	2,937

The occurrence of a total of 21 phytoplankton species representing 6 taxonomic groups was confirmed. The greatest abundance was observed for Cyanophyceae (Table 2).

POPULATION OF SIGNAL CRAYFISH

The diagrams in Fig. 3 depict the abundance, size distribution and sex ratio of the crayfish caught in particular years. Catches lasting 24 hours were conducted in the first three years; this resulted in a relatively small number of samples. Females dominated in them. More numerous samples were obtained in 2000 and 2001, when catches lasted for four and five days, respectively. The numbers of males and females were similar in these samples. Specimens between 6.4 and 16.9 cm in length and 11.1 to 193.2 g in weight were present in the sample. The catch efficiency of the crayfish traps increased and was 2.5 specimen trap^{-1} night^{-1} in 2001. Table 3 presents data regarding the times and effectivity of catches, the numbers of specimens caught, the sex ratio and the averages and ranges of body lengths and weights.

TABLE 3

Results of control catches of signal crayfish (average values (x), ranges and standard deviation - SD)

Parameter	Sampling Date				
	1996 29-30 August	1997 29-30 August	1999 29-30 September	2000 4-8 September	2001 3-7 and 25-26 September
Catch effectivity (spec. trap^{-1} night^{-1})	1.40	1.33	1.35	1.67	2.46
Females					
Body length (cm)					
n	16	15	7	263	320
x (min-max)	10.5 (8.0-13.4)	11.9 (8.1-15.5)	11.0 (8.9-14.4)	11.9 (8.4-15.2)	11.9 (7.6-15.9)
SD	1.6	1.8	2.1	1.2	1.3
Body weight (g)					
n			7	263	51
x (min-max)			43.1 (18.5-83.9)	55.1 (11.1-128.6)	56.5 (27.9-99.1)
SD			25.3	18.1	18.0
Males					
Body length (cm)					
n	26	25	31	283	327
x (min-max)	11.0 (7.1-13.3)	10.9 (8.3-13.9)	12.5 (8.6-15.5)	12.4 (7.9-16.0)	12.5 (6.4-16.9)
SD	1.7	1.9	1.9	1.4	1.8
Body weight (g)					
n			31	283	68
x (min-max)			81.9 (19.9-181.1)	86.1 (16.5-180.1)	90.3 (12.1-193.2)
SD			43.2	32.1	41.5

