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SEX STRUCTURE, RECRUITMENT RATE, AND SIZE OF MATURING SPECIMENS OF EUROPEAN EEL (*ANGUILLA ANGUILLA* (L.)) IN A POPULATION FROM LAKES IN NORTHEASTERN POLAND

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ABSTRACT. Studies of the sex structure and recruitment rates of silver eels from a population occurring in natural conditions in a large lake complex were conducted in the 1985-1990 period based on a sample of 6998 specimens. The fish were caught in 60 connected lakes with a combined surface area of 300 km^2 using box traps, cross traps, stownets on stakes and electric fishing. It was determined that the share of males in the eel population occurring in the lakes was barely 1.03%, and in the group of fish with body lengths (Lt) of up to 46.0 cm it was 3.17%. Silver and yellow eels were noted among both males and females. The share of silver eels increased from 0 to 100% in the body length categories from 39.0 to 46.0 cm among males and from 47.5 to 95.0 cm among females. In both instances, the dependence of the share of silver eels on the total length of the body was described with linear regression with a high correlation coefficient and high regression significance ($P < 0.05$). The studies indicated that in the lakes of northeastern Poland, which are located within a large complex that is permanently connected, the share of males is small and the recruitment of silver eels from this group occurs within a narrower and lower size range than it does in females.

Key words: EUROPEAN EEL (*ANGUILLA ANGUILLA*), GROWTH POTENTIAL, SEXUAL MATURATION

INTRODUCTION

Sex determination in the European eel, *Anguilla anguilla* (L.), is a two-phase process. In the initial phase, the genetic sex of the embryo forming inside the egg is determined by the connection of the male homogamete (Z) with one of the female heterogametes (W or Z) (Lieder 1963, Park and Grimm 1981). However, the initial sex structure, which is close to a ratio of 1:1, is not definitive and undergoes substantial fluctuation in the postembryonic period. Environmental conditions probably impact the ultimate sex differentiation, and factors may include specimen density, stress, food, etc. Confirmation of this can also be found in the results of studies of the sex structure of eel populations in

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natural conditions as well as those of cultivated stocks in aquaculture (Poole et al. 1990, Holmgren and Wicstrőm 1993, Beullens et al. 1997a, b, Acou et al. 2003). In eel, the sex structure of the population is of the utmost importance to the general population of the species. It represents the potential reproductive power and, due to the complexity of the European eel life cycle, it is most probably responsible for steering it.

Although in continental waters eel ovaries and testes only achieve maturity stages III and I, respectively, on the six-stage maturity scale according to Sakun and Buckaja (1968), during sexual maturation individuals of both sexes undergo a very clear metamorphosis (Brylińska et al. 1978). Morphological changes include body coloring (silver eels are characterized by distinct black-brown dorsal coloring with a silver abdomen), a lengthening of fins, as well as enlarged eyeballs (Pankhurst 1982a, b, c, 1983, Pankhurst and Lythoge 1982). Additionally, the sensory organs, including the lateral line and the sense of smell, become keener (Sorensen and Pankhurst 1988, Zacchei and Tavolaro 1988).

The morphological consequence of sexual differentiation in eels is sexual dimorphism. This is characterized by the distinct differences in the body sizes attained by males and females (Boëtius and Boëtius 1967). This phenomenon is caused by the different maximum growth potential that is steered by the sexual maturation process (Svedäng et al. 1996). This process, which is commonly known as silvering, initiates the spawning migration and also limits significantly eel age and growth. Males inhabiting natural conditions often fully utilize their growth potential and attain their maximum size. Among females, silver specimens are noted within a larger size range and the share of them in size groups differs according to area and the environmental conditions prevailing there (Bergersen and Klemetsen 1988, Beullens et al. 1997a, b, Acou et al. 2003).

The aim of the current work was to determine the sex ratio in a population of eel inhabiting a large lake complex, to identify the size range of specimens undergoing metamorphosis associated with sexual maturation, and to evaluate the rate at which they are recruited to the population.

