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Research Article

Seasonal Changes in Condition Factor and Weight-Length Relationship of Invasive *Carassius gibelio* (Bloch, 1782) from Leszczynskie Lakeland, Poland

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Samples of invasive cyprinid fish, the Prussian carp (*Carassius gibelio*), were collected by fyke nets in Leszczynskie Lakeland (Poland) during the summer and autumn, 2010, and during the spring, 2011. All captured fish were females. For each fish, the total weight (W, g) and the standard length (L, cm) were measured and Fulton's condition factor ($K_C = 100\,\mathrm{W/L^3}$) was computed. Graphical investigation and the Mann-Whitney-Wilcoxon test showed statistically significant location shift of the K_C distribution from summer to autumn (upward) and from autumn to spring (downward). Relationship between total weight and standard length was described with the mean growth curve $E(W \mid L) = aL^b$. Seasonal parameters (a and b) were estimated with a nonlinear regression approach, that is, numerical optimization methods. Growth was allometric in summer and autumn and isometric in spring. The differences between summer and autumn growth curves and between autumn and spring growth curves were statistically significant. The seasonality exhibited by the condition factor and the growth curve may be due to different spawning, breeding, and feeding activity in the different seasons and to variable environmental conditions.

1. Introduction

The cyprinid genus *Carassius* is widespread across Europe and North and East Asia. At least five species are considered: *C. carassius* (Linnaeus, 1758) in most of Europe and Western Siberia [1], *C. langsdorfii* (Temminck and Schlegel, 1846) and *C. cuvieri* (Temminck and Schlegel, 1846) in Japan [2, 3], *C. auratus* (Linnaeus, 1758) in Mainland East Asia [4], and *C. gibelio* (Bloch, 1782) in Europe, Siberia, and Northeast Asia [1, 5]. Some authors recognize additionally the species *C. grandoculis* and *C. buergeri* from Japan [6, 7]. In Poland the first documented records of *C. gibelio* came from 1933, when it was found in ponds northward from Lvov (currently Ukraine) and in southern part of Central Poland. Due to escapes from ponds it appeared in open waters and successively penetrated to next drainages [8]. During the last 20 years it has become more abundant and frequent than native *Carassius carassius*. Nowadays, it is very common on the whole territory of Poland, particularly numerous in lowland lakes, ponds, and rivers. As a result of lake stocking, *C. gibelio* began to feature in lake fish landings. In recent years, the total catch in inland waters of Poland was 2090.3 tons, including 81.4 tons of fish from genus *Carassius*. In Leszczynskie Lakeland, *C. gibelio* contributed from 42.4% to 62.1% to the total weight of fish catch [9]. This fish is turning out to be more and more important in Poland due to its tasty meat and a relatively low price. In addition, on account of its size, the species is an attractive target for anglers.

Condition factor and weight-length relationship are important tools in fish biology, physiology, ecology, fisheries assessment, and conservation [10, 11]. Condition factors are used for comparing the condition, fatness, or well-being of fish [12]. Weight-length relationship is needed to estimate growth rate, length and age structures, the average weight at

Figure 1: Prussian carps were captured in Wonieskie Lake (52°00′23″N; 16°54′54″E), Łoniewskie Lake (52°00′19″N; 16°41′43″E) and Zbechy Lake (51°53′58″N; 16°41′37″E), Leszczynskie Lakeland, Poland.

a given length group, the health status, and other components of fish population dynamic [13–15]. It allows fisheries scientists to convert growth-in-length equations to growth-in-weight in stock assessment models [16, 17], estimate biomass from length frequency distributions [18, 19], and compare life history and morphological aspect of population inhabiting different regions [20]. This relationship also enables the computation of condition indexes and allows for comparison of species growth trajectories between sexes and different seasons and regions [19, 21].

The available literature contains few reports on *C. gibelio*. Despite its importance, there is inadequate published information about seasonal changes of condition factor and weight-length relationship of this species.

In this study we investigated seasonality in condition factor and weight-length relationship of invasive *C. gibelio* from three connected lakes of Leszczynskie Lakeland (West Poland): Wonieskie Lake, Łoniewskie Lake, and Zbechy Lake. The sampling sites and the three lakes were in the same hydrological and environmental condition. The lakes are connected by rivers and canals. The fish move in whole lake and even migrate from lake to lake. We did not expect differences in the fish population characteristics from one sampling site or lake to another. The study question was instead if they showed seasonal variation. Since the condition factor and the weight-length relationship for fish may be conditioned by spawning, breeding, and feeding activity as well as by environmental conditions, we hypothesized that these peculiarities of Prussian carps in Leszczynskie Lakeland change seasonally.