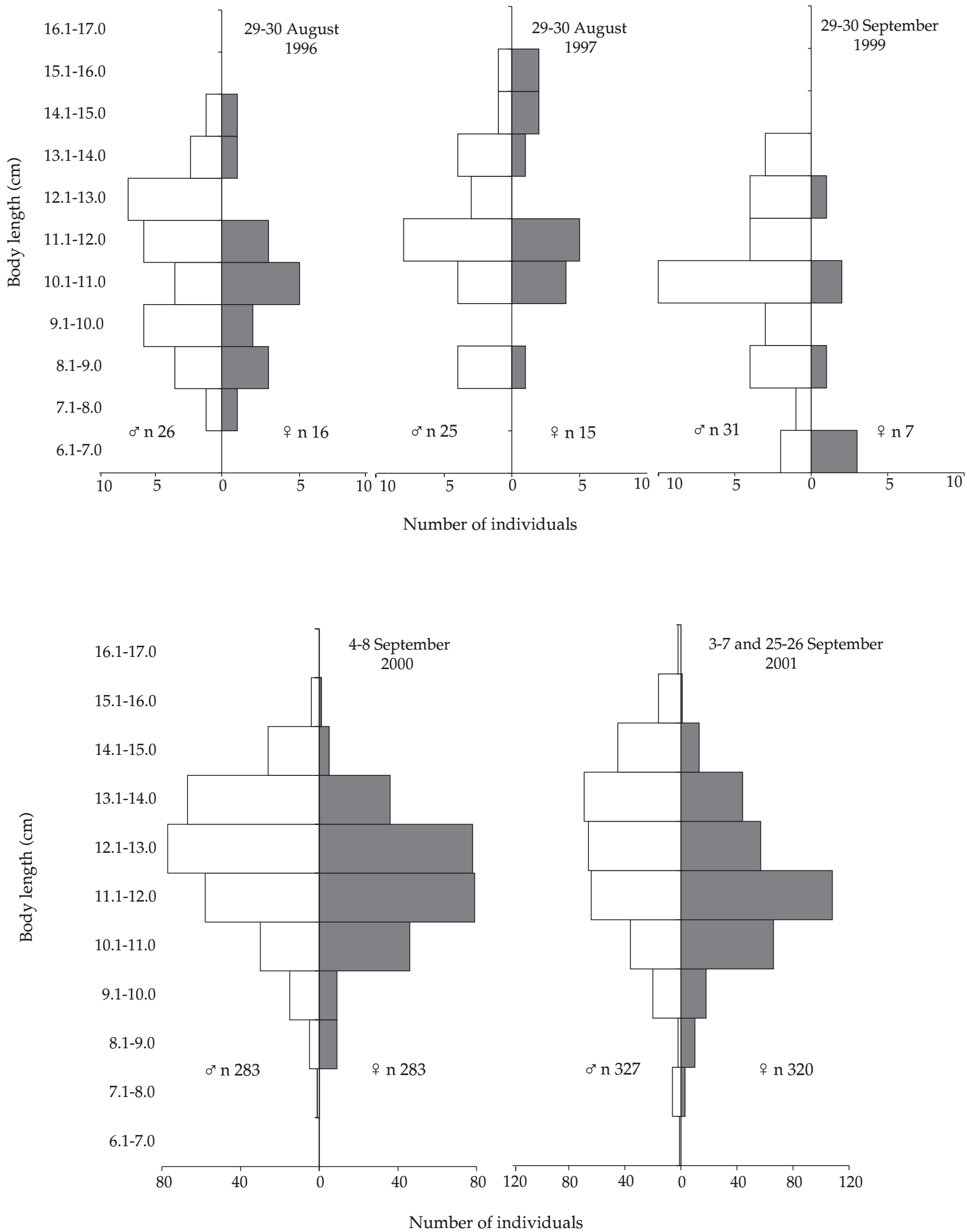

Fig. 3. Quantitative distribution of the catch population in the years studied.

The presence of the noble crayfish and spiny-cheek crayfish has been observed since 1999. In control catches of crayfish in 2001, the noble crayfish constituted approximately 3% and the spiny-cheek crayfish approximately 27%.

The signal crayfish inhabiting the lake reproduced in late September and early October.

DISCUSSION

Based on the majority of the physical and chemical parameters, this lake can be classified as one with a medium degree of eutrophication, which places it in purity class II (Kudelska and Soszka 1996).

The phytoplankton species composition, dominated by Cyanophyceae, also indicates that there is a medium degree of eutrophication in the lake. The small amounts of phytoplankton and seston and good Secchi disk visibility confirm that the trophic status of the lake is not very advanced. What is regarded as a relatively good trophic level in Poland, however, is far from that of the oligotrophic Lake Tahoe, where the nitrogen and potassium content were an average six and ten times lower, respectively, and visibility extended to 28 m (Goldman 1973, Goldman and Rundquist 1977). Signal crayfish from Lake Tahoe were introduced in Europe in the 1960s (Abrahamsson 1973, Brinck 1977). The Swedish lakes where the greatest numbers of signal crayfish were first introduced have lower trophic levels, though they usually contain less calcium and have a lower pH than the optimum for crayfish (Appelberg 1992). The pH and calcium content in the lake featured in the current study are close to the optimum for crayfish.

A significant oxygen deficit is observed in the deeper layers of the studied lake during the summer and winter stagnation periods. At the peak of summer stagnation the necessary oxygen content for crayfish survival is found only in the 5 m layer of the epilimnion, and by late August, crayfish were caught only in this layer. Autumn winds deepened the epilimnion (Fig. 2), and in late September, the layer penetrated by crayfish reached 9 m, and specimens were caught at this depth.

Some of the introduced crayfish were able to mate as soon as the autumn of 1992, i.e. in the second year of life. Observations at the Dgał Experimental Hatchery, where signal crayfish were also cultivated, confirm this (Krzywosz 1994). In 1996 control catches were first conducted in this lake, and, in addition to the parents, four crayfish generations were observed. The two older generations, along with the parents, comprised the catch population. The signal crayfish population in the studied lake was not exploited commercially; only incidental catches of them occurred during expeditionary fishing. Crayfish poaching was also not an issue.

The effectivity of catches with crayfish traps can be viewed as an approximate measure of crayfish population density (Edsman and Söderbäck 1999). An increase in the studied lake was observed until last year when the average catch per trap per night was 2.5 specimens. This may indicate that population abundance has not yet peaked. In two Californian lakes, Tahoe and Donner, the signal crayfish catch effectivity was similar at approximately 3.5 specimens per trap. In Swedish lakes the effectivity of signal crayfish catches varied from 0.8 to 3.5 specimen per trap in years six and seven following introduction (Brinck 1977).