MATERIAL AND METHODS

The material for the study of the eel population was collected from 1986 to 1990 from 60 lakes in the Great Mazurian Lakes (GML) complex with a total surface area of 300 km^2. There are permanent connections among the lakes, which differ with regard to size, depth, and trophic status. The trophic status of the majority of the lakes was classified from mesotrophic to hypertrophic (Carlson 1977, Zdanowski 1993a,b, c, Zdanowski and Hutorowicz 1994).

The climatic conditions of the GML region differ significantly from the remaining regions of Poland. The vegetation period in this region is a mere 160 days per year (Gumiński 1951). The ichthyofauna of the GML is typical of eutrophic lakes. The fish assemblages that inhabit the lakes are represented by species from the following families: Cyprinidae, Percidae Salmonidae, Esocidae, Osmeridae, Anguillidae, Cobitidae, Ictauluridae, Gadidae, Gasterosteidae, and Cottidae. Fisheries exploitation is based primarily on roach, *Rutilus rutilus* (L.), bream, *Abramis brama* (L.), pike, *Esox lucius* L., tench, *Tinca tinca* (L.), vendace, *Coregonus albula* (L.), and eel.

The sample numbering 7051 eels was obtained using electric fishing and commercial catches made with cross traps, box traps, and stownets. The occurrence of eel in the lakes was the result of cyclic stocking with glass eels and of stocks from farms at intensities ranging from several to several tens of specimens per ha depending on the type of stocking material.

The application of a codend with a mesh bar length of 18 mm allowed catching fish whose length exceeded 45 cm and whose average body weight exceeded 152 g, in accordance with the following dependency: $a = k_1 \times Lt$, where Lt – total fish length (mm), a – mesh bar length (mm), k_1 – length selectivity coefficient for inland waters (0.041) (Dembiński 1977).

In order to limit the impact of fishing gear selectivity on the results of the studies, the electric fishing method was used from May to mid June in the shallow littoral (0.1-1.5 m depth). Samples were collected depending on the size and shape of the lake at one or several stations. Each fishing session was continued until at least thirty specimens had been caught. This number of specimens allowed for the comparison of the individual stocks and groups of fish with statistical methods, *i.e.*, determining and calculating basic statistics and defining the relationships of the studied traits using correlation and regression (Łomnicki 2002).

Prior to manipulation, the eels were euthanized. The total length of the fish (Lt) was measured to the nearest 0.5 cm and body weight (BW) was determined to the nearest 1 g. The sex and gonad maturity stage were both determined. Sex was determined macroscopically according to the build of the ovaries and testes (Boëtius and Boëtius 1967, Beullens et al. 1997a). Specimens with gonads that resembled frilled ribbon organs of various widths (ovaries) were classified as females. Fish that had gonads shaped as an undifferentiated or lobed thread (testes) were classified as males. In a few instances the gonads were not clearly shaped (Lt < 22 cm), and sex could not be determined.

The eel gonad maturity stage was determined based on body pigmentation and the size of the eye (Stramke 1972, Pankhurst 1982 a, c, Pankhurst and Lythgoe 1982). It was assumed that intense brown-silver body pigmentation and distinctly enlarged eyes are characteristic of specimens in which the sexual maturation process had begun. Green-yellow body pigmentation and proportionally small eyes were taken as an indication that the specimens were still in the feeding stage. The results of the study were verified on a selected sample of fish with the eye index (I) according to the dependence in Pankhurst (1982a) and the formula: $I = [((A+B)/4) \times \pi / Lt] \times 100$; where I – eye index ($I < 6.5$ – yellow specimens; $I > 6.5$ – silver specimens), A – horizontal eye diameter (mm), B – vertical eye diameter (mm), Lt – total fish length (cm).

