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CHARACTERISTICS OF POPULATIONS OF NARROW-CLAWED CRAYFISH *PONTASTACUS LEPTODACTYLUS* IN THREE BELARUSIAN LAKES OF THE BALTIC SEA CATCHMENT AREA

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Abstract

The population characteristics of narrow-clawed crayfish were studied in three Belarusian lakes of the Baltic Sea catchment area. The life history of crayfish is 7 years. The number of larvae I, produced by all females of the population in late spring – early summer is the highest in eutrophic lake Bobrovichskoe – 26.37 ind./m2, the lowest number of larvae I is in mesotrophic lake Ginkovo – 7.09 ind./m2. The number of individuals that survive the transition period from larvae I to the age of one year is 2.80 ± 0.46%, to sexual maturity at the age of 3 years – 0.73 ± 0.15% of crayfish individuals. In the considered populations, the annual survival rate of sexually mature females in the considered populations is 50.7 ± 1.53%. The average generation time is 4.03 ± 0.13 years.

Key words: narrow-clawed crayfish, population size, survival rate, population growth rate

INTRODUCTION

Narrow-clawed crayfish is the most widespread species of commercial invertebrates in the water bodies of Belarus and can be found almost everywhere in rivers, lakes, and reservoirs. The commercial annual catch of crayfish is 6-8 tons (State Cadastre…). Amateur crayfish catch is also significant, but it cannot be estimated. In order to organize a rational fishery and to determine the standards of acceptable catch, it is necessary to have information regarding the abundance, age structure, replenishment and loss of individuals in crayfish populations. When organizing the narrow-clawed crayfish fishery, one should consider the information regarding the population dynamics, and, above all, the mortality of individuals of the commercial part of population.

The assessment of loss and replenishment are well developed for populations of fish, hunting species of mammals, to a lesser extent for other economically valuable species. There is no data on annual replenishment of crayfish (the total number of larvae I produced by all females of the population per year). The information regarding crayfish population dynamics can be found in the works of Budnikov and Tretyakov (1952), Brodsky (1981), Cukerzis (1988). The data on mortality of the commercial part of crayfish population is presented in the following articles: Alekhnovich (2012), Deval et al. (2007). The values of instantaneous mortality of commercial narrow-clawed crayfish individuals in the water bodies of Ukraine are presented in the monograph by S. Ya. Brodsky(1981). The works by Cukerzis (1988) and Westman et al. (1990) provide data on the mortality of crayfish individuals in the first year of life. In general, there are very few sources of information on the subject.

The Black Sea–Baltic watershed passes through the territory of Belarus, which divides Belarus into two approximately equal parts (Romanovsky 1977). The studies of the dynamic characteristics of narrow-clawed crayfish populations began with water bodies that belong to the catchment area of the Baltic Sea: lakes Selyakhi, Bobrovichskoe and Ginkovo.

The purpose of the work is to determine the replenishment, decline, growth rate of populations of the narrow-clawed crayfish *Pontastacus leptodactylus* in the lakes of Belarus belonging to the catchment area of the Baltic Sea.

MATERIAL AND METHODS

Brief description of the lakes

Lake Selyakhi is located in the basin of the river Zapadnii Bug. The area of the lake is 0.50 km^2. The deepest spot is 8.6 m. Shallow water is narrow, sandy, the bottom deeper is muddy (up to 12 m thick) with moderateovergrowth. There is a stream in the southwest flowing into the lake and a canalized steam flowing out in the west, connecting the lake with an extensive system of stream flows in the southeast, a canalized stream flows out in the west, connecting the lake with an extensive system of reclamation canals (Blakitnaya kniga Belarusi… 1994).

Lake Bobrovichskoe is located in the basin of the river Neman. The area of the lake is 9.47 km^2, the maximum depth is 8.0 m, the average depth is 2.5 m (Blakitnaya kniga Belarusi… 1994). The main area depth is 2-4 m. The shores are low, peaty, overgrown with shrubs. The catchment area is a flat lowland, half covered with forests and shrubs, half with marshes and wetlands. Channel Devyatii connects the lake with the river Grivda (the left tributary of the Shchara, the Neman basin).