2. Material and Methods

2.1. Sampling and Measurements. The Prussian carps were captured by fyke nets during summer and autumn 2010 and spring 2011 in Wonieskie Lake (52°00′23″N; 16°54′54″E), Łoniewskie Lake (52°00′19″N; 16°41′43″E), and Zbechy Lake (51°53′58″N; 16°41′37″E), Leszczynskie Lakeland, Poland (see Figure 1).

The fish were caught in similar proportions from each lake and for each season.

The characteristics of the fyke nets were mesh size = 20 mm (knot-to-knot), leader length = 6 m, total length = 9 m, height = 70 cm (at first ring), and 1 funnel throat.

Fyke nets were set in the morning in 4 sample sites in the coastal part of each lake, at a depth of 2 m. Distance between sample sites was around 50 m. The nets were raised after 72 hours. The raising time periods were July 12th to 14th and 19th to 21th, 2010 (summer), November 22th to 24th and December 1th to 3th, 2010 (autumn), March 29th to 31th and April 5th to 7th, 2011 (spring). Each one of the previous three-day periods was composed of one raising day for each lake in the following order: Wonieskie, Łoniewskie, Zbechy.

The sample sizes for season were summer = 105, autumn = 110, and spring = 96.

All captured and analysed *C. gibelio* in this study were females.

For each fish, the total weight (W, g) and the standard length (L, cm) were measured, respectively, by Axis Electronics scales to the nearest 0.1 g and by electronic Vernier caliper to the nearest mm.

2.2. Statistical Methods. We started with a graphical data exploration process. Dotplots, boxplots, and bivariate scatter plots were used to detect outliers and gain preliminary insights about seasonal data distributions and relationships [22]. Fulton's condition factor, $K_C = 100\,\mathrm{W/L}^3$ [23], was calculated for all individuals. Preliminary statistics (mean and standard deviation) were computed seasonably for W, L, and K_C. Conditional boxplots were used to gain insight about the seasonal variation of the condition factor. The Mann-Whitney-Wilcoxon test was used to evaluate statistical significance of seasonal shift of the distribution of K_C. Relationship between W and L was described with the nonlinear regression model $W = aL^b + \varepsilon$, with mean growth curve $E(W \mid L) = aL^b$, characterized by the intercept a and the growth parameter b, and normal error $\varepsilon \sim N(0, s^2)$. The model was fitted to data, for each season, with a nonlinear regression approach. That is, the minimization of the residual sum of squares was reached by numerical iterative optimization procedures. The Gauss-Newton algorithm was applied at each step. It relies on linear approximations to the nonlinear (with respect to b) mean function $E(W \mid L)$ [24]. Graphical procedures (residual plots) were used to check and validate the assumptions underlying our model: correct mean function, variance homogeneity, normality, and independence with respect to sampling sites and lakes and with respect to sampling time in each season [25].

Wald 95% confidence intervals for b were also computed for each season. For b (and similarly for a) they are defined as $\widehat{b} \pm t(0.975, n-2)\mathrm{se}(\widehat{b})$, where $\widehat{b}$ is the seasonal estimate of b, $\mathrm{se}(\widehat{b})$ is the estimated asymptotic standard error of $\widehat{b}$, $t(0.975, n-2)$ is the percentile of a t-distribution with $n-2$ degrees of freedom, and n is the number of observations [25]. Confidence intervals were also used to test for isometry or allometry of growth in each season. That is, the isometry null hypothesis ($H0 : b = 3$) was rejected at the 5% significance level if the 95% confidence interval for b did not contain the value 3.

Table 1: Seasonal summary statistics for standard length (L), total weight (W), and Fulton's condition factor (K_C) of Prussian carps from Leszczynskie Lakeland, Poland. Values are minimum, maximum, and sample mean ± standard deviation.