RESULTS

The study was conducted on a sample of 7051 eels, of which sex was determined in 6998 specimens (99.25%). In 53 eels (0.75%) with a body length of less than 22 cm, sex was not determined. In the group of fish of a determined phenotype, sex was confirmed in 6926 females (98.97%) and 72 males (1.03%). Yellow specimens dominated the overall sample. In the group of males, there were 52 yellow (72.23%) and 20 silver (27.77%) specimens, while among the females, there were 6086 yellow (87.88%) and 840 silver (12.12%) specimens (Table 1).

The reliability of the sexual maturity evaluation was verified with the eye index based on the probability of decision accuracy P = 0.9798. The sexual maturity stage of the females determined with the eye index ranged from 2.98 to 9.00, which corresponds to the I, II, and III stage ovary developmental.

The average male body length was 36.5 cm and ranged from 28.5 to 46.0 cm (V_{Lt} = 12.57%); the average body weight was 83 g and ranged from 37 to 155 g (V_{BW} = 39.80%). The body length of yellow males ranged from 28.5 to 42.0 cm at an average of 34.5 cm, while body weight ranged from 37 to 126 g at an average of 68 g. Male silver eels ranged from 39.0 to 46.0 cm in length (average of 42 cm) with a body weight range of 90 to 155 g (average of 123 g). The coefficients of variance of these two parameters were decidedly lower in comparison to those of the yellow specimens (Table 1). Variance analysis of the length and weight of the silver and yellow males indicated highly statistically significant differences between these two groups ($P < 0.001$).

TABLE 1

Size structure of male and female eel in the Great Mazurian Lakes complex

Sex	Stage	n	Total length Lt (cm)				Body weight (g)			
			Range	Mean	SD	V(%)	Range	Mean	SD	V(%)
Male	Yellow	52	28.5-42.0	34.5	3.404	9.87	37-126	68	23.239	34.18
	Silver	20	39.0-46.0	42.0	2.002	4.76	90-155	123	17.612	14.31
	Total	72	28.5-46.0	36.5	4.588	12.57	37-155	83	33.041	39.81
Female	Yellow	6086	23.0-90.0	46.5	11.371	24.50	17-1340	198	154.869	78.21
	Silver	840	47.5-95.0	64.5	8.293	12.83	175-1555	468	223.851	47.83
	Total	6926	23.5-95.0	51.0	12.551	25.87	17-1555	231	187.256	81.06

There was a markedly higher degree of size variance in the group of females. Among both the silver and yellow females, the coefficients of variance for length and body weight were two-fold higher than those of the males (V_{Lt} = 25.87%; V_{BW} = 81.06%). The minimum body length noted among the yellow females was 23.0 cm at a body weight of 17 g, while the respective maximums were 90.0 cm and 1340 g (average of 46.5 cm and 198 g), (V_{Lt} = 24.50%, V_{BW} = 78.21%). Among the silver females the body length of the specimens ranged from 47.5 to 95.0 cm (average of 64.5 cm), while the mass ranged from 175 to 1555 g (average of 468 g). The value of the coefficients of variance in this group were 12.83% (Lt) and 47.83% (BW) and were nearly two-fold lower than in the group of yellow specimens (Table 1).

There was a highly statistically significant difference between the size range of the males and females (Kołmogorova-Smirnova test, df = 6998; $P < 0.001$). The body length range of yellow and silver males and females is presented in Figures 1 and 2.

The share of silver males in the studied sample increased in a length class range of just 4.0 cm (39.0-42.0 cm Lt) by 17.83% cm^{-1} of body length growth, while the share of silver females did so at a rate of nearly 2% cm^{-1} of body length growth (47.5-95.0 cm Lt). The increase of the share of silver males in body length classes corresponded to linear regression: $Y = 17.83\ x - 660.88$ ($R^2 = 0.8531$; $P = 0.0116$), and for females it was: $Y = 1.9788\ x - 94.2$ ($R^2 = 0.9629$; $P < 0.001$), where x was body length Lt (Figs. 3 and 4).