Lake Ginkovo is located in the basin of the river Zapadnaya Dvina. This is the third deepest lake in Belarus. The lake is surrounded by high, steep, wooded and ravine-carved slopes. The area of the lake is 0.51 km^2. The maximum depth is 43.3 m, the average depth is 15.4 m. The shallow water is narrow, sandy (in some places up to a depth of 10 m), the deeper bottom is muddy (Blakitnaya kniga Belarusi… 1994) with moderate overgrowth. A narrow channel in the south of the lake is connected to the river Nehrist, tributary of the Auta, right tributary of the river Disna (Basin of the Zapadnaya Dvina).

The hydrochemical characteristics of the studied lakes are given in accordance with Vlasov et al. (2004) see Table 1.

Table 1

The hydrochemical indicators of the lakes

Lakes	Fe mg/l	Ca mg/l	Mg mg/l	Cl mg/l	SO4 mg/l	Total mineralization	Transparency
Selyakhi	2.20	34.4	4.3	8.9	7.3	186.6	1.8
Bobrovichskoe	0.10	32.3	5.2	2.9	7.0	157.3	0.4
Ginkovo	0.03	27.1	7.2	4.8	9.4	178.7	4.0

Lake Selyakhi is less eutrophic, Bobrovichskoe is eutrophic, Ginkovo is mesotrophic with signs of oligotrophy.

Crayfish were caught with crayfish traps made of two nets, interconnected by an 2.5 m insert net. Crayfish that is moving along the bottom, stumbles upon an insert net, starts moving left or right and falls into the trap. The average area fished per day by one trap was 20 m^2, the catch factor was 0.5.

Since the replenishment of the population is determined by females, population calculations were carried out only for females.

Determining the size structure and age began with the modal values of the sizes of crayfish in individual age classes using the Bertalanffy growth equation (Alekhnovich 2015) and then adjusted the age classes considering that within each age class the sizes of individuals are distributed in accordance with the law of normal distribution. On the graph, where the frequency of occurrence of individual sizes is plotted on the y-axis, individual age groups are represented by straight line segments. The calculation of these straight segments on the polymodal frequency-size distribution of individuals makes it possible to distinguish age classes. The deciphering of the size-age structure was carried out based on catches in late May-early June.

The number of females caught for analysis is as follows: lake Selyakhi – 77, lake Ginkovo – 92, lake Bobrovichskoe – 124. The total number of females was then redistributed in accordance with the total daily area of the catch and the proportion of individual age classes in the overall size structure of the fished part of the population. After that the values of instantaneous rate of change in the number of females were determined. Due to the selectivity of fishing gear, differences in distribution and behavior, crayfish individuals aged one to two years, sometimes even three years, were not caught or were not caught to the full extent. Therefore, the size structure of the catches had a bell-shaped distribution curve with an ascending left branch and a descending right one. The decrease in individuals in the right descending branch of the size series was analyzed: the number of individuals decreased with increasing age of females, which was considered as a reflection of the real decrease in individuals with an increase in the size and age of females. The females of the right side of the curve of the size-age distribution were 3 or more years old for lakes Selyakhi and Bobrovichskoe and 4 years old for females of the Ginkovo Lake.

In order to determine the values of total instantaneous mortality (Z), a linear relationship between the natural logarithm of the density of females, as a dependent variable, and the corresponding age, as an independent variable was used; the slope coefficient gives us the value of instantaneous mortality.

Survival (S) was defined as e^{-Z}, where e is the base of the natural logarithm.

For female populations of lakes Selyakhi and Bobrovichskoe, it was assumed that the mortality of females at the age of 1-2 years was the same as that of individuals of older age groups. For the population of Ginkovo, the same assumption was made for age classes 1-3 years.