The comparison of the sizes of crayfish caught in different years indicates that beginning with at least the seventh year of life the catch population size does not change. This may indicate that the oldest specimens in this population do not live longer than seven years and the recruitment of young specimens is stable. Specimens measuring from 11 to 14 cm in body length dominate. The largest specimens reach lengths of 16 cm, but there are few such specimens and this size is exceeded very rarely. In a Masurian Province river inhabited by signal crayfish, specimens measuring from 8 to 11 cm dominated, and the largest specimens did not exceed 13 cm (Krzywosz and Krzywosz 2001). The size distribution of the signal crayfish catch population in Swedish lakes is similar to that in the studied lake (Brinck 1977).

In Lake Tahoe, an oligotrophic lake located in a subalpine zone, the average length of the catch population was slightly above 6 cm, and the largest specimens caught were 11 years old and had reached lengths of approximately 11 cm (Goldman and Rundquist 1977). It can be postulated that in the trophically poor and cold Lake Tahoe, the slower metabolism of these heterothermic animals resulted in slower growth but allowed them to live longer. In both the currently studied lake and Swedish lakes, signal crayfish growth is more intense. There are also many indications that their lives are several years shorter in comparison with those of the noble and narrow-clawed crayfish.

A sample of 288 females and 348 males from the studied lake was used to calculate condition, i.e. the dependence of body weight on length (Chybowski, unpublished data). The weight of specimens of the same length but different sex varies; this is principally due to sexual dimorphism, which is especially apparent in the pincer increments. As crayfish body length increased, so did the predominance of male weight over female weight. In crayfish measuring 10 cm, males weighed up to 17.5%

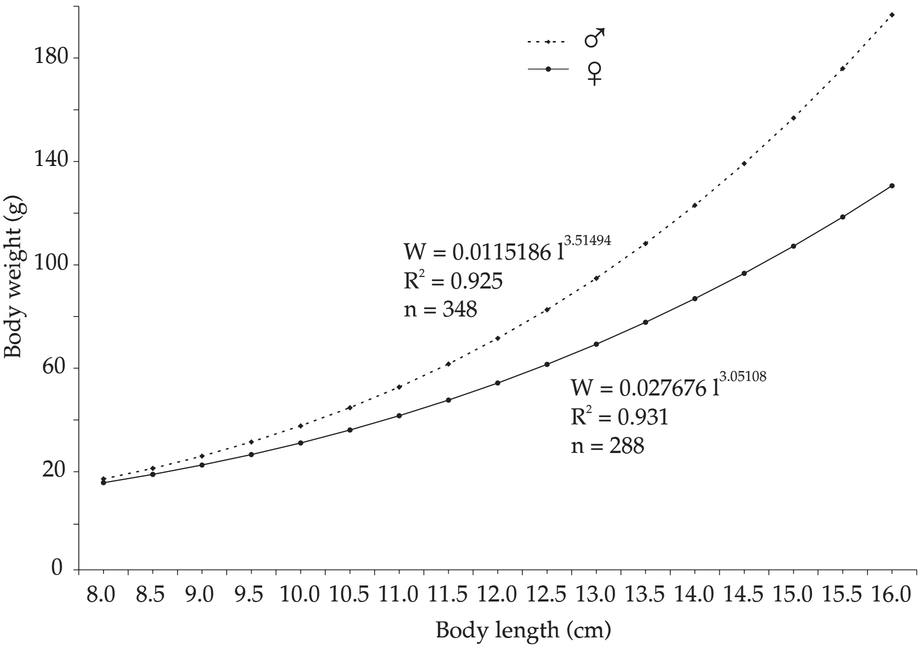

Fig. 4. Dependence of body weight (W) on body length (l) of signal crayfish in the studied lake.

more than females, while in 16 cm long specimens, this figure was 33.6% (Fig. 4). The condition of the signal crayfish in the studied lake was very similar to that of the same species in pond cultures in Poland (Krzywosz 1994) and the Czech Republic (Kozák and Policar 2001). A comparison of the weight (at the same lengths) of signal crayfish with other species in Polish waters indicates that it is similar to that of noble crayfish (Dröscher 1906, Kossakowski 1966) and narrow-clawed crayfish (Dröscher 1906) and higher than for spiny-cheek crayfish (Pieplov 1938, Krzywosz et al. 1995b).