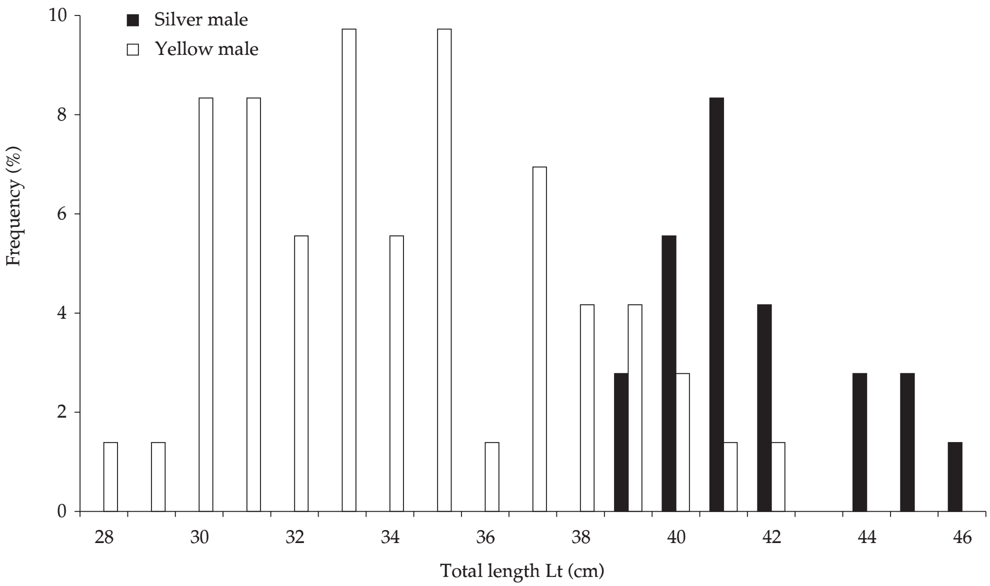

Fig. 1. Size distribution of male yellow and silver eels.

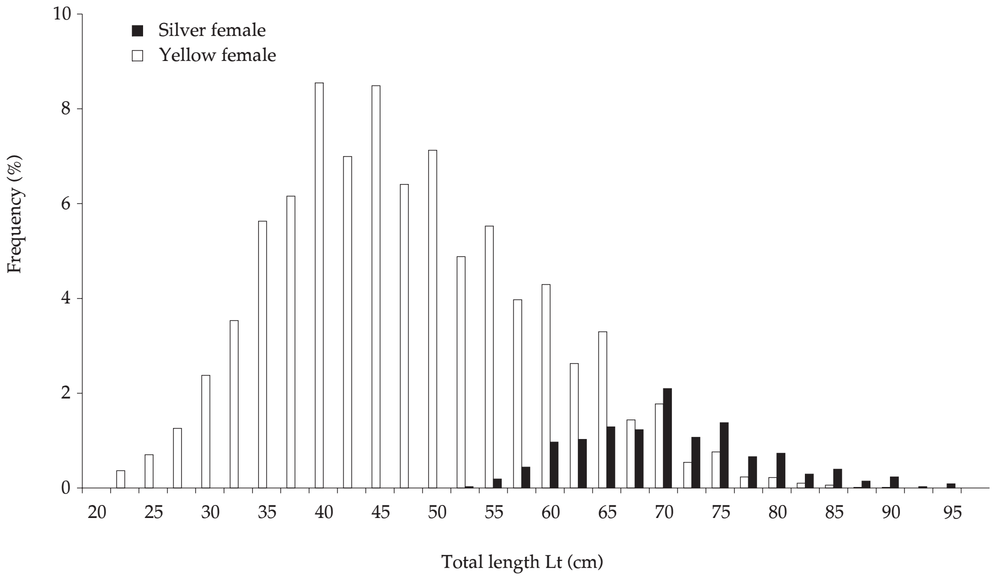

Fig. 2. Size distribution of female yellow and silver eels.