Season	L, cm	W, g	K_C, g·cm^{-3}
Summer (n = 104)	20.4, 30.0, 25.6 ± 1.9	325, 920, 612.6 ± 127.6	2.8, 4.6, 3.6 ± 0.4
Autumn (n = 110)	19.4, 34.4, 25.8 ± 2.9	280, 1540, 717.7 ± 248.0	3.2, 5.4, 4.1 ± 0.4
Spring (n = 94)	21.3, 34.5, 26.6 ± 3.0	320, 1620, 740.3 ± 280.5	2.8, 4.4, 3.7 ± 0.3

Statistical significance of the difference between the growth curves related to subsequent seasons was evaluated comparing, with an F-test, two nested models: Model A, with different parameters between seasons, and Model B, with the same parameters for both seasons. Model B is a submodel of Model A. The F-test statistic is defined as

$$F = \frac{(\mathrm{RSS_B} - \mathrm{RSS_A}) / (\mathrm{df_B} - \mathrm{df_A})}{\mathrm{RSS_A}/\mathrm{df_A}}, \quad (1)$$

where RSS stays for Residuals Sum of Squares, df stays for degrees of freedom, and subscripts A and B refer to Model A and Model B, respectively. A large F-value means a large improvement in the fit when considering Model A instead of Model B, that is, considering two different seasonal growth curves instead of a single one. The P value was obtained from an F-distribution with degree of freedom $(\mathrm{df_B} - \mathrm{df_A}, \mathrm{df_A})$. The method is also called the extra-sum-of-squares F-test [26].

All graphs and statistical analysis in this paper were produced using the software package R [27].

3. Results

All captured fish were unisexual female.

In the preliminary graphical data exploration process (not shown here), few outliers were detected and removed from the data set. In the final sample, the number of individuals for each season was summer = 104, autumn = 110, and spring = 94. In Table 1, the minimum, maximum, and sample mean ± standard deviation for L, W, and K_C are presented for each season.

The conditional boxplots for K_C, shown in Figure 2, exhibited a clear seasonal variability, with its maximum in autumn and its minimum in summer.

The Mann-Whitney-Wilcoxon test showed that the upward shift, from summer to autumn, of the K_C distribution was statistically significant (MWW-value = 2191, P value < 0.001, based on normal approximation). The downward shift from autumn to spring was also statistically significant (MWW-value = 7536, P value < 0.001, based on normal approximation).

Figure 3 shows the conditional scatter plot of W versus L for each season.

Estimates and Wald's 95% confidence intervals for parameters a and b, for each season, are shown in Table 2. In summer and autumn, growth was allometric ($H0 : b = 3$ rejected at the 0.05 significance level). In spring, growth was isometric ($H0 : b = 3$ not rejected at the 0.05 significance level).

Residual plots did not show any evident departure from model assumptions.

Table 2: Seasonal growth curve parameters a and b for Prussian carps from Leszczynskie Lakeland, Poland. Values are estimates (bold) and Wald's 95% confidence intervals in a nonlinear regression model.

Season	a	b
Summer	**0.152** (0.022, 0.282)	**2.555** (2.294, 2.816)
Autumn	**0.074** (0.032, 0.116)	**2.816** (2.645, 2.987)
Spring	**0.029** (0.017, 0.041)	**3.078** (2.953, 3.203)

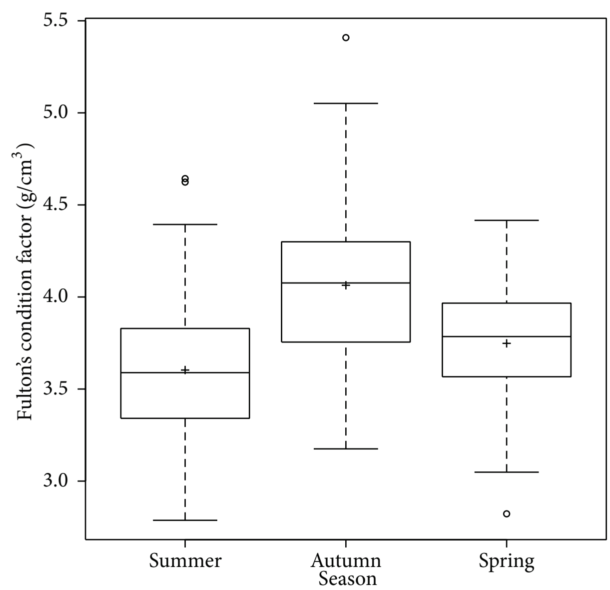

Figure 2: Seasonal variation of average Fulton's condition factor (K_C) of Prussian carp, *Carassius gibelio*, in Leszczynskie Lakeland, Poland. Rectangular part of the plot extends from lower to the upper quartile; centerline within each box show location of sample median and cross location of sample mean. Circles indicate (not extreme) outliers.