Fecundity before hatching of the larvae was determined by counting all the eggs on the pleopods of the female at the end of the embryonic development of the eggs. This pleopod fecundity is equated to the number of first stage larvae produced by the female. Sample collection time is the end of May.

Replenishment, as the number of larvae of zero age, was determined by multiplying the density values of females of different ages by their fecundity. The total number of replenishment is equal to the sum of larvae produced by all sexually mature females of the population per year.

The generation time or the average age at which females reproduce was determined by adding the products obtained by multiplying the replenishment of each age group by the age of the females in this group and dividing the resulting sum by the total number of replenishments.

The annual population growth rate was determined by raising the total replenishment values to the reciprocal power of the average generation time.

Crayfish individuals were measured from the tip of the rostrum to the end of the telson.

RESULTS

Female narrow-clawed crayfish become sexually mature at the age of 3 years in the reservoirs of Belarus. The fertility of females was calculated starting from this age.

The fecundity before hatching of larvae for the populations of narrow-clawed crayfish of lakes Selyakhi, Ginkovo and Bobrovichskoe fluctuates from 42 to 300 eggs (Fig. 1). The dependence of fecundity on the length of females is described by linear equations:

Lake Selyakhi $E_{pl} = -183.51 + 37.54*TL$; $r = 0.80$; $p = 0.00$ [1]
Lake Ginkovo $E_{pl} = -160.59 + 30.42*TL$; $r = 0.60$; $p = 0.00$ [2]
Lake Bobrovichskoye $E_{pl} = -214.17 + 38.07*TL$; $r = 0.77$; $p = 0.00$ [3],

where TL is the length of the female from the tip of the rostrum to the end of the telson, cm; E_{pl} – fecundity before hatching of larvae.

The obtained values of changes in fecundity depending on the length of females are reliable.

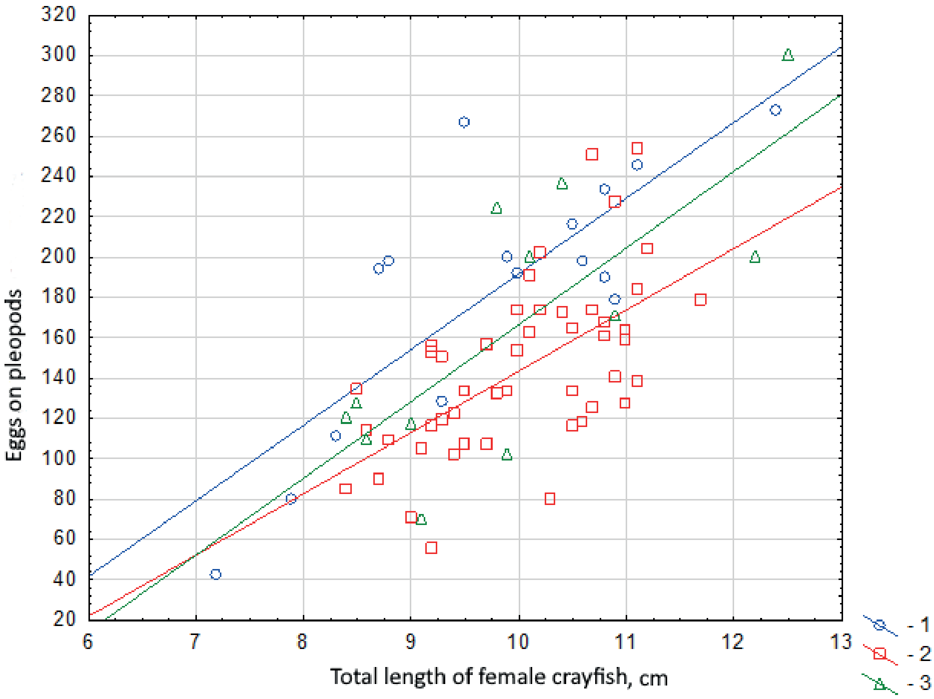

Fig. 1. Fecundity before hatching of larvae depending on the total length of female crayfish
1 – the Selyakhi Lake, 2 – the Ginkovo Lake, 3 – the Bobrovichskoe Lake

Dynamic characteristics of populations

The maximum life span of females is 7 years. There are no specimens from 11.3 cm to 12.0 cm in length in the size structure of females of the population of the Selyakhi Lake. Females of this length can be attributed to the six-year age group, but this age class was absent in the catches for unknown reasons.