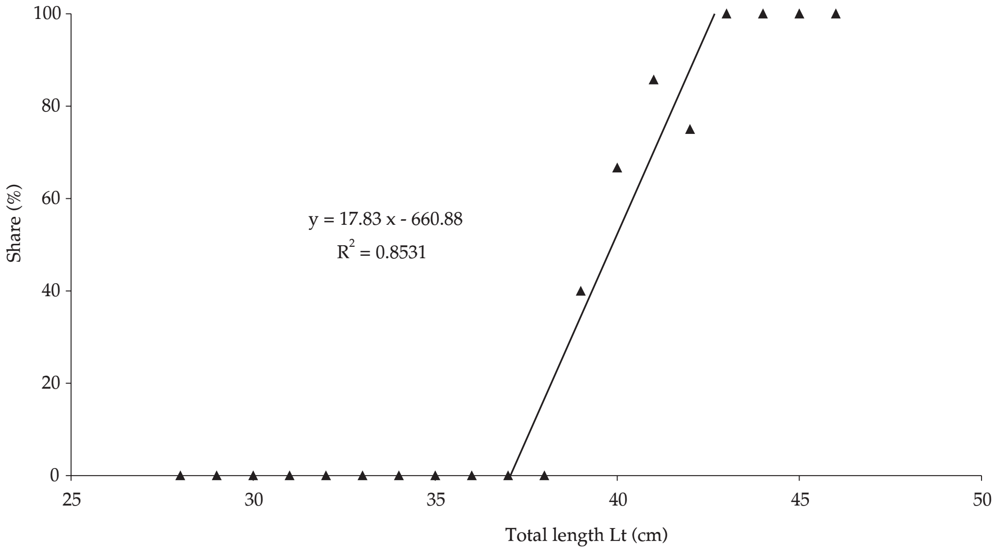

Fig. 3. Share of male silver eels in length classes.

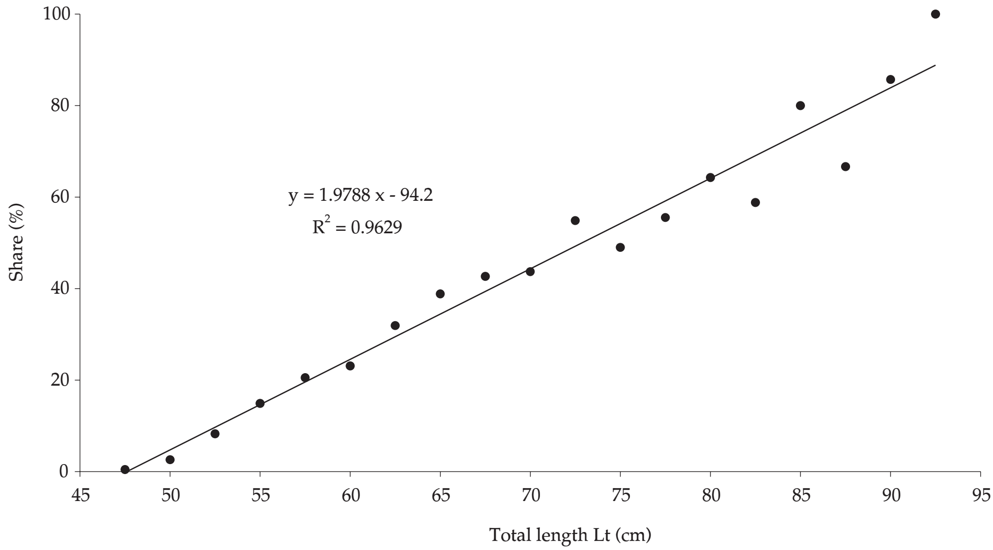

Fig. 4. Share of female silvers eels in length classes.