Difference between the summer and the autumn growth curves (see Figure 4) was statistically significant (F-value = 46.585, df = (212, 210), and P value < 0.001). Difference between the autumn and spring growth curves (see Figure 5) was also statistically significant (F-value = 14.078, df = (202, 200), and P value < 0.001).

4. Discussion

The Prussian carp, *Carassius gibelio*, represents an interesting and unique species in which the coexistence of gynogenetic

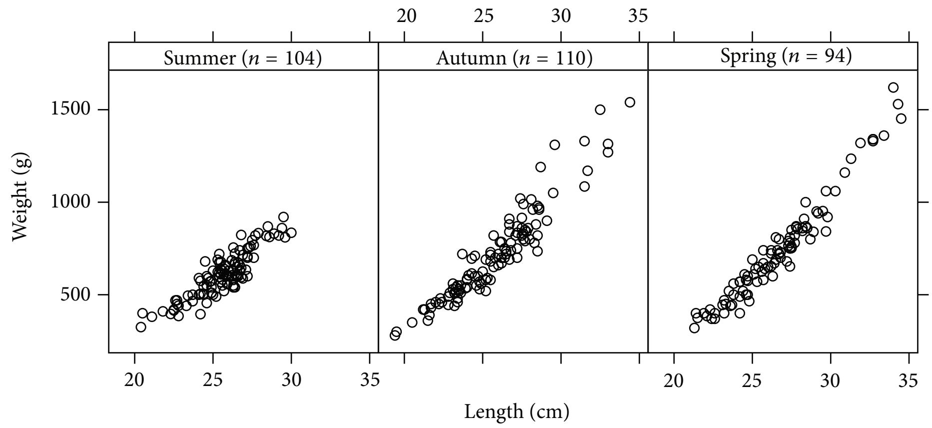

FIGURE 3: Scatter plot of Weight (g) versus Length (cm) of Prussian carps in Leszczynskie Lakeland, Poland, conditional on season.

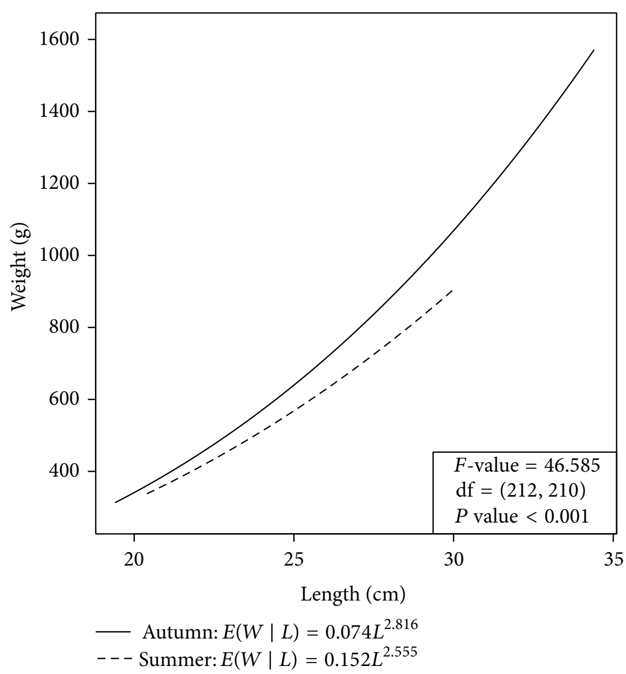

FIGURE 4: Graphical comparison of the growth curves $E(W \mid L) = aL^b$ fitted to autumn data and to summer data. F-value = $((\mathrm{RSS_B} - \mathrm{RSS_A})/(\mathrm{df_B} - \mathrm{df_A}))/(\mathrm{RSS_A}/\mathrm{df_A})$, where subscripts A and B refer to a model with different parameters between seasons and a model with the same parameter for both season, respectively; P-value obtained from an F-distribution with degree of freedom $(\mathrm{df_B} - \mathrm{df_A}; \mathrm{df_A})$ [26].