The size and age structure, density, and fertility of females in the populations of the studied lakes differ (Table 2).

Starting from the age of 3 years, for the populations of lakes Selyakhi and Bobrovichskoye and from 4 years for the Ginkovo Lake, the number of females of the previous age class is higher than the next. The decrease in the number of females with increasing age reflects the overall mortality rate (Fig. 2).

The dependence of the natural logarithm of the density of females on their age is well approximated by a straight line, the correlation is strong and significant (Equations 4, 5, 6). The slope of the equations of linear dependencies shows the total instantaneous mortality.

Table 2

Size–age structure and fecundity of female populations of narrow-clawed crayfish in the catchment area of the Baltic Sea

Lake	Trait	Age, years					
		2	3	4	5	6	7
Selyakhi	Modal length, TL, cm	7.9	8.9	10.2	10.9	11.5	12.3
	Fecundity	-	151	199	226	-	278
	Density estimated from catches, females/m^2	0.010	0.042	0.031	0.022	-	0.003
Ginkovo	Modal length, TL, cm	6.7	8.2	9.3	10.2	10.8	11.2
	Fecundity	-	89	122	150	168	180
	Density estimated from catches, females/m^2	0.001	0.004	0.012	0.009	0.005	0.002
Bobrovichskoe	Modal length, TL, cm	7.9	8.9	9.7	10.6	11.5	12.3
	Fecundity	-	125	155	189	224	254
	Density estimated from catches, females/m^2	0.006	0.092	0.058	0.023	0.005	0.009

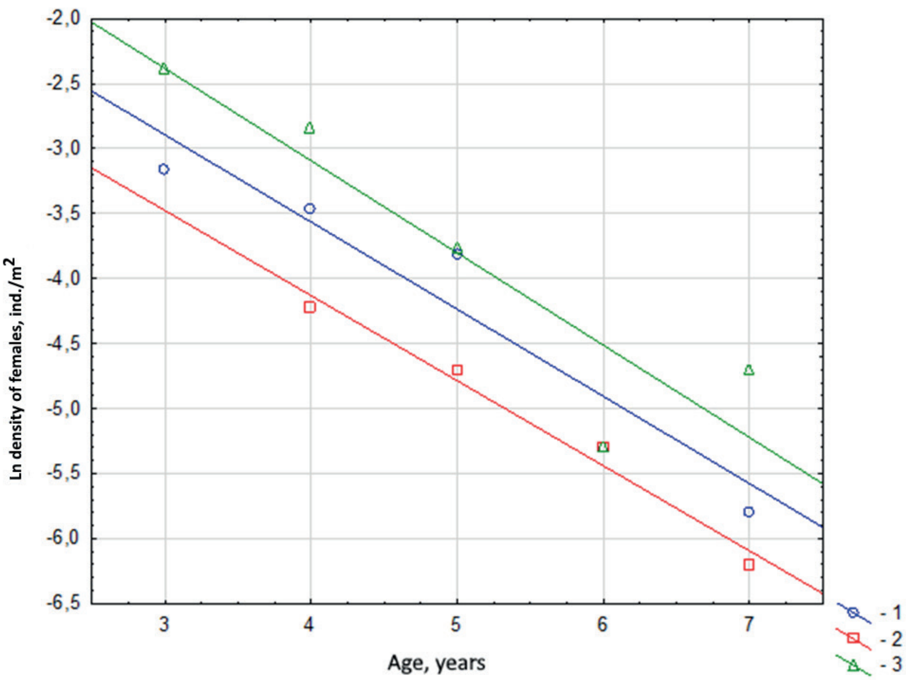

Fig. 2. Natural logarithm of density of females depending on age in lakes 1 – Selyakhi, 2 – Ginkovo, 3 – Bobrovichskoe