The average silver female body length was 64.6 cm at a weight of 468 g. The sexual maturity stage assessed with the eye index was similar in all the size groups at values of 9.0 > I > 6.5.

DISCUSSION

The first sex cells appear in eel during the early phase of ontogenetic development, and their growth was confirmed in specimens with body lengths of 9.0-10.0 cm (Colombo et al. 1984, Petrikov and Fernando 1993). Eel undergo definitive sexual differentiation at various sizes. In the study by Brylińska et al. (1978), the female sexual phenotype was noted in specimens 22.0 cm in length, and the male in those of 29.5 cm. Attempts to steer the sex of eels with testosterone and estradiol derivatives was ineffective in fish longer than 22.0 cm (Colombo and Grandi 1992). It is not known why such a wide size and age range of females become silvers. Previously, it was assumed that the basis for the metamorphosis was the physical state brought about by the condition of the fish (Larrson et al. 1990, Svedäng et al. 1996). Currently, this phenomenon is thought to be linked to interactions among individuals. It is initiated by the recruitment intensity and manner of a given population as well as by habitat conditions and the growth rate (Panfili et al. 1994, Beullens et al. 1997a, b). Normally, the share of males in a population is shaped by environmental conditions. The indirect impact external conditions have on the shaping of eel phenotype sex was confirmed during studies at rearing facilities. Under intensive rearing conditions at high stocking density with high stress levels, the share of males was as high as 75% (Holmgren and Wickström 1993). Under natural conditions with a low stock density, the process of shaping the sex structure can vary. Poole et al. (1992) reported large fluctuations in migrations of male eel in the Burrishoole River System in Ireland. Over the course of thirty years of observations, the share of males exhibited a tendency to decrease from 94.5% in 1962 to 32.7 % in 1986. This important change was probably the result of the smaller area of eel occurrence caused by changing environmental conditions along the migration route of glass eels. Parsons et al. (1977) called attention to the similar role of biotic and abiotic factors in studies of the eel population from Lough Neagh in the Bann River catchment area in Northern Ireland. Parsons estimated that variations in the sex ratio in eel stocks exploited by fisheries was not only an effect of the recruitment of glass eels, but was also caused by changing environmental conditions, fishing mortality, genetic conditioning, as well as differences in the sexual maturation period among males and females. Among the migratory eel from southwest Norway, silver females dominated comprising from 93 to 95% of the specimens (Bergersen and Klemetsen 1988).

In the GML, males comprised only 1.03% of the entire population and 3.17% of the group of fish up to 46.0 cm in body length. That the males comprised such a small share was probably due to the small size of the eel population in these lakes, which, in turn, is shaped by low intensity stocking programs. This is plausible considering that the eels face practically no environmental limitations since they can migrate to feed or locate better habitats throughout the lake complex that provides a variety of conditions in its combined surface area of 300 km^2. The length distribution, particularly among females, is certainly not fully indicative of the size structure and the share of specimens in the population as the majority of the eels were obtained through electric fishing in the shallow littoral where small specimens occur. The decline in the number of specimens of Lt > 50 cm is also the result of high fishing mortality (legal limit – BW > 300 g); however, both green and silver specimens are caught to the same degree in commercial fisheries. The length distribution of the yellow and silver females in the GML is comparable to that in most of the populations described (Deelder 1957, Parsons et al. 1977, Poole et al. 1990, De Leo and Gatto 1995, Tesch 1999).

The current studies indicate that the metamorphosis process among females occurs within a wider length and weight range than it does in males. Similar ranges among silver fish were reported by Rasmussen (1952) for fish from Lake Esrum in Denmark. The studies of Acou et al. (2003) indicated that the female silvering process occurred at a length range from 40.0 to 75.0 cm. Among males, larger than average sizes were noted in the studies by Beullens et al. (1997a), who reported that under cultivation conditions in groups, silver male specimens occurred at a body length of 58.2 cm, which is practically unheard of under natural conditions.