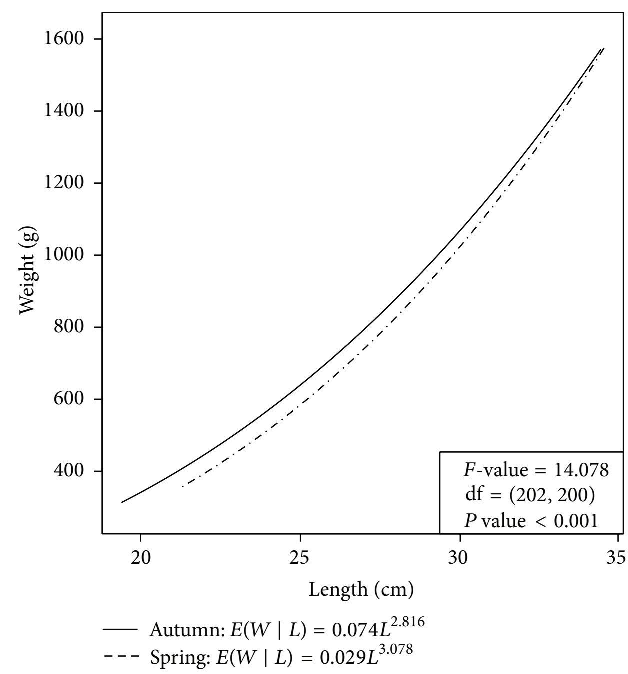

FIGURE 5: Graphical comparison of the growth curves $E(W \mid L) = aL^b$ fitted to autumn data and to spring data. F-value = $((\mathrm{RSS_B} - \mathrm{RSS_A})/(\mathrm{df_B} - \mathrm{df_A}))/(\mathrm{RSS_A}/\mathrm{df_A})$, where subscripts A and B refer to a model with different parameters between seasons and a model with the same parameter for both season, respectively; P-value obtained from an F-distribution with degree of freedom $(\mathrm{df_B} - \mathrm{df_A}; \mathrm{df_A})$ [26].

reproduction and gonochoristic reproduction is known. The majority of the European populations of this species have been considered unisexual, consisting of triploid females reproducing by gynogenesis [28]. In Leszczynskie Lakeland, all caught fish were unisexual female. All the eggs of the triploid Prussian carps developed gynogenetically into females when stimulated by sperm from other species.

Usually, in deep lakes, fish migrate because of diet or reproductive needs, although in some cases the reason for migration remains unknown [29]. Wonieskie, Łoniewskie, and Zbechy are shallow lakes. In most of each lake depth does not exceed 3 m. The maximum depth is less than 9 m. Prussian carps migrate to lake surface when looking for food. In the breeding season these fish migrate to shallow shores with aquatic plants (at a depth of about 1-2 m) for spawning. In winter all fish move to deeper warmer water. Like in other lakes [30], fish overwinter in an inactive state and avoid freezing by burrowing into the warmer mud at the lake bottom. In summer we captured fish leaving the breeding place after spawning. In autumn we captured fish after an intensive feeding activity. In spring we captured fish that had gone through a hard and cold period.

The condition factor and the weight-length relationship have got significant role in fishery management. In this paper we showed that the mean condition factor of *Carassius gibelio* from Leszczynskie Lakeland exhibits a clear seasonal variability. This is in accordance with other published results on unisexual female population [31], bisexual populations of Prussian carp [32, 33], and other species of fish [23].

In Poland, Prussian carp reproduction begins at the end of May, when water temperature is about 18-19°C [5]. For *Carassius gibelio*, the minimum K_C values were recorded after spawning had just occurred, mainly in the triploid gynogenetic females [31], which dominated in European lakes. In summer, after the breeding season, we found fish in the worse condition, because most of them were spawned. Spawning is a physically demanding and stressful period, which can affect also immune function [34, 35]. Cyprinid fish reach the highest values of immune variables including respiratory burst, leukocyte count, and leukocrit in spawning period [36]. High number of leucocytes, especially granulocytes, is a common consequence of infection and it may play an important role on fish condition.

However, since in summer water temperature is optimal for growing and the greatest feeding activity starts [30, 37], the condition of Prussian carps increased reaching the highest value in autumn. This is due to fats deposition during the preceding growing season [21].

Winter temperatures of Polish lakes are very low, usually below the freezing point of water. In that season, Prussian carps enter into a phase of anabiosis by radically altering metabolism and consuming all the energy stored during the previous warmer period. In this period condition got worse. After winter, in spring, Prussian carps were back in poor condition. The same results were found in [38].