For individual lakes, this dependence is described by the corresponding equations:

Lake Seloyahi D = -0,88 - 0,67*t; r = -0,96; p = 0,00 [4],
Lake Ginkovo D = -1,51 - 0,65*t; r = -0,99; p = 0,00, [5],
Lake Bobrovichskoe D = -0,25 – 0,71*t; r = -0,92; p = 0,02 [6],

where D is the natural logarithm (ln) of female density, t is age, years.

The average values of the total instantaneous mortality of sexually mature females in lake Selyakhi will be: -0.67, lake Ginkovo: -0.65, lake Bobrovichsky: -0.71. The obtained dependencies are more clearly perceived if they are expressed in terms of survival: females of the population of the Selyakhi Lake are characterized by survival $e^{-0.67}$ = 0.51. Accordingly, the survival rate of females of the Ginkovo Lake will be 0.52 and the Bobrovichskoe Lake: 0.49. The survival rate of females within one year period ranges from 49 to 52%.

For females aged 1-2 years in lakes Selyakhi and Bobrovichskoye and for females 1-3 years old in the Ginkovo Lake, the same values of total instantaneous mortality were taken as in the older age groups of the corresponding lakes (Table 3). According to the equation 4, 5, 6, the density values of females aged 1-7 years were calculated, replenishment was estimated as the product of fecundity and density of females, and the product of age and replenishment was estimated.

Table 3

Average values of female density dynamics and population replenishment of narrow-clawed crayfish in lakes Selyakhi, Ginkovo, Bobrovichskoe

Lake	Trait	Age, years						
		1	2	3	4	5	6	7
Selyakhi	Estimated density, females/m^2	0.212	0.109	0.056	0.028	0.014	-	0.004
	Replenishment, ind./m^2	-	-	8.460	5.570	3.160	-	1.110
	The product of the age of females by replenishment, females/m^2	-	-	25.380	22.280	15.800	-	7.770
Ginkovo	Estimated density, females/m^2	0.115	0.060	0.031	0.016	0.009	0.004	0.002
	Replenishment, ind./m^2	-	-	2.760	1.950	1.350	0.670	0.360
	The product of the age of females by replenishment, females/m^2	-	-	8.280	7.800	6.750	4.020	2.520
Bobrovichskoe	Estimated density, females/m^2	0.383	0.188	0.092	0.045	0.022	0.011	0.005
	Replenishment, ind./m^2	-	-	11.500	6.980	4.160	2.460	1.270
	The product of the age of females by replenishment, females/m^2	-	-	34.500	27.920	20.800	14.760	8.890

The population of narrow-clawed crayfish of the Selyakhi Lake will produce 18.30 larvae of the first stage per 1 m^2 at the end of May. The estimated density of females at the age of 1 year will be 0.212 females/m^2.

Due to the asynchrony of the processes of growth, molting, and activity during reproduction, the sex ratio in catches changes, but generally over a year period, it is close to equilibrium. Therefore, the density of females at the age of 1 year can be doubled in order to obtain the density of yearlings: 0.424 individuals/m^2. During the period from the appearance of larvae to the age of 1 year, the survival of individuals in lake Selyakhi will be 2.3% (0.424 ÷ 18.3). Only 0.6% of individuals survive from larva I to sexual maturity.

The total value of the product of age and replenishment will be 71.23. Dividing 71.23 by 18.3, we get the generation time of the lake population, which is 3.89 years for Selyakhi. The annual growth rate of the population of lake Selyakhi is 2.11 ($18.3^{1/3.89}$).

The population of narrow-clawed crayfish of the Ginkovo Lake will produce 7.09 larvae per 1 m^2 at the end of May-beginning of June. The estimated density of females at the age of 1 year will be 0.115 females/m^2 (see Table 3). The total number of yearlings will be 0.230 individuals/m^2. The survival rate of crayfish in the first year of life will be 0.23 ÷ 7.09 = 0.032 or 3.2%. Only 0.9% of individuals survive from larva I to sexual maturity.