If it is assumed that the sexual maturation process occurs in both sexes at distinctly varied sizes and at a body length range of up to 45 cm at comparable growth rates, the metamorphosis of specimens from one generation occurs earlier among males (Fernández-Delgado et al. 1989, EIFAC 2003). It has been confirmed that the life span of males in continental waters is only a few years (3-8), while that of females is usually longer (8-20 years); this undoubtedly has an impact on the rate of silver specimen recruitment in both groups (Deelder 1957, Berg 1985, Svedäng et al. 1996). The length distributions of yellow and silver specimens indicate that in the GML the process of full metamorphosis among males occurs within a range of only 8.0 cm (39.0-46.0 cm), while among females the corresponding figure is 48.5 cm (47.5-95.0 cm).

CONCLUSIONS

1. The share of male eels in the lakes of northeastern Poland is 1.03% of the total population and 3.17% in the group with total lengths (Lt) of up to 46.0 cm.
2. The recruitment of sexually maturing females and males within the range of 0 to 100% is described by linear regression with significant differences in the value of the regression coefficients.
3. The maximum size of male silver eels in the studied lake (Lt ≤ 46.0 cm; BW ≤ 155 g) was smaller than the minimum size of the female silver eels (Lt ≥ 47.5 cm; BW ≥ 175 g).

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STRESZCZENIE

STRUKTURA PŁCI, TEMPO REKRUTACJI ORAZ WIELKOŚĆ OSOBNIKÓW DOJRZEWAJĄCYCH PŁCIOWO W POPULACJI WĘGORZA (*ANGUILLA ANGUILLA* (L.)) Z JEZIOR PÓŁNOCNO-WSCHODNIEJ POLSKI

W trakcie 5 lat badań z 60 jezior o łącznej powierzchni 300 km^2, mających stałe połączenia, metodą połowów elektrycznych i narzędziami rybackimi zebrano próbę liczącą 6998 węgorzy. Wszystkie ryby poddano badaniom, w trakcie których określono długość (Lt), masę ciała, płeć i stopień dojrzałości płciowej. Stadium dojrzałości płciowej określano metodą makroskopową i indeksem oka I, klasyfikując węgorze na osobniki żółte ($I < 6,5$) i srebrzyste ($I \geq 6,5$). Złowiono 72 samce i 6926 samic znajdujących się w różnych fazach dojrzewania płciowego (tab. 1). Udział samców wyniósł 1,03% w ogólnej populacji i 3,17% w grupie ryb o długości ciała $Lt \leq 46$ cm. Stwierdzono, że w jeziorach proces dojrzewania płciowego samców rozpoczyna się, gdy osiągną długość $Lt \geq 39,0$ cm i masę ciała $W > 90$ g, a samic odpowiednio $Lt \geq 47,5$ cm i $W \geq 175$ g (rys. 1 i 2). Wzrost udziału osobników srebrzystych w populacji od momentu zapoczątkowania procesu metamorfozy do jej zakończenia, czyli od 0 do 100% w grupie samców stwierdzono w zakresie od 39,0 do 46,0 cm długości ciała Lt, w tempie około 18% cm^{-1} przyrostu (rys. 3) Wśród samic zjawisko dojrzewania płciowego stwierdzono u osobników w przedziale od 47,0 do 95,0 cm Lt, to jest w zakresie 49,0 cm, w tempie 1,98% cm^{-1} Lt (rys. 4). Wzrost udziału osobników srebrzystych (samców i samic) w badanej populacji miał przebieg zgodny z regresją prostoliniową według równań: $Y = 17,83 \times x - 660,88$; (samce, $R^2 = 0,9629$) i $Y = 1,9788 \times x - 94,2$; (samice, $R^2 = 0,8531$), gdzie x to długość ciała Lt (cm).