The condition values of *Carassius gibelio* from Leszczynskie Lakeland were higher than other published values from some European waters [39, 40], Turkey [32, 41, 42], and Iran [43]. This may be due to the fact that the three lakes considered are all eutrophic. There are a lot of aquatic plants, mainly: *Phragmites australis*, *Acorus calamus*, Canadian waterweed, Hornwort, and Nymphaeids. The composition of the bottom substrate in all sites was sand = 60%, organic matter = 10%, and lake mud = 30%. This is a very good feeding habitat for fish, because usually distribution of diet resources for fish is influenced by presence of aquatic plants. According to [44], macroinvertebrate biomass is higher in aquatic plants than in unstructured open water habitat. The presence of larger areas of colonisable substrates and the refuge effect of the aquatic plants in the considered lakes makes the complex habitat generally more favourable for the benthic fauna [45]. It should be noted that bottom fauna has a main role in diet of *C. gibelio*.

Seasonality is also very important in structuring the isometry or allometry of a fish species because the weight-length relationship is largely determined by seasonally oscillating natural factors such as diet, habitat, reproductive activity, and stress [21].

For *Carassius gibelio*, some authors reported value of the growth parameter b ranging from 2.1 to 3.3 [41, 42, 46]. According to [31, 46] the fish showed positive allometric growth ($b > 3$) in some lakes but in others isometric growth ($b = 3$). We found that b values ranged between 2.555 and 3.078 in *C. gibelio* and differ between seasons. Difference between the summer growth curve and the autumn growth curve was statistically significant as well as the difference between the autumn and spring growth curves. Our results agree with earlier report [12] which stated that season might influence the weight-length relationship. In [46], for example, the authors found that the b value recorded in the winter was significantly lower than 3 indicating hypoallometric growth. In other seasons average b slightly deviated from isometric growth. Our studies showed allometric growth in summer and autumn and isometric growth in spring. There has been continuous debate on the impact of seasons on the weight-length relationship in fish and majority of fish biologists believe that b values depend on physiological growth condition such as gonad development or food availability [47], biological and environmental condition, and geographical, temporal, and sampling factor [21, 48].

Note that, with $K_C = 100\,\mathrm{W/L^3}$ and $E(W \mid L) = aL^b$, $E(K_C \mid L) = 100aL^{b-3}$. It follows that the mean condition factor does not depend on L if growth is isometric ($b = 3$) and decreases with L (that is, small fish have a better condition than big fish) if growth is hypoallometric ($b < 3$). Concerning the $K_C - L$ relationship there are contradictory published results in the literature. In [41] the authors pointed out that the mean condition factor of the Crucian carps in age group I (at mean fork length 11.3 cm) was 2.239 g/cm^3 and in age group VI (mean fork length 29.6 cm) was higher: 3.326 g/cm^3. According to [46], in the Dal Lake, and [31], in the Chimaditis Lake, fish of different size showed no difference in condition; that is, small specimens had the same condition as large specimens. In [49] the authors conducted studies on the biological aspects of fish in Manasbal Lake and found that, for the Crucian carp (*C. carassius*), $b = 2.47$, so that the condition factor decreased with length.

Our results showed no differences in condition between small and large specimens only in spring. In summer and autumn the condition factor decreased with length. Hypoallometric growth in the summer sample may indicate that bigger fish were sexually mature and spawned and had a decreased condition factor compared to their smaller and immature counterparts. However, we point out that the lack of bigger sized specimens may have influenced K_C values in summer.

5. Conclusion

Our results showed that the condition factor and the weight-length relationship of Prussian carp varies according to season; that is, it is influenced by environmental conditions. In Leszczynskie Lakeland, the lowest condition values were in summer, after spawning season, and the highest were in autumn, after fish have deposited fat for the coming cold season. Furthermore, seasonality of condition factor could be attributed to low feeding intensity and degeneration of ovaries during winter. The value obtained in this study showed that specimens from Leszczynskie Lakeland were in better condition than some other populations from European and Asian waters. This may be due to environmental differences between lakes.

The seasonal changes, notably in the period during and immediately after spawning, affect the weight-length relationship in Prussian carps. Values of the growth parameter in the weight-length relationship imply hypoallometric growth in summer and autumn; that is, the increase in weight is not faster than the cube of the increase in length. In these seasons small specimens are in better condition than bigger ones. Probably, hypoallometric growth may indicate that bigger fish were sexually mature and spawned.

Our hypotheses were confirmed by the results of this study.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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