The total value of the product of age and replenishment will be 29.37. Dividing 29.37 by 7.09 we get the time of generation of crayfish of the Ginkovo Lake: 4.14 years. The annual growth rate of the population of lake Ginkovo is 1.60.

The population of narrow-clawed crayfish of the Bobrovichskoye Lake will produce 26.37 first stage larvae per 1 m^2 at the end of May. The total number of yearlings will be 0.766 individuals/m^2. The survival rate of crayfish in the first year of life will be 0.766 ÷ 26.37 = 0.029 or 2.9%. Only 0.7% of individuals survive from larva I to sexual maturity.

The total value of the product of age and replenishment will be 106.87. Dividing 106.87 by 26.37 we get the time of generation of crayfish of the Bobrovichskoe Lake: 4.05 years. The annual growth rate of the population of lake Bobrovichskoye is 2.24.

DISCUSSION

In a few studies, the survival rate of juvenile crayfish can range from 4 to 30%. Thus, the mortality rate of juvenile noble crayfish was suggested to be 0.7 (Cukerzis 1988) in the first year of life for populations in natural habitats. According to other data (Meyer et al. 2007), this indicator should be 0.9. It is noted in (Westman et al. 1990) that more than 90% of young crayfish both *Astacus astacus* and *Pacifastacus leniusculus* die in the first year of life during the growing season. Mortality should be lower in older age groups. M. Fürst (1989) notes that 5-10% of noble crayfish individuals survive the period from stage II to maturity.

K. N. Budnikov, F. F. Tretyakov (1952, p. 33), assessing the survival rate of crayfish: “There is an opinion that 12% of underyearlings from the offspring of one female narrow-clawed crayfish survive till the end of summer, 24% fornoble crayfish”.

S. Ya. Brodsky (1981, p. 34) gives the following information regarding the dynamics of the numbers of narrow-clawed crayfish: the number of eggs in the ovaries – 100%, fecundity on pleopods – 74-76%, larva I – 54-49%, larva II – 27-41%, underyearlings – 7-13%, yearlings – 2-3%, two-year-olds – 0.6-0.8% Therefore, if we consider fecundity on pleopods, the survival at the age of one year will be 3.3%. The survival at the age from one to two years will be 28%. The same author (Brodsky 1981 in Table 9, p. 34) indicates the total instantaneous mortality of sexually mature crayfish 121-140 mm long: 0.41-0.74, which corresponds to an average survival rate of 55%. It should be noted that the authors' works do not provide methods of how to determine the survival rates of crayfish juveniles.

The proposed method for determining the survival of juveniles in the first year of life by determining the density of females and their fecundity makes it possible to obtain fairly realistic values, but does not guarantee the absolute accuracy of calculations. Possible errors lie in determining the mortality of individuals by comparing adjacent age groups, extrapolating the mortality values of mature individuals to crayfish aged from 1 to 3 years.

Crayfish should be classified as a stable type of population dynamics. The constant number of populations is maintained by such mechanisms of population regulation as low fecundity, relatively long life expectancy, the presence of a significant number of age groups, high care for offspring, territoriality, a wide range of food, and cannibalism. These regulatory mechanisms maintain the population size within certain density limits.

In order to analyze the population dynamics, the populations with a high number of individuals were studied, assuming that mechanisms of population regulation are implemented and the dynamics of the number of individuals in a series of years is relatively stable, which makes it possible to estimate the mortality of individuals per year by comparing adjacent age classes. The material was collected at the same time of the year in order to reduce possible errors in mortality values.