CONCLUSIONS

Signal crayfish adapt well to conditions which occur in Polish lakes with moderately advanced trophic levels. During the peak of summer stagnation, oxygen deficits limit its occurrence to bottom areas located in the epilimnion. It can live for up to 7 years and reaches a maximum body length of approximately 16 cm and a weight of approximately 200 g. Specimens measuring from 11 to 14 cm play the most important role in the catch population, which is not commercially exploited.

It has been confirmed that this species currently inhabits several stations in Poland, and this may indicate the potential of its further, uncontrolled spreading. It is necessary to conduct more research on the signal crayfish; studies focusing on abundance, population biomass, interactions between species and the mutual effects of these interactions are especially important.

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STRESZCZENIE

OBSERWACJE RAKA SYGNAŁOWEGO *PACIFASTACUS LENIUSCULUS* (DANA) W JEDNYM Z JEZIOR POJEZIERZA WSCHODNIOSUWALSKIEGO

Celem pracy było poznanie możliwości adaptacyjnych i cech populacji raka sygnałowego *Pacifastacus leniusculus* (Dana) introdukowanego do jeziora przed jedenastoma laty. Powierzchnia jeziora wynosi 57,6 ha, głębokość maksymalna 15,4 m, a głębokość średnia 5,9 m (rys. 1). Roślinność wynurzona porasta prawie całą linię brzegową jeziora i zajmuje około 10% powierzchni. Roślinność zanurzona, zdominowana przez moczarkę kanadyjską *Elodea canadensis* Rich. i ramienice *Chara* sp. porasta dno do 5 m głębokości i zajmuje około 21% powierzchni jeziora. Ichtiofauna jeziora zdominowana jest przez ryby karpiowate Cyprinidae, którym towarzyszy okoń *Perca fluviatilis* L. i szczupak *Esox lucius* L. Węgorz *Anguilla anguilla* L. nie występuje.

Większość parametrów fizykochemicznych wody (tab. 1) jak również skład gatunkowy fitoplanktonu zdominowanego przez sinice (tab. 2) wskazuje na średni stopień zeutrofizowania jeziora. W szczycie stagncji letniej warstwa dobrze natlenionej wody epilimnionu sięga 5 m (rys. 2) i do tej głębokości ograniczał się zasięg występowania raków. Jak na polskie warunki, stosunkowo jeszcze dobry stan troficzny badanego jeziora dalece odbiega od warunków panujących w oligotroficznym jeziorze Tahoe, skąd ten rak trafił do Europy. Ustępuje ono również jeziorom szwedzkim, do których najwcześniej i najliczniej trafiły introdukowane raki.

Wiosną 1992 roku do badanego jeziora introdukowano 1100 jednorocznych raczków. W 1996 roku, w którym rozpoczęto coroczne połowy kontrolne, w jeziorze, prócz rodziców, bytowały już cztery pokolenia raków, z których przynajmniej dwa najstarsze tworzyły z rodzicami populację łowną. Efektywność połowów, prowadzonych przy użyciu szwedzkich raczników typu „Evo”, rosła i w ostatnim roku badań wyniosła 2,5 raka w pułapce przez noc. Może to świadczyć o stałym wzroście liczebności populacji w badanym okresie.

Od 1999 roku w połowach kontrolnych spotykany jest również rak szlachetny *Astacus astacus* (L.) i rak pręgowaty *Orconectes limosus* (Raf.).

Z porównania wielkości poławianych raków sygnałowych wynika, że od siódmego roku życia raków bytujących w jeziorze nie zmienia się skład wielkościowy populacji łownej (tab. 3). Dominują w niej osobniki o długości od 11 do 14 cm, zaś długość nielicznych, największych osobników zbliża się do 16 cm lub tylko wyjątkowo nieznacznie ją przekracza (rys. 3). Świadczy to o tym, że w jeziorze najstarsze osobniki dożywają siódmego roku życia. Podobnie kształtuje się rozkład wielkościowy populacji łownej raka sygnałowego w jeziorach szwedzkich.

Kondycja wyliczona dla 288 samic i 348 samców pochodzących z badanego jeziora wskazuje, że wraz ze wzrostem długości ciała przewaga masy ciała samców nad samicami stale wzrasta i przy długości 16 cm wynosi już 33,6% (rys. 4).

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