The made assumptions of constant replenishment and constant total annual mortality of crayfish allowed us to estimate the average instantaneous mortality without conducting long-term observations based on observations of individual cohorts. The data obtained are quite comparable with the values that are based on the analysis of the dynamics of the number of cohorts (groups of the same age individuals) over a number of years. For example, analysis of the population dynamics of a cohort of narrow-clawed crayfish in lake Sominskoye over 5 years made it possible to estimate the annual survival rate of the commercial part of the population at 50% (Alekhnovich 2012). In lakes Selyakhi, Ginkovo, Bobrovichskoe, the survival rate of females for the period of one year fluctuates in the values of 49-52%.

The survival rate of individuals at the age of 1-3 years was assumed to be the same as that of mature individuals. This is a necessary measure, since it is more difficult to estimate the number of crayfish in these age groups, as well as age 0+, than in age groups of mature large individuals. The accepted assumption about the equality of the survival of immature and mature individuals is partly valid, since, in comparison with large individuals, immature crayfish will have lower commercial mortality, but natural mortality is higher and overall mortality can be comparable.

Possible errors in determining the density of individuals can change the number of mature females, which in turn leads to a change in replenishment values, but the ratio between replenishment and the number of mature females remains fairly stable. Therefore, the estimated survival rate of juvenile crayfish in the first year of life (2.3% in the Lake Selyakhi, 3.2% in the Lake Ginkovo and 2.9% in the Lake Bobrovichsky) will not change.

The calculations were carried out according to the data on the numbers and fecundity of females. For the entire population, the values were doubled, assuming equal survival of males and females in the process of growth and development of individuals. The equality of the survival rate of males and females of sexually mature individuals was proved for the population of the Lake Sominskoe (Alekhnovich 2012).

0.6-0.9% of individuals survive from fecundity on pleopods, which was equal to the number of larvae of the first stage, to sexual maturity.

The average generation time is shorter and the annual population growth rate is higher in shallow eutrophic lakes Selyakhi and Bobrovichsky compared to the deep-water mesotrophic Ginkovo Lake, but the survival rate of individuals that reach sexual maturity is lower.

The net breeding rate or number of larvae I produced by all females in a population is maximum in a eutrophic lake and minimum in a mesotrophic one.

CONCLUSION

The populations of narrow-clawed crayfish in the lakes of the Baltic Sea catchment area in Belarus are able to increase their numbers by 1.6-2.24 times per year. The average generation time or age at which females produce offspring is 4.03 ± 0.13 years. 2.80 ± 0.46% of individuals survive from larvae I to the age of one year; 0.73 ± 0.15% to sexual maturity at the age of 3 years. In populations with a high density of individuals, the annual survival rate of sexually mature females is 50.7 ± 1.53%. In eutrophic lakes populations of narrow-clawed crayfish have greater growth characteristics, but lower survival of juveniles, compared to mesotrophic lakes.

Effective management of crayfish populations should include growing crayfish juveniles in aquaculture conditions, which will significantly increase the survival rate of juveniles, with the subsequent resettlement of underyearlings in natural water bodies.

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CHARAKTERYSTYKA POPULACJI RAKÓW WĄSKOPŁETWYCH *PONTASTACUS LEPTODACTYLUS* W TRZECH BIAŁORUSKICH JEZIORACH ZLEWNI MORZA BAŁTYCKIEGO

Streszczenie

Przedmiotem badań była charakterystyka wybranych parametrów trzech populacji raka błotnego pochodzących z jezior należących do zlewni Morza Bałtyckiego. Wyznaczono długość życia raków, która wyniosła 7 lat. Liczba larw I w okresie późnowiosennym-wczesnoletnim jest największa w eutroficznym jeziorze Bobrovichskoe i wynosi 26,37 os./m^2, a najmniejsza w mezotroficznym jeziorze Ginkovo – 7,09 os./m^2. Przeżywalność w okresie przejściowym od larwy I do wieku 1 roku wynosi 2,80±0,46%, do 3 roku życia – 0,73±0,15%. Roczny wskaźnik przeżywalności dojrzałych płciowo samic wynosi 50,7±1,53%. Średnia długość życia wynosi 4,03±0,13 